CSIRO OCEANS AND ATMOSPHERE
www.csiro.au

Torres Strait rock lobster (TRL) Final Report 2019 on fishery surveys, CPUE, stock assessment and harvest control rule development

AFMA Project 2016/0822

Éva Plagányi, Rob Campbell, Mark Tonks, Nicole Murphy, Roy Deng, Kinam Salee, Mick Haywood, Judy Upston, Frank Coman, Steven Edgar, Trevor Hutton, Chris Moeseneder

June 2019

Australian Fisheries Management Authority
Thursday Island

DRAFT REPORT JUNE 2019

Australian Government

Australian Fisheries Management Authority

CSIRO Oceans and Atmosphere

Citation

Éva Plagányi, Rob Campbell, Mark Tonks, Nicole Murphy, Roy Deng, Kinam Salee, Mick Haywood, Judy Upston, Steve Edgar (2018) Torres Strait rock lobster (TRL) Final Report 2019 on fishery surveys, CPUE, stock assessment and harvest control rule development: AFMA Project 2016/0822. June 2019 Draft Final Report.

Copyright

Important disclaimer

Contents

Figures

Tables

Acknowledgments

This research project was co-funded by the Australian Fisheries Management Authority and CSIRO to provide annual Torres Strait Tropical Rock Lobster surveys and stock assessment for effective management of the TRL fishery. We are grateful for support and inputs provided by Tim Skewes and Darren Dennis. Thanks to staff of M.G. Kailis Pty Ltd for continued support in providing size data from commercial catches. Thank you to the owner (Wade Alleyn) and master (Ben Bright) of the *M.V. Kerra Lyn* and the owner/ master (Rob Benn) of the *Wild Blue* for their support before, during and after the TRL population surveys conducted over the last three years. Thank you to all TRL RAG members and observers for constructive comments and feedback on all aspects of this research. Finally, a special thank you to the Traditional Owners for regularly hosting us on their land and supporting all aspects of this research.

Executive summary

The Torres Strait TRL fishery provides an important source of income for greater than 400 Torres Strait islanders and many island communities and also supports a non-islander sector, based on ~11 licensed primary vessels. The TRL stock is shared with adjacent fisheries in Papua New Guinea (PNG) and on the northern Queensland coast. The Australian and PNG Torres Strait catch has averaged 684 t live weight since 1989. The Australian Torres Strait catch is important economically to all sectors, and primarily supports a lucrative export market for live lobsters to China. Given its significant traditional, economic and social importance there is a need to address the long-term biological sustainability of the stock through research supporting management decisions.

Annual fishery-independent monitoring of the Torres Strait ornate rock lobster (TRL) *Panulirus ornatus* population has been carried out during 1989 to 2018. These surveys, conducted mid-year (June) up until 2014, and again in 2018, and pre-season (November) during 2005-2008 and from 2014-2018, provide the only long-term information on the relative abundance of recruiting (1+) lobsters. Prior to the introduction of mandatory logbooks in the TVH sector and subsequently the docket book system in the TiB sector these surveys also provided the only long-term information on the relative abundance of fished (2+) lobsters.

Pre-season population surveys of recruiting (1+) lobster abundance were identified by the TRL RAG as critical to support the move to a quota managed system (QMS) proposed in 2005. As a result annual pre-season surveys were conducted during 2005-2008, in addition to mid-year surveys, and have replaced midyear surveys since 2014, to provide managers with information on the abundance and biomass of fishery recruits and the likely stock biomass available to be fished each year. These data sets are integral to the outputs of the fishery model developed to assess fishery status and to forecast stock size and inform the Recommended Biological Catch (RBC). In addition, these data are essential inputs to an empirical Harvest Control Rule (eHCR) that has been developed for TRL.

As a result of a low RBC for the 2018 fishing season (in part an outcome of low 2017 pre-season survey abundance indices) and locally high reported catches of lobster in the north-western region, a midyear survey was conducted in July 2018. To further investigate the reported higher catches of lobster in the north-western region, five additional sites were included to identify lobster distribution and abundance within this region. Outcomes of the Midyear survey were communicated to TRLRAG in October 2018 and were consistent with the 2017 preseason survey which supported the low abundance of recruiting (1+) lobster.

The 2018 TRL Pre-season Population Survey (the survey) was conducted between 11th and 23rd November, using the mothership “Wild Blue” (Rob Benn Holdings Pty Ltd) and a 5 metre CSIRO naiad. Conditions during the 12 day survey varied with winds ranging between 15-25 knots for the first week and dropping to 5-10 knots for a majority of the second week.

Visibility averaged between 2.5-3m with neap tidal flows allowing for a good visual census and collection of lobster. Ninety percent of dives had more than 2m visibility. Measured belt transects (500 m by 4 m) were employed as the primary sampling unit. At the completion of each transect a diver recorded; the number of lobsters caught (and measured), the number and age-class of those observed but not caught, depth, visibility, distance swum, numbers of pearlshell (*Pinctada maxima*) and holothurian species observed, and percent covers of standard substratum and biota (including seagrass and algae species) categories.

A total of 82 sites were surveyed, 77 of these were long-term repeated TRL survey sites and 5 were additional sites recently included in the July 2018 Midyear survey (as well as in earlier Midyear surveys). Recruiting (1+) lobster abundance observed during the 2018 pre-season survey was widespread and relatively consistent across most of the survey stratums (regions). Recruitment and abundance indices were highest for the Buru and Mabuiag stratums (north-western region of the survey area). The lobster abundance data were used to calculate age-class abundance indices for input to the TRL stock assessment and to inform a RBC for the 2019 fishing season.

The population surveys were initially designed to provide accurate and precise indices of 1+ and 2+ lobster abundance, and 0+ lobsters were rarely observed during mid-year surveys as they only settle in June. Hence, refined sampling would likely provide better estimates of 0+ abundance. Although all 0+ lobsters observed during the pre-season surveys are recorded, it is not known how many are missed due to their small size and cryptic behaviour. Nevertheless, if the percentage of lobsters observed has remained constant throughout the study period, the density indices should be a reliable indicator of relative recruitment strength one year in advance. As for recruiting lobsters, additional future industry-run surveys could provide greater certainty about strength of the 0+ year-classes, and even earlier forecasting of stock size and TAC.

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. 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. On the other hand, the data for the TIB sector is less complete and the measure of effort (days fished) is less accurate and incomplete in many instances. 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 actually occurred and whether there are differences between the different sellers and trends over the years.

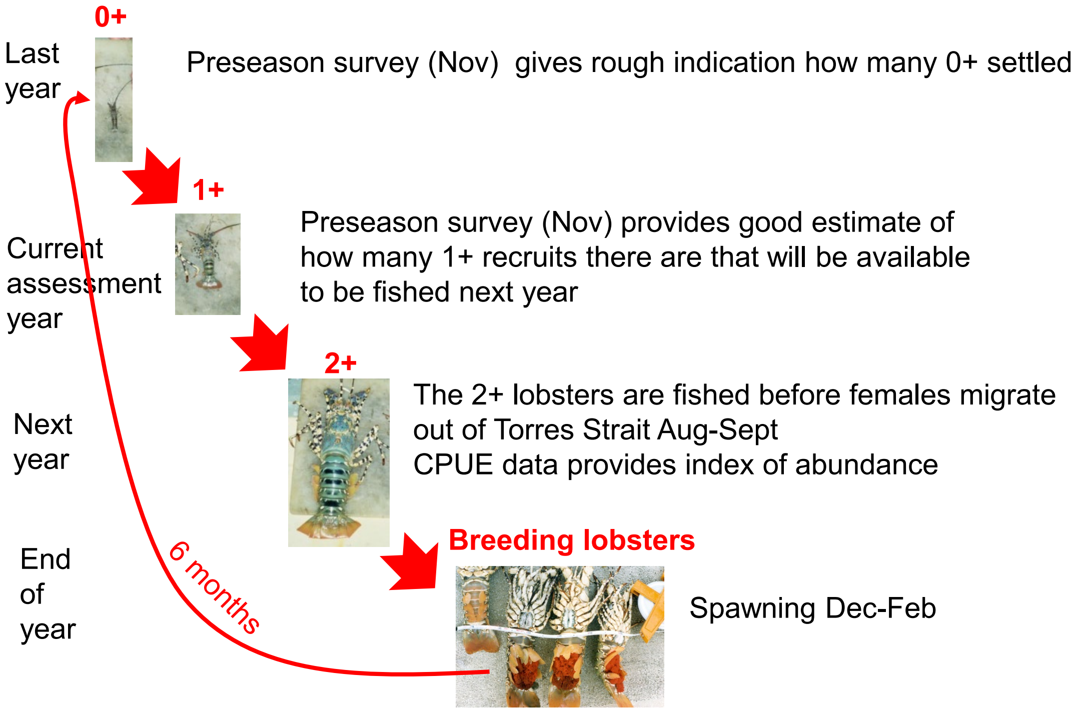
With the introduction of the new Torres Strait Catch Disposal Record it is hoped that the improvements seen in data recording will continue. While the recording of several data fields (e.g. Fisher Name, Fisher Type, Boat Symbol, and catch details) will be mandatory in the new form, it is also essential that the other fields in the voluntary sector of the form (e.g. detailing fishing effort and methods) are completed if the required information is to be available for standardising the TIB catch and effort data. As with the TVH data, continued effort needs to be placed on ensuring the completeness and accuracy of these data if they are to be used on a continuing basis.

The TRL integrated stock assessment model was again used to inform an RBC for the 2019 fishing season. The TRLRAG agreed that if the fishery transitions to using an empirical Harvest Control Rule (eHCR) to inform the Recommended Biological Catch (RBC), then the stock assessment would only need to be conducted every three years. However until such time as this is formally adopted, the stock assessment model is being used to inform the RBC.

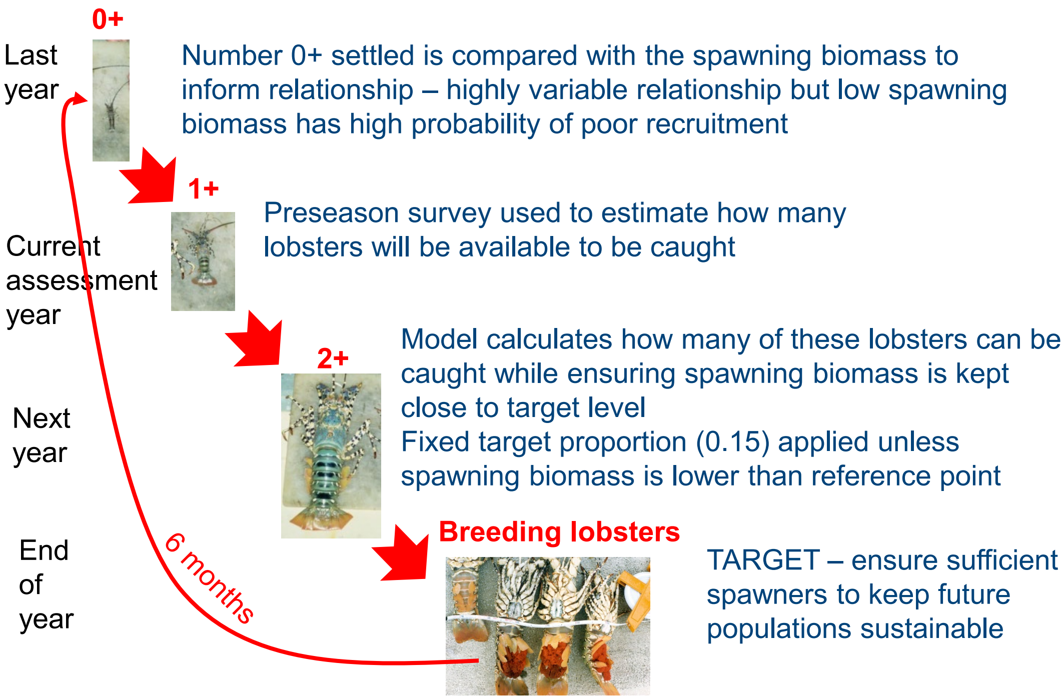
The full details of the stock assessment model are provided in this report. A schematic summary of the model and inputs used to inform on trends in the abundance of the different age classes is given at the end of this summary. The data updates include the latest (Nov 2018) pre-season survey results, the catch total for 2018, and revisions and updates to the commercial CPUE (TVH & TIB) data series. The Reference case model presented here is fitted to the TVH CPUE Main Effects Int1 option and the standardised Seller CPUE TIB series.

The revised reference case model suggests a RBC (2019) of 641t [90% CI 426-857t]. Using the revised reference case, the stock is currently estimated to be at 46% of the pristine (1973) spawning biomass level (K). Previous analyses forewarned that the 2018 spawning biomass may be lower than average and provides support for the management decisions taken in 2018 to limit catches so that sufficient lobsters would remain for spawning purposes and subsequent recruitment to the fishery in 3 years' time. The good 1+ numbers observed in the most recent survey means that the model spawning biomass projection for the following year is once again much more positive. The very large inter-annual variability in the stock has long been recognised. Hence it is entirely plausible that the current lobster stock have been boosted by good recruitment, however we suggest ongoing monitoring of 2019 catch and the next survey observations will be prudent.

Summary of Life Cycle and Assessment



Assessment Basics



Chapter 1 Torres Strait Tropical Rock Lobster Fishery – Summary of the Catch and Effort Data pertaining to the 2018 Fishing Season (Dec-17 to Jul-18)

Robert Campbell, Eva Plagányi, Roy Deng, Mark Tonks, Mick Haywood

1.1 Introduction

This paper provides a summary of the catch and effort data pertaining to the Torres Strait Rock Lobster (TSRL) fishery during the 2018 fishing season. (Note, a fishing season begins on 1-December in a given year and extends through to 30-September the following year). In particular, as the 2018 ended early at the end of July, the paper provides a comparison of the annual trends in catch, effort and catch-rates in the eight months of December through to July so that the relative performance of the fishery during the 2018 season can be assessed relative to comparative periods of previous seasons. Note, this paper updates the previous paper presented to the Torres Strait Rock Lobster RAG in May 2018 (Campbell et al 2018).

1.2 Data

TIB-Sector

A new logbook, known as the Torres Strait Catch Disposal Record (TDB02), was introduced in the TSRL fishery on 1-December 2017. This logbook, which is mandatory to complete, records the catch weight of lobsters landed at the completion of all fishing trips. As well as information related to the fish receiver, the logbook also records information related to the fisher (name, boat symbol, etc), the sector of the fishery that the fisher operated (e.g. TIB or TVH) and the process state of the catch (e.g. whole, live or tailed). Additional information related to fishing effort (e.g. days fished, number of fishers) together with the area fished and methods used is currently only optional.

The TDB02 logbook replaces the Torres Strait Seafood Buyers and Processors Docket Book (TDB01) which had been used in the TIB sector to record the catch sold by fishers at the end of a fishing trip. Completion of this docket-book had only been voluntary and in several fishing seasons (2013-2016) the catch data for the TIB sector was supplemented with aggregate catch data obtained directly from several processors. The introduction of the compulsory TDB02 should rectify this past issue. Hopefully, the TDB02 logbook will also rectify previous issues which were associated with the use of the TDB01 docket-book such as the double recording of catches (see Campbell and Pease 2017). Whether or not the introduction of the compulsory TDB02 logbook will lead to an increase in the reporting levels of the TIB catch will also need to be assessed.

Data related to the TDB02 CDR logbook was last obtained from AFMA on 26 September 2018 while the last batch of data related to the TDB01 docket-book was obtained from AFMA in late October 2017. For the data summaries presented in this paper for the TIB sector, all data before December 2017 is based from this latter data while all data since December 2017 is taken from the TDB02 CDR logbook. The TDB01 docket-book data may be incomplete to some extent for the last few months up until November 2017; however the TDB02 data for
Figure 1-1. Number of data records per month for each sector of the TSRL fishery present in the TDB02 CDR data sent by AFMA on 25-Sep-18. Note, the month of each record is based on the trip-end date. The date of the last trip/shot date recorded for the TIB and TVH sectors is 30-Jul-18 and 24-Jul-18 respectively.

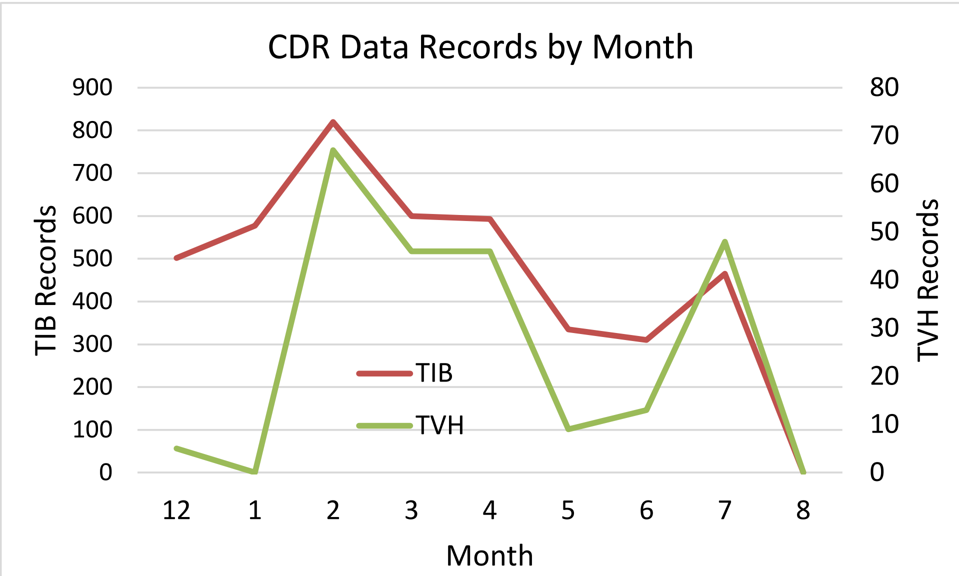


Figure 1-1 Summary of number of data records per month for each sector of the TSRL fishery present in the TDB02 CDR data

The 2018 season is considered to be complete (c.f. Figure 1-1). A more detailed summary of the TIB data for the period up to October 2017 is provided in Campbell et al (2017a).

TVH-Sector

Together with the catch landed by the TIB-sector of the TSRL fishery, the new Torres Strait Catch Disposal Record (TDB02), introduced in the TSRL fishery at the start of November 2017, also records the catch landed by the TVH-sector. However, unlike for the TIB-sector, catch and effort data related to the TVH sector also continues to be recorded in the Torres Strait Tropical Rock Lobster Fishery Daily Fishing Log (TRL04).

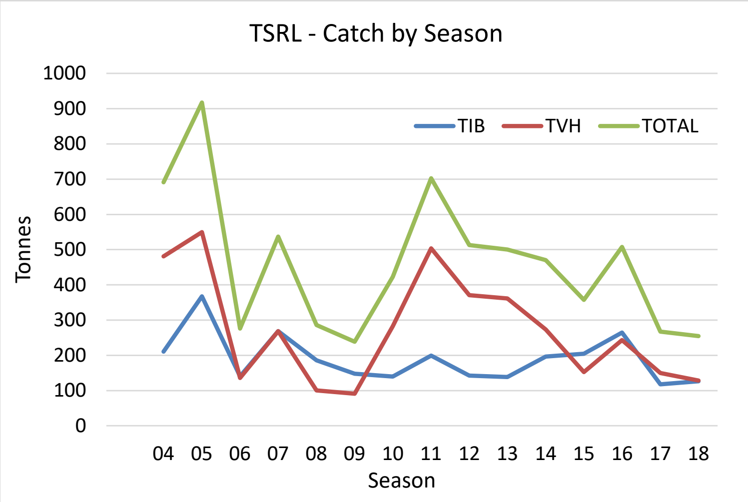
Data related to the TRL04 logbook for the 2018 season was obtained from AFMA on 25 September 2018. For the data summaries presented in this paper for the TVH sector all data is based on information recorded in the TRL04 logbook. As with the TSDB01 logbook, the TRL04 logbook data may also be incomplete to some extent up until November 2017, while the TRL04 data (as with the TDB02 logbook) for the 2018 season is considered to be complete (c.f Figure 1-1). A more detailed summary of the TVH data for the period up to October 2017 is provided in Campbell et al (2017b).

1.3 Catch by Season

A comparison of the estimated total catch by sector for the seasons 2004 to 2018 is shown in Figure 1-2. As the TVH catch is recorded in both the TRL04 logbook and the TDB02 logbook, two estimates for the 2018 season are provided for this sector. The small difference noted in the estimated TVH catch from these two logbooks is likely due to the fact that TRL04 weights are often estimated compared to more accurate weighing on land and a discrepancy of between 5-10% can usually be expected. Some differences in these catch estimates may also be due to differences in the times that AFMA receive and enter data from the two logbook during the season.

The reported catch by month for each sector of the TSRL for the 2004-2018 fishing seasons is shown in Table 1-1. The catch by month for the TVH sector is based on information reported in the TRLO04 logbook, while the catches for the TIB sector are based on information reported in the TBD01 docket-book and TDB02 CDR. Furthermore, for the TIB sector the catch by month for the 2013-2016 fishing seasons is an estimate as the catch month is not known for a substantive portion, *P,* of the total catch in these seasons (*P*=39%, 34%, 33%, 55% respectively). These relate to the aggregate catches reported by several processors on a seasonal basis to account for missing docket-book records. For these seasons the catch within each month was estimated by raising the known catch in each month by the factor *R= 1/(1-P*). This assumes that the distribution of the catches by month in the aggregate catch data is the same as the distribution within the docket-book recorded catches.

Based on the catch-by-month estimates provided in Table 1-1, the time-series of catch by month for the eight months December-to- July is shown in Figure 1-3 for each sector of the TSRL over the seasons 2004-2018.



SEASON	TIB	TVH	TOTAL
2004	210.4	481.1	691.5
2005	367.6	549.9	917.6
2006	140.5	135.5	275.9
2007	268.7	268.6	537.3
2008	185.7	100.4	286.1
2009	147.8	91.1	238.9
2010	140.0	282.6	422.7
2011	199.1	503.5	702.6
2012	142.4	370.5	512.9
2013	138.4	361.7	500.1
2014	196.8	273.2	470.0
2015	204.7	152.7	357.4
2016	264.7	243.0	507.7
2017	117.9	149.7	267.6
2018	126.5	128.3	254.8

NB. TVH (2018) =134.1 based on CDR

Figure 1-2. Time-series of total catch by fishing season (December-November) and sector since 2004. TIB data is based on TDB01 docket-book and TDB02 CDR data, while TVH data is based on TRL04 logbook data. Data for 2018 only covers the period December-July as the fishery was closed at the end of July-2018.

Table 1-1. Catch by month (kilograms) for (a) the TIB sector, (b) the TVH sector and (c) the total TSRL fishery for the 2004-2018 fishing seasons. Note, the catch by month for the TVH is based on information reported in the TRL04 logbook, while the catches for the TIB sector are based on information reported in the TBD01 docket-book and TDB02 CDR. Furthermore, for the TIB sector the catch by month for the 2013-2016 fishing seasons is an estimate as the catch month is not known for a substantive portion P of the total catch in these seasons (P=39%, 34%, 33%, 55% respectively). For these seasons the catch within each month was estimated by raising the known catch in each month by the factor R= 1/(1-P).

(a) TIB (From TBD01 and TDB02 logbooks

SEASON	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
2004		15,542	24,309	35,574	17,737	30,356	28,516	26,449	18,976	12,873	24	25	210,381
2005	21,648	15,098	50,625	58,221	47,575	56,758	43,061	34,474	23,682	16,088	314	71	367,615
2006	12,507	9,447	24,018	26,814	19,091	18,380	9,814	9,910	7,672	2,747	0	51	140,451
2007	19,002	24,941	24,716	62,040	29,185	33,759	29,025	23,193	13,907	8,920	0	0	268,688
2008	10,435	13,461	31,237	36,127	24,110	16,711	14,805	23,516	9,277	5,969	18	0	185,666
2009	9,716	13,273	20,547	23,103	23,733	15,647	13,242	15,393	7,811	4,819	529	0	147,813
2010	5,764	6,198	21,259	15,829	14,995	12,180	16,348	19,073	17,001	9,782	1,610	0	140,039
2011	6,929	18,215	30,141	49,767	20,400	23,990	18,686	18,856	8,858	3,218	0	0	199,060
2012	9,036	13,403	19,028	24,718	19,606	9,689	22,874	11,194	10,836	1,996	0	0	142,380
2013	3,080	1,371	15,940	13,421	20,778	18,606	16,324	18,656	14,425	15,837	0	0	138,439
2014	10,773	13,339	18,379	38,920	28,385	25,455	16,908	17,455	17,388	9,639	187	0	196,827
2015	18,513	9,495	31,813	21,672	27,456	17,212	45,680	13,204	11,819	7,512	283	0	204,659
2016	10,156	15,604	52,833	36,406	23,176	34,192	33,687	25,025	22,438	10,821	220	168	264,725
2017	11,536	8,290	23,339	15,831	11,697	14,959	7,476	9,730	10,803	4,075	155	0	117,891
2018	15,097	13,067	20,950	19,104	17,075	10,137	10,629	20,418	0	0	0	0	126,477

(b) TVH (From TRL04 logbook)

SEASON	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
2004	4,949	452	58,965	73,180	57,142	70,551	79,438	65,766	48,014	22,625	0	0	481,082
2005	4,984	398	108,962	106,276	73,510	59,475	53,618	60,103	51,795	30,814	0	0	549,935
2006	25	0	22,512	24,860	17,491	14,798	11,490	21,952	16,756	5,589	0	0	135,473
2007	0	0	20,768	41,389	47,980	62,933	48,836	26,689	13,633	6,368	0	0	268,596
2008	0	0	12,285	17,166	10,334	10,809	7,997	15,482	16,819	9,545	0	0	100,437
2009	0	0	13,905	18,881	12,748	10,479	13,408	7,824	10,345	3,470	0	0	91,060
2010	0	0	27,311	32,164	29,202	29,192	30,315	44,734	52,026	37,670	0	0	282,614
2011	0	0	69,994	85,730	83,334	65,515	62,084	61,867	45,097	29,913	0	0	503,534
2012	0	0	39,228	59,636	51,696	35,159	39,807	69,718	48,959	26,280	0	0	370,483
2013	0	0	55,428	41,275	45,929	45,030	41,502	56,818	47,621	28,058	0	0	361,661
2014	0	0	47,338	36,706	30,230	42,088	38,160	39,061	23,418	16,213	0	0	273,214
2015	0	0	32,992	21,166	24,051	17,623	16,745	14,460	19,782	5,891	0	0	152,710
2016	0	750	46,101	31,830	24,474	40,200	42,871	28,854	18,851	9,079	0	0	243,010
2017	690	1,051	37,432	17,478	17,701	23,982	19,559	16,105	12,939	2,801	0	0	149,738
2018	0	565	45,187	25,440	22,791	101	2,628	31,612	0	0	0	0	128,324
TDB02	34	0	42,429	28,610	23,390	3,115	2,967	33,563					134,108

(c) TOTAL

SEASON	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
2004	4,949	15,994	83,274	108,754	74,879	100,907	107,954	92,215	66,990	35,498	24	25	691,463
2005	26,632	15,496	159,587	164,497	121,085	116,233	96,679	94,577	75,477	46,902	314	71	917,550
2006	12,532	9,447	46,530	51,674	36,582	33,178	21,304	31,862	24,428	8,336	0	51	275,924
2007	19,002	24,941	45,484	103,429	77,165	96,692	77,861	49,882	27,540	15,288	0	0	537,284
2008	10,435	13,461	43,522	53,293	34,444	27,520	22,802	38,998	26,096	15,514	18	0	286,103
2009	9,716	13,273	34,452	41,984	36,481	26,126	26,650	23,217	18,156	8,289	529	0	238,873
2010	5,764	6,198	48,570	47,993	44,197	41,372	46,663	63,807	69,027	47,452	1,610	0	422,653
2011	6,929	18,215	100,135	135,497	103,734	89,505	80,770	80,723	53,955	33,131	0	0	702,594
2012	9,036	13,403	58,256	84,354	71,302	44,848	62,681	80,912	59,795	28,276	0	0	512,863
2013	3,080	1,371	71,368	54,696	66,707	63,636	57,826	75,474	62,046	43,895	0	0	500,100
2014	10,773	13,339	65,717	75,626	58,615	67,543	55,068	56,516	40,806	25,852	187	0	470,041
2015	18,513	9,495	64,805	42,838	51,507	34,835	62,425	27,664	31,601	13,403	283	0	357,369
2016	10,156	16,354	98,934	68,236	47,650	74,392	76,558	53,879	41,289	19,900	220	168	507,735
2017	12,226	9,341	60,771	33,309	29,398	38,941	27,035	25,835	23,742	6,876	155	0	267,629
2018	15,097	13,632	66,137	44,544	39,866	10,238	13,257	52,030	0	0	0	0	254,801

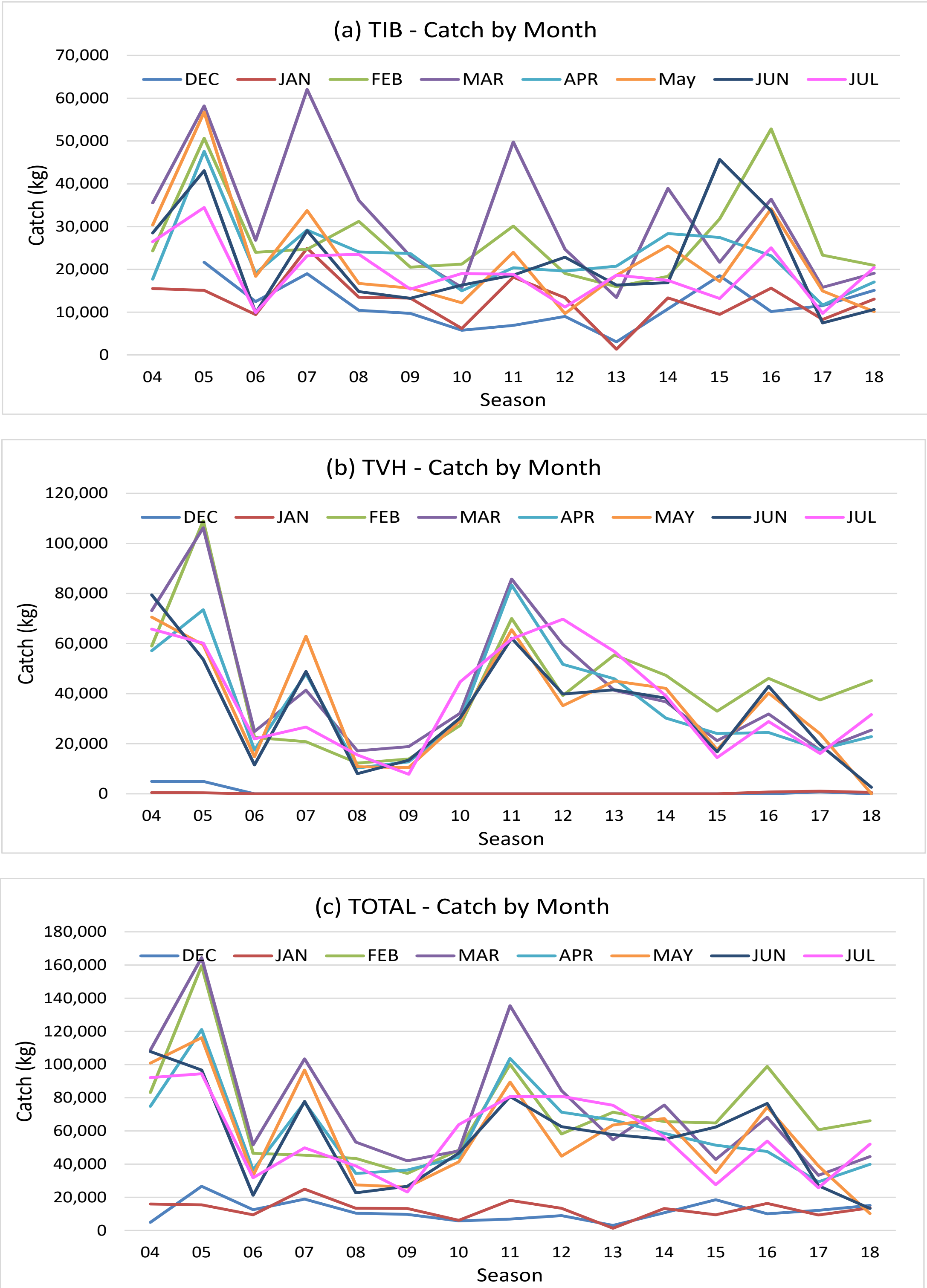


Figure 1-3. Time-series of catch by month for the eight months December-to-July for (a) the TIB sector, (b) the TVH sector and (c) the total TSRL fishery. Note, the catch by month for the TVH is based on information reported in the TRL04 logbook, while the catches for the TIB sector are based on information reported in the TBD01 docket-book and TDB02 CDR. Furthermore, the TIB sector the catch by month for the 2013-2016 fishing seasons is an estimate as the catch month is not known for a substantive portion *P* of the total catch in these seasons (*P*=39%, 34%, 33%, 55% respectively). For these seasons the catch within each month was estimated by raising the known catch in each month by the factor *R= 1/(1-P)*.

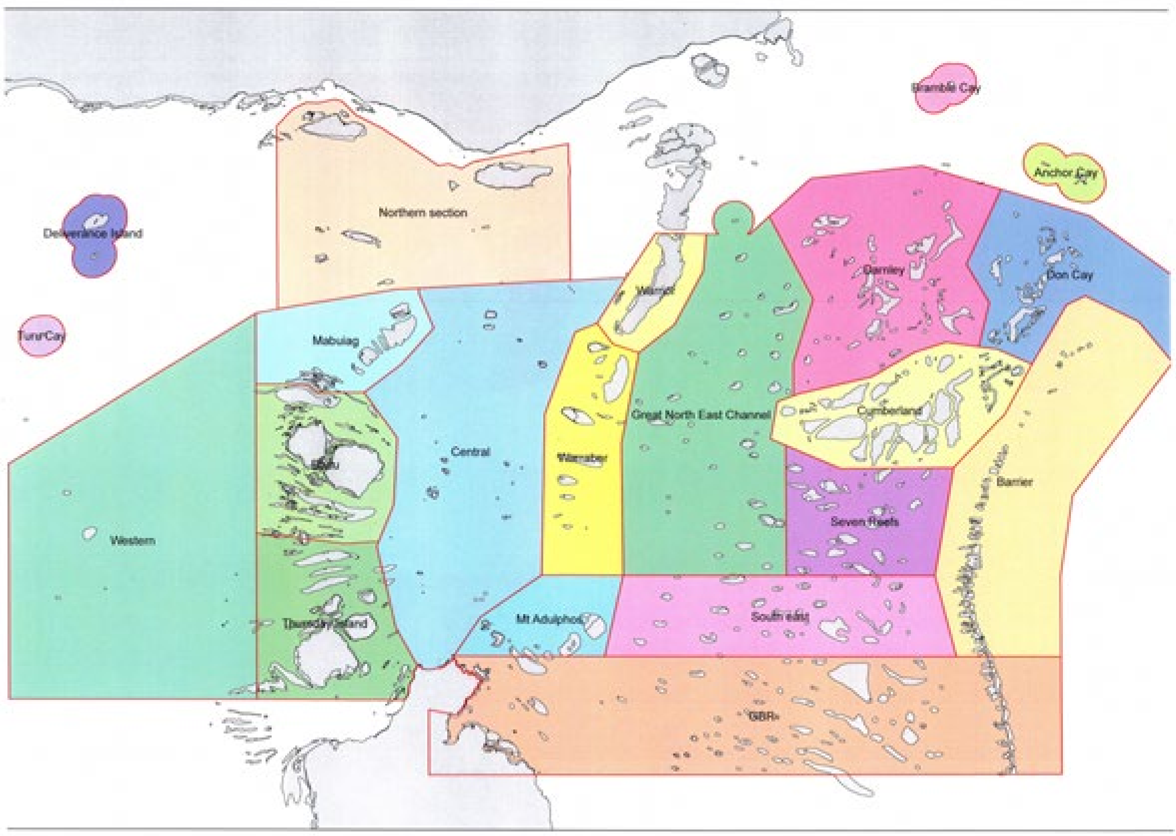


Figure 1-4. Map of the TIB fishing areas described in the analysis.

Table 1-2. (a) List of the area codes and names used in the TIB fishery together with the total number of data records associated with each area. A revised listing of area codes and names based on aggregating areas with few data records is shown in (b).

Area-Name	Area	Area-Rev	N-Records
Unknown	0	0	4,477
Turu Cay	1	6	249
Deliverance Island	2	6	29
Northern Section	3	6	269
Bramble Cay	4	16	19
Anchor Cay	5	16	9
Western	6	6	21
Mabuiag	7	7	6,181
Badu	8	8	5,915
Thursday Island	9	9	21,827
Central	10	10	763
Warrior	11	11	3,157
Warraber	12	12	4,319
Mt Adolphus	13	13	698
Great NE Channel	14	14	2,041
South East	15	15	118
Darnley	16	16	1,269
Cumberland	17	17	819
Seven Reefs	18	15	8
Don Cay	19	16	7
Barrier	20	15	10
GBR	21	15	155
		Total	52,360

Area-Name	Area-Rev	N-Records
Unknown	0	4,477
North-Western	6	568
Mabuiag	7	6,181
Badu	8	5,915
Thursday Island	9	21,827
Central	10	763
Warrior	11	3,157
Warraber	12	4,319
Mt Adolphus	13	698
Great NE Channel	14	2,041
GBR/South-east	15	291
Darnley	16	1,304
Cumberland	17	819
	Total	52,360

1.4 TIB Sector Summary

The 21 areas used to record the spatial location of catch taken in the TIB sector are shown in Figure 1-4 and listed in Table 1-2(a). The total number of data records associated with each area for the 2004-2018 seasons is also shown. For the purpose of the following analyses, several areas where the data coverage was low were combined. A revised listing of area codes and names based on aggregating some areas is shown in Table 1-2(b). These are the areas and names referred to in the following Figures.

A comparison of the percent of the total TIB catch within each fishing season by (a) fishing method and (b) processed form is shown in Figure 1-5 while a comparison by area fished is shown in Figure 1-6. Note these results are based on all data available for each season, i.e. they are not limited to the temporal period (December-July) covered by the data for the 2018 season. Also note that some concerns were expressed at the RAG meeting held in May 2018 that the area-fished recorded on the TDB02 logbook may not coincide with the area where the actual fishing took place (it may instead coincide where the lobsters were sold). As such, the reader is reminded that the area-fished associated with catches in the TIB-sector may not be correct.

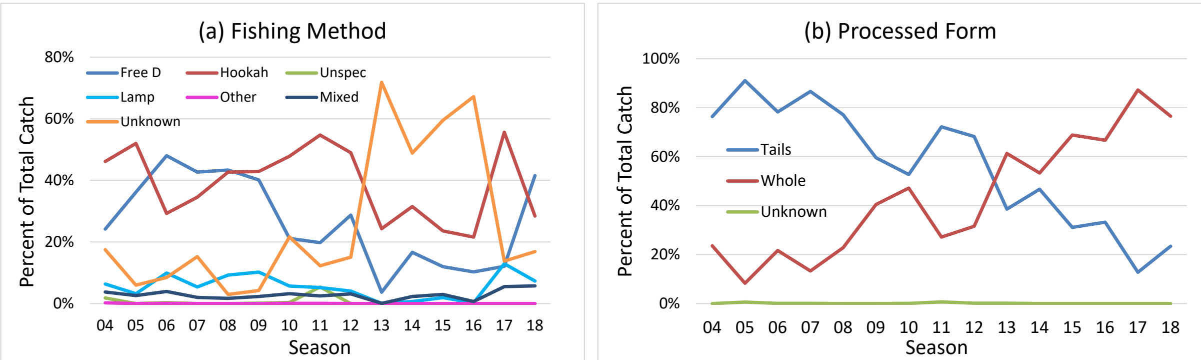


Figure 1-5. Time-series of percent of the total TIB catch within each fishing season by (a) fishing method and (b) processed form.

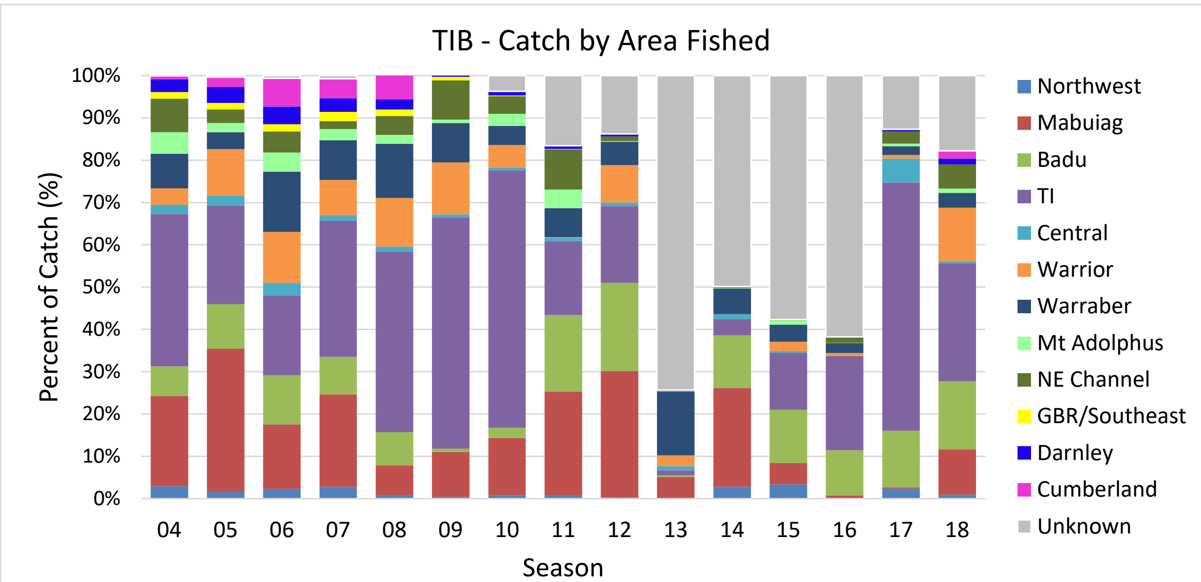


Figure 1-6. Time-series of percent of the total TIB catch within each fishing season taken in each area fished (as recorded on the TDB01 and TDB02 docket-books).

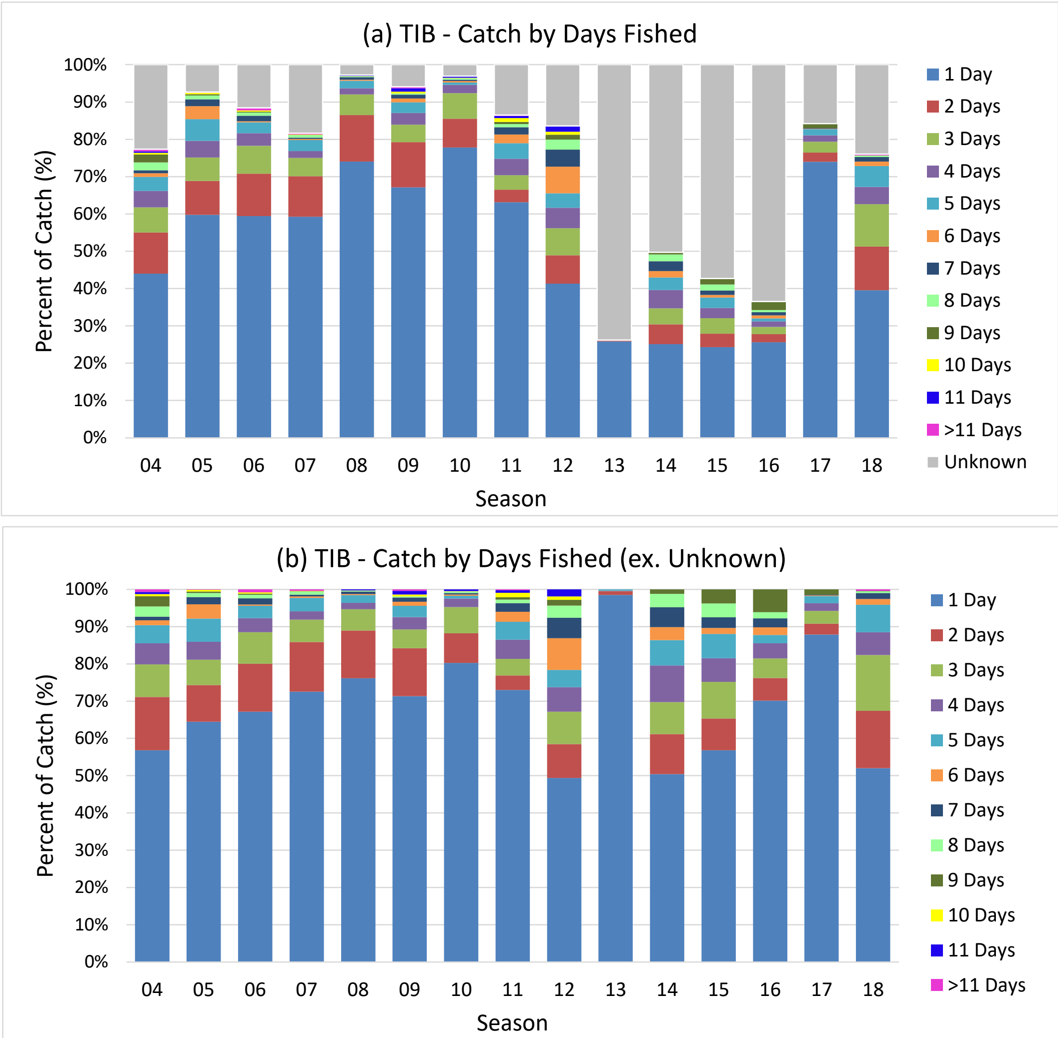


Figure 1-7. Comparison of percent of the TIB total annual catch stratified by the number of days fished per trip based on (a) all records including those where the days fished is unknown, and (b) those records where the unknown days fished are excluded.

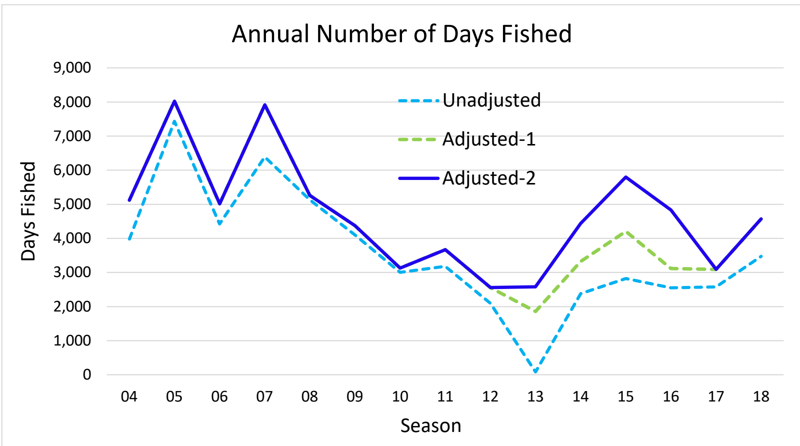


Figure 1-8. Seasonal comparison of estimated effort in the TIB fishery during the eight month period December-July. Analysis based on the method outlined in Campbell (2017).

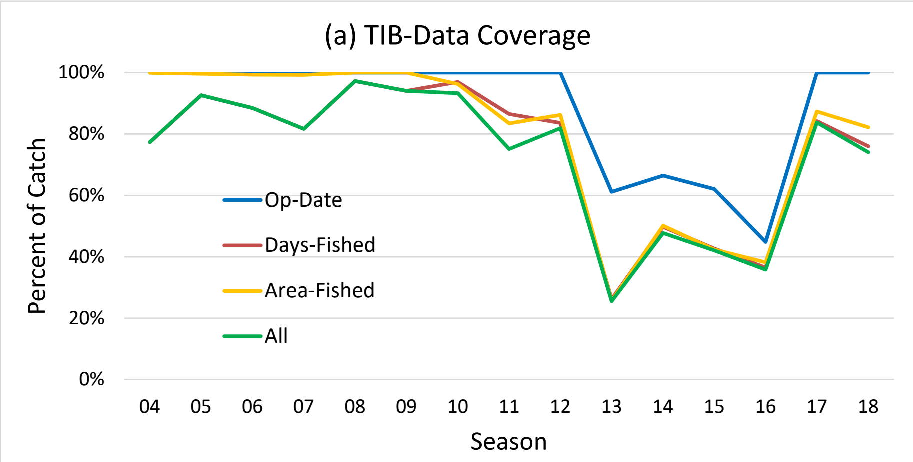
A comparison of percent of the TIB total annual catch stratified by the number of days fished per trip is shown in Figure 1-7. As the number of days fished was not recorded for all docket-book records, and was also not available for the TIB catch provided in aggregate form by several processes, the proportion of the catch where the days fished is unknown is included in the result shown in Figure 1.7a. If one assumes that the distribution of days fished associated with the catch for which the effort information remains unknown is the same as that associated with the catch for which the effort information is known, then one can ascertain an estimate of the effort distribution across the entire catch by just excluding that portion of the catch where the effort information remain unknown. This result is shown in Figure 1.7b and indicates an increase in the proportion of the catch associated with trips of length greater than 1 day during the 2018 season. Finally, a seasonal comparison of estimated effort in the TIB fishery during the eight month period December-July is shown in Figure 1-8 This estimate is based on the method outlined in Campbell (2017) and uses as the total catch during these eight months those estimates shown in Table 1.1.

As noted above, not all the data fields on either the TBD01 or TDB02 logbooks are complete due to the voluntary nature of the provision of this information on both books. As noted above the incompleteness of these data fields creates problems in providing a complete analysis of the information for the TIB sector. An indication of availability of information is shown in Figure 1-9, which provides the annual percentage of the total TIB catch associated with records where various data fields are non-null. The data fields are, (i) Trip operation-date, (ii) Number of days fished, (iii) Area fished, (iv) Vessel-symbol and (v) Seller-name.

Another issue noted in previous analyses of the TIB data is the observation that while the structure of the Docket-Book would seem to indicate that there should be a unique Record-Number (Record-No) associated with each vessel, date and seller-name this structure is not strictly adhered to in the data. While analysis indicates that there is a single date, vessel and seller-name associated with each Record-No, further investigation also indicates that there are often multiple Record-Nos associated for a given vessel, date and seller-name. While the reason for these multiple records remains uncertain (they could be recording errors), in order to identity an appropriate data structure the following two sets of data were prepared for analysis:

First, the multiple Record-Nos associated for a given vessel, date and seller-name were assumed to be due to the recording of an incorrect date. As such the TIB data was aggregated by Record-No, which were each assumed to be associated with a unique record of sale for a given vessel, date and seller. Where the vessel or seller was not recorded, these fields were set to 'Unknown'. Records were not retained where the Days-Fished was unknown, and those records associated with TIB data recorded in the TVH logbook were also eliminated as the structure of the data for these records are different. In the following this data-set is known as the By-Rec data.

Second, the TIB data was aggregated over vessel-symbol, date and seller-name and any resulting data rows associated with more than one Record-No were eliminated. Again, where the vessel-symbol or seller-name was null these fields were set to 'Unknown'. Data where either the number of Days-Fished or the Area-Fished was not recorded, the record pertained to the TVH logbook, or the weight of the catch was zero or greater than 1000 kg were eliminated. Finally, only those data where the first fishing method listed was either 'Hookah diving' or 'Free diving' or 'Lamp fishing' were retained. In the following this data-set is known as the By-VesD data and is equivalent to the data sets used in previous GLM-analyses of the TIB-data.



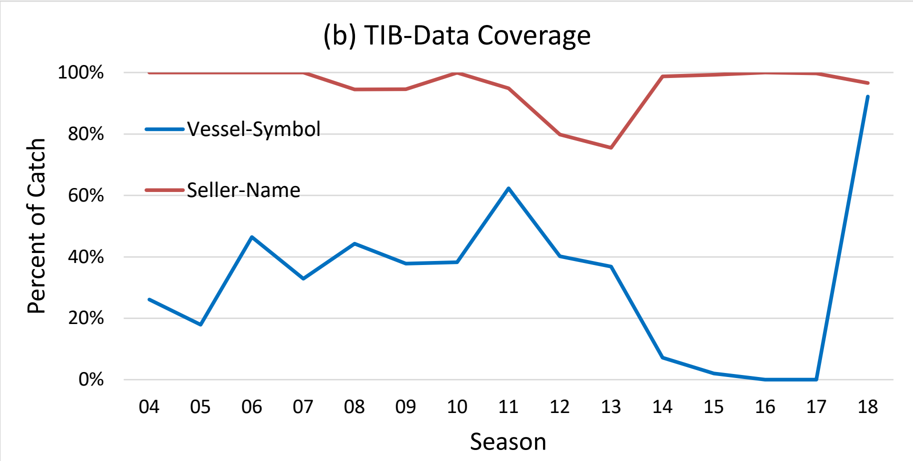


Figure 1-9. Time-series of the percent of the total seasonal TIB catch associated with data records where various data fields are non-null. (a) Trip operation-date, number of days fished, area fished and all three together, and (b) vessel-symbol and seller-name.

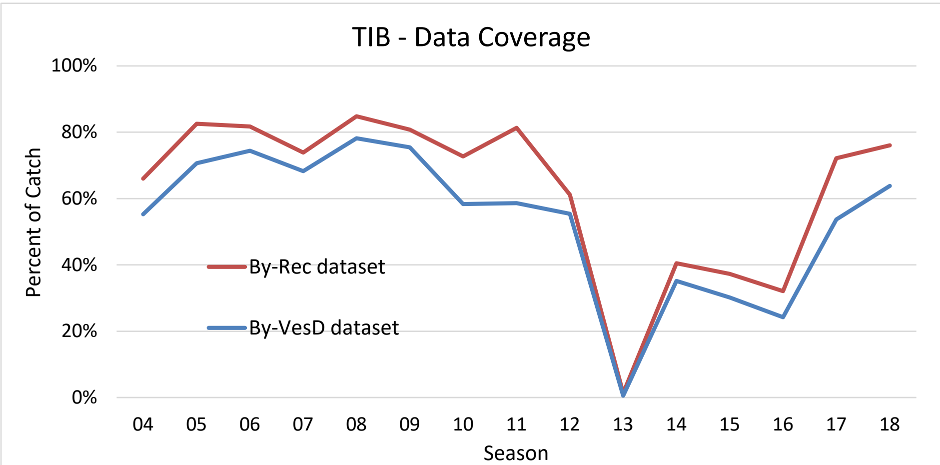


Figure 1-10. Time-series of the percent of the total TIB catch for the eight month period from December-to-July associated with data records included in the (a) By-Rec dataset and (b) By-VesD dataset.

The total number of data records pertaining to the eight month period December-to-July and over the 2004-to-2018 seasons was 40,068 and 34,814 for the By-Rec and By-VesD datasets respectively, while the respective coverage of the seasonal catch for these months by each data set is shown in Figure 1-10.

Using these two data sets, a series of analyses were undertaken to compare the nominal catch-rates (CPUE) according to various data stratifications. These results are shown on Figure 1-11 and Figure 1-12. A comparison of the nominal CPUE within each area fished based on both data sets is shown in Figure 1-13.

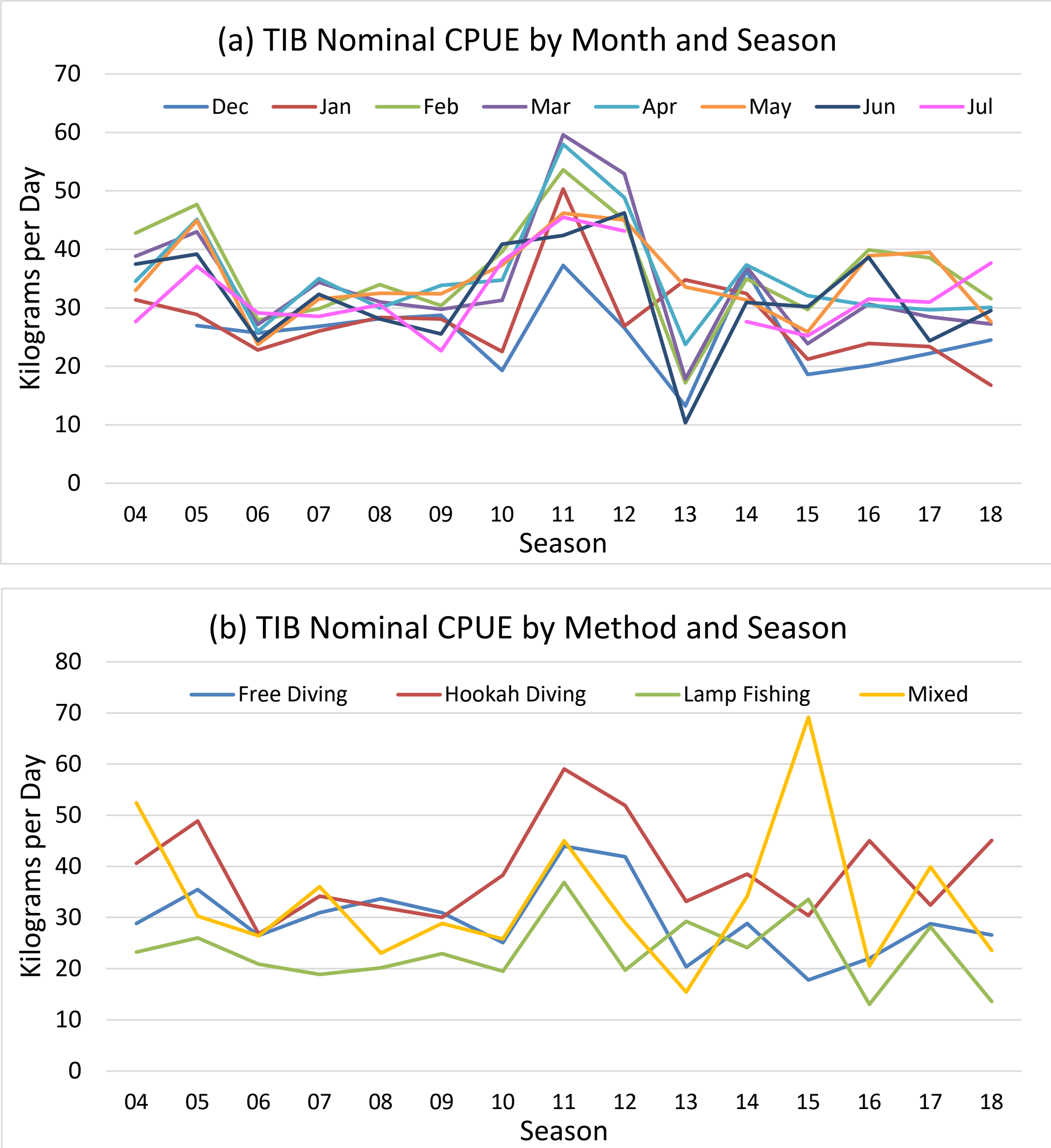


Figure 1-11. Annual time-series of nominal CPUE for the TIB fleet within (a) month and (b) by fishing method during the eight month period December-July. Based on the By-Rec data set.

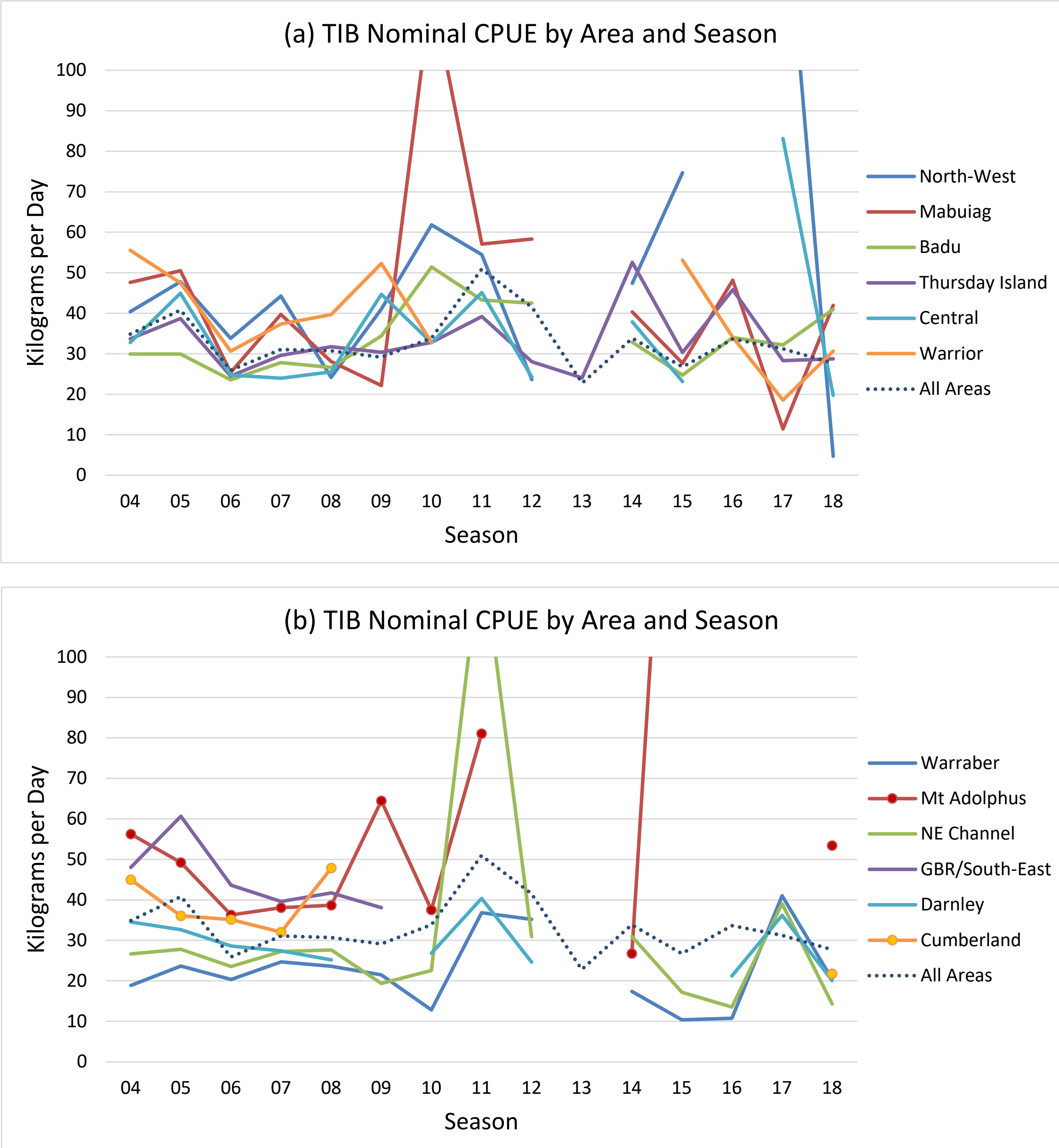


Figure 1-12. Annual time-series of nominal CPUE for the TIB fleet within each area fished during the eight month period December-July. For comparison, the mean nominal CPUE across all areas is also shown. Based on the By-Rec data set. Note, results are only shown for seasons and areas where five or more data records are available. Also, the reader is reminded that the area-fished associated with catches in the TIB-sector may not be correct.

Figure 1-13. Comparison of the nominal TIB CPUE within each area fished (shown in Figure 1.12) based on both the By-Rec data set and the By-VesD data. For each area the mean CPUE across all seasons is also shown. For the 2018 season catch rates have been above the long term average in 3 areas, below the average in 8 areas, and there was no data in 1 area (GBR/Southeast). Note, results are only shown for seasons and areas where five or more data records are available. Also, the reader is reminded that the area-fished associated with catches in the TIB-sector may not be correct.

1.5 TVH Sector Summary

As for the TIB-sector, a series of analyses were undertaken of the catch and effort data for the TVH-sector to provide a comparison of fishery indicators for the 2018 season and previous seasons. As the TVH data is not plagued by the same level of non-reporting of information associated with many of the data fields note in the TIB-data (e.g. the fishing date is known for all catches in the TVH data) the analyses were able to be more focused on the six-month period between February and July each year. The results of these analyses are shown in Figures 1.14-1.22. The captions above each Figure should hopefully provide sufficient information to help the reader adequately interpret each result. Note, the TRL04 logbook limits the reporting of catch and effort to a single location, generally the location where the primary boat is anchored and not the location where tenders are actually fishing (which can range as far as 20 nm from the primary boat).

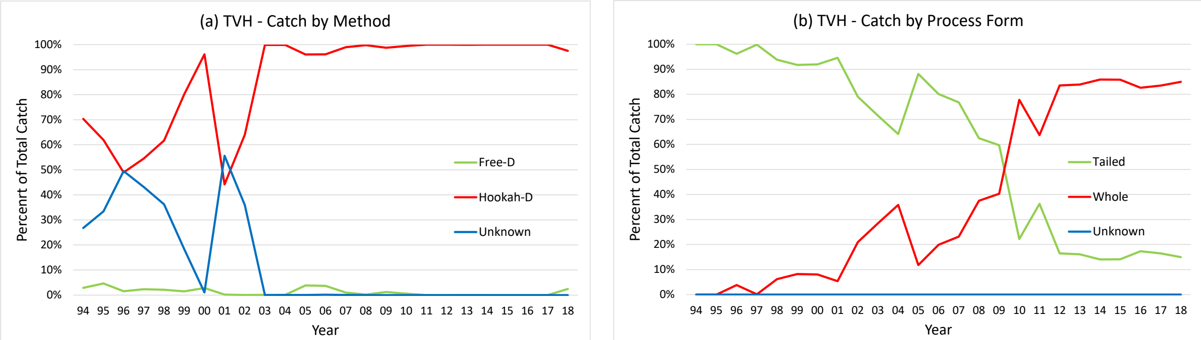


Figure 1-14. Annual time-series of the percent of the total TVH catch during the six month period February-July stratified by (a) fishing method and (b) process form.

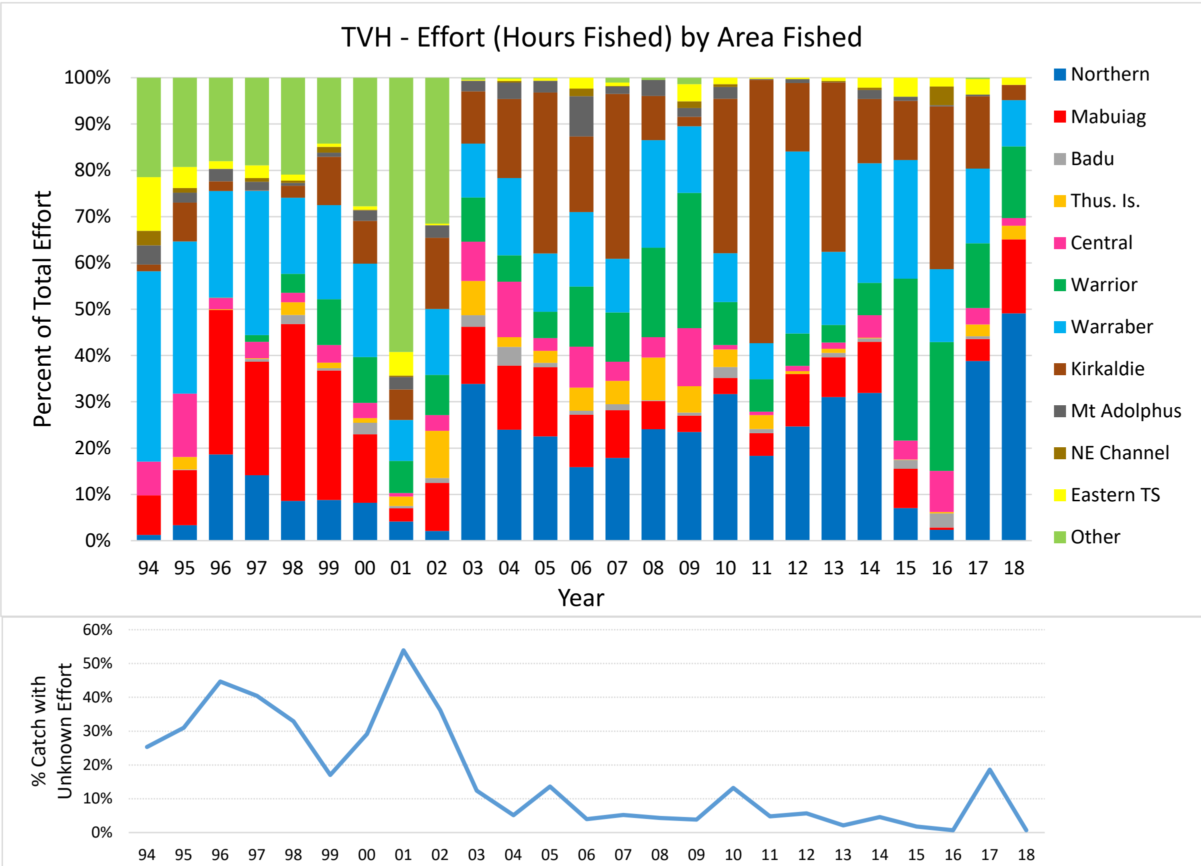


Figure 1-15. Annual time-series of percent of the total TVH effort (total hours fished by tenders) during the six month period February-July within each area fished. Note, this result is based only on those logbook data where effort has been recorded. The percent of the total TVH catch each year for which effort is not recorded is shown in the bottom figure. Note, during 2018 47% of total effort has been in the Northern area, 18% in the Warrior area, 15% in the Mabuiag area, and 12% in the Warraber area.

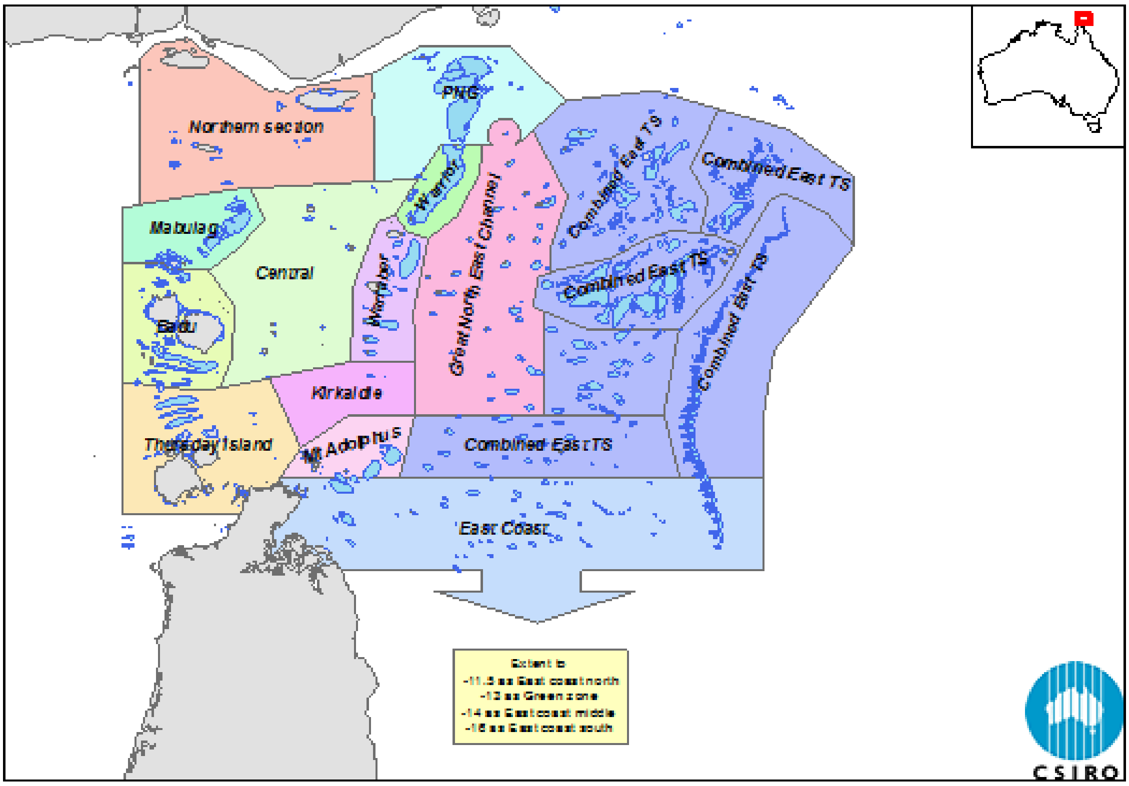


Figure 1-16. Map of the TVH fishing areas described in the analysis.

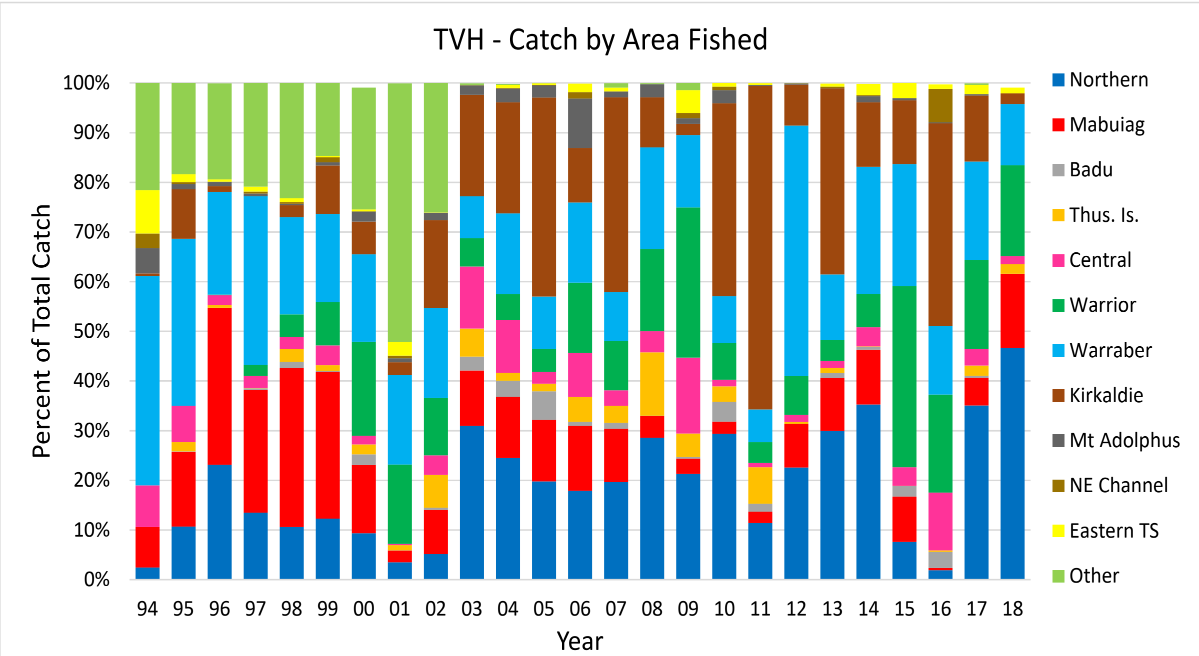
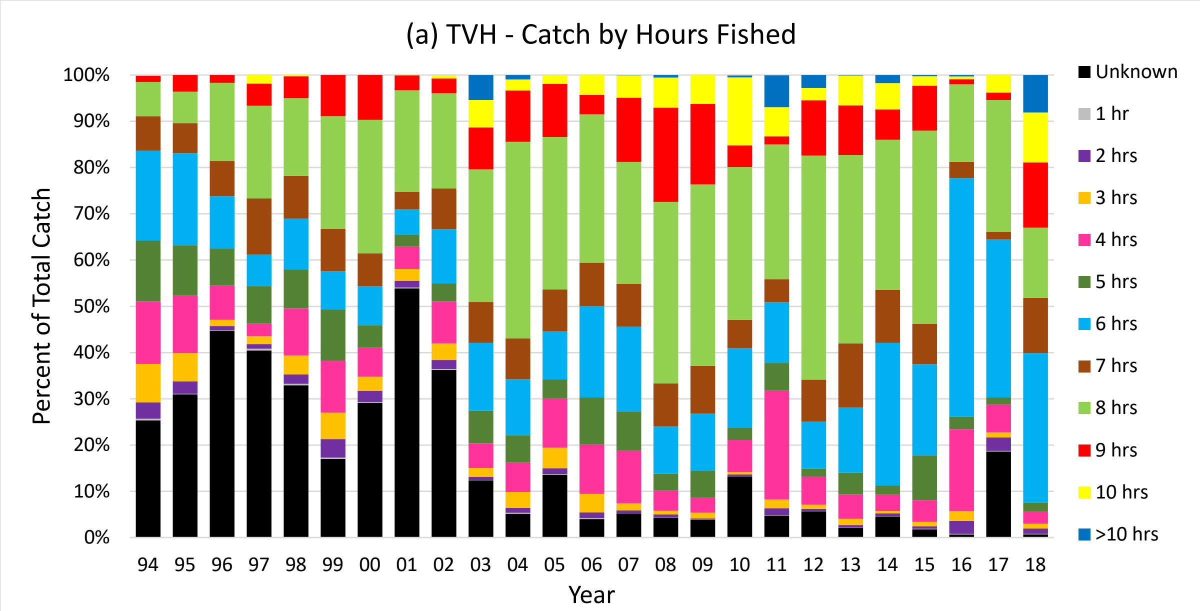


Figure 1-17. Annual time-series of percent of the total TVH catch during the six month period February-July taken within each area fished. Refer to Figure 1-16 for location of TVH areas. Note, during 2018 47% of total catch has been in the Northern area and 18% in Warrior.



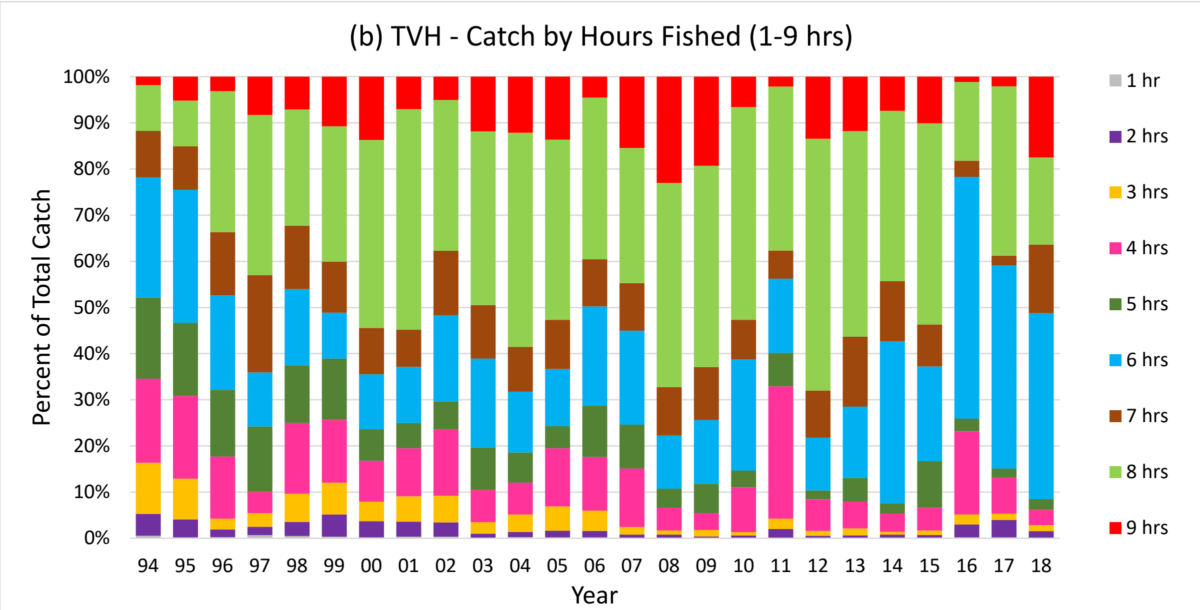
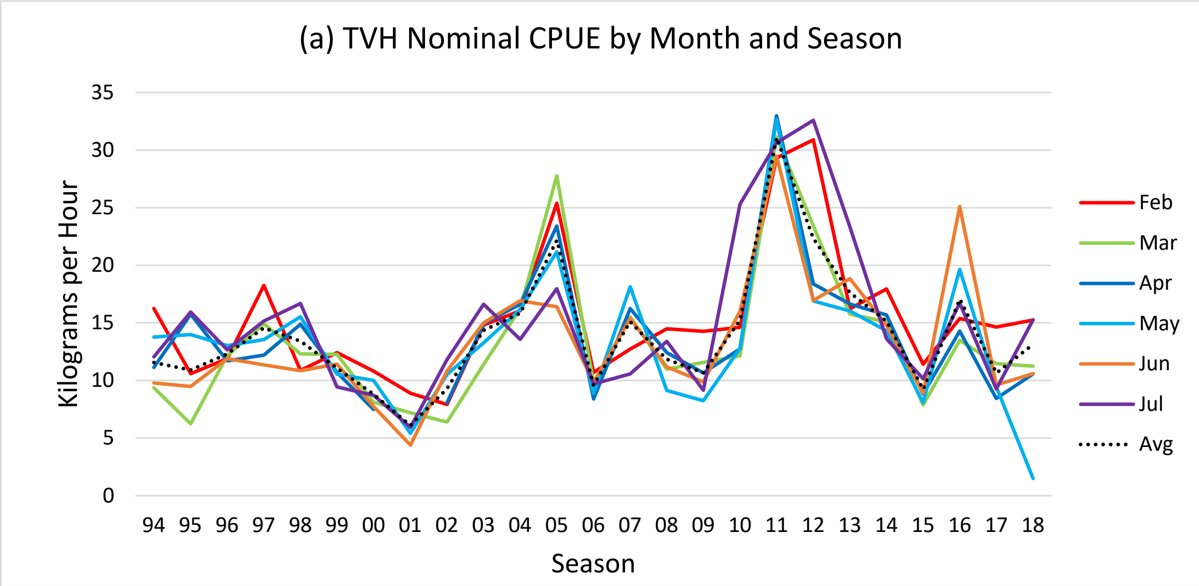


Figure 1-18. Comparison of percent of the TVH total catch in the six month period February-July stratified by the number of hours fished per tender-day based on (a) all records, including those where the hours fished is unknown, and (b) those records where the unknown days fished are excluded and the number of hours fished is limited to 1-9. Note, compared to the previous two years, during 2018 a higher proportion of the catch has been taken on sets with effort of more than 6 hours.



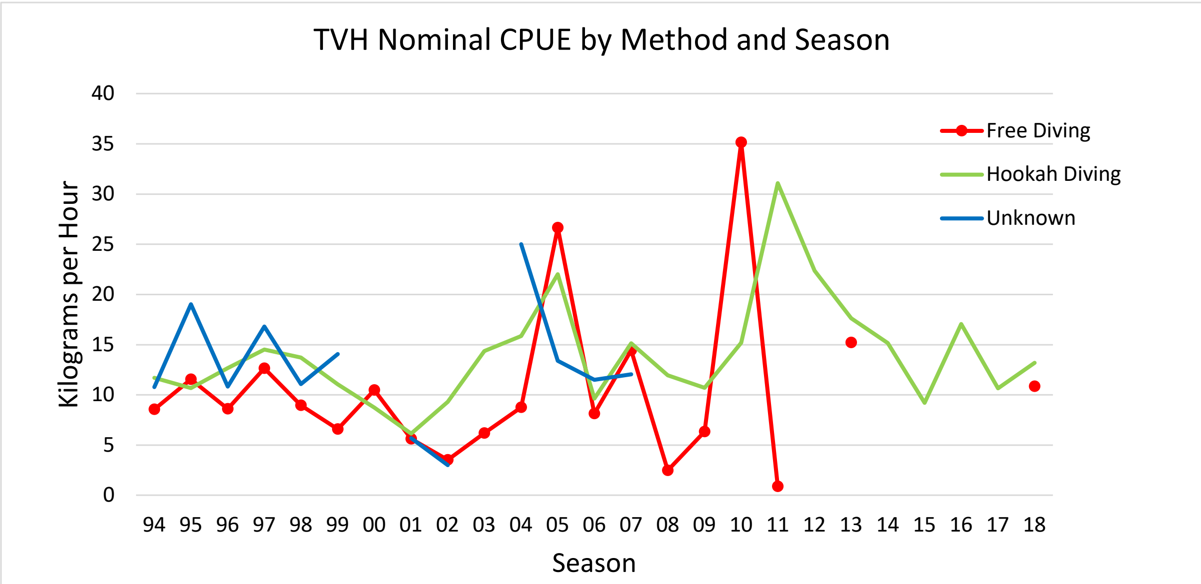


Figure 1-19. Annual time-series of nominal CPUE (kilograms per hour) for the TVH fleet within (a) month and (b) by fishing method during the six month period February-July. Note, generally CPUE decreases after February and in 2018 was similar in March, April and June. In 2018, the mean CPUE in March and April was 28.4% lower than in February (whereas the average decrease over the previous 6 years between 2012 and 2017 was 7.6%). Note, very little TVH fishing took place in May 2018.

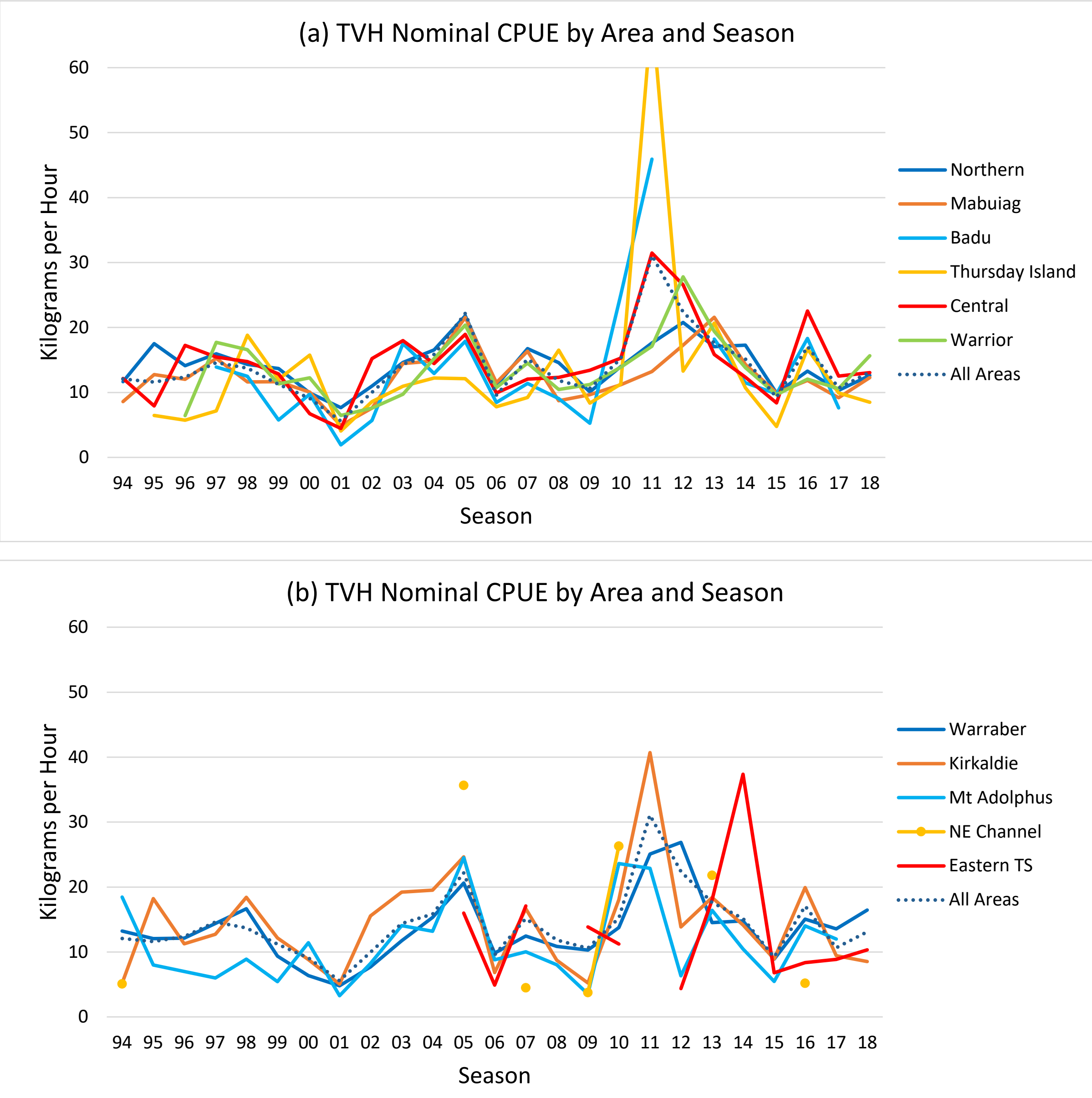


Figure 1-20. Annual time-series of nominal CPUE (kilograms per hour) for the TVH fleet within each area fished during the six month period February-July. For comparison, the mean nominal CPUE across all areas is also shown. Note, across all areas the mean CPUE in 2018 of 13.1 is lower than the mean catch rates over the previous 6 years (15.4), though slightly higher than in 2017 (10.7).

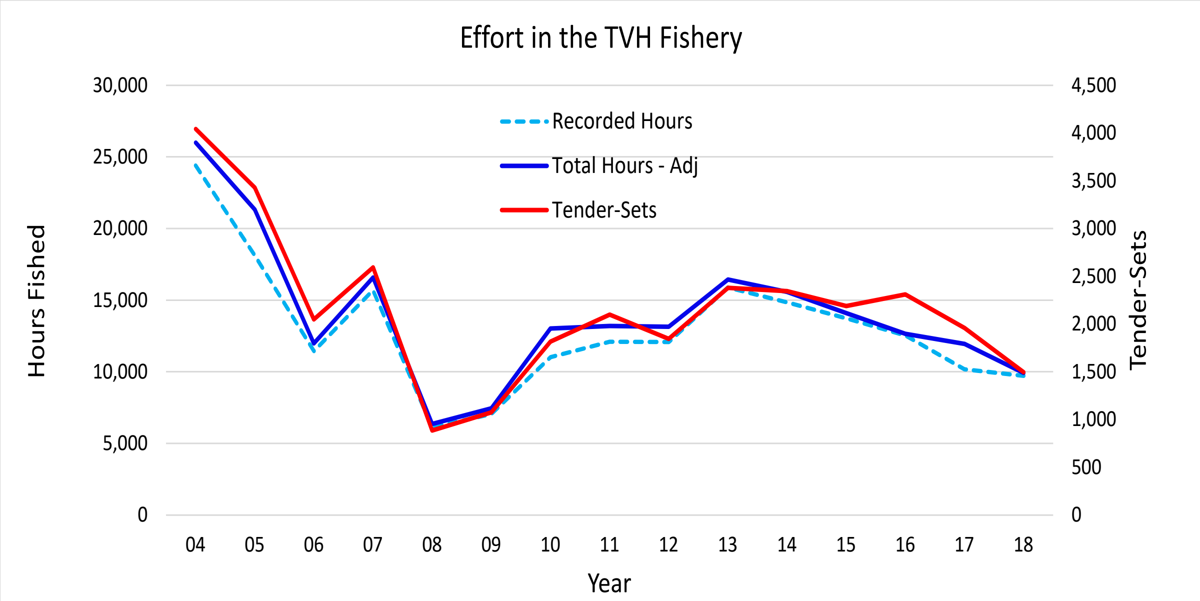


Figure 1-21. Annual comparison of effort in the TVH fishery during the six month period February-July. Analysis based on the method outlined in Campbell (2017).

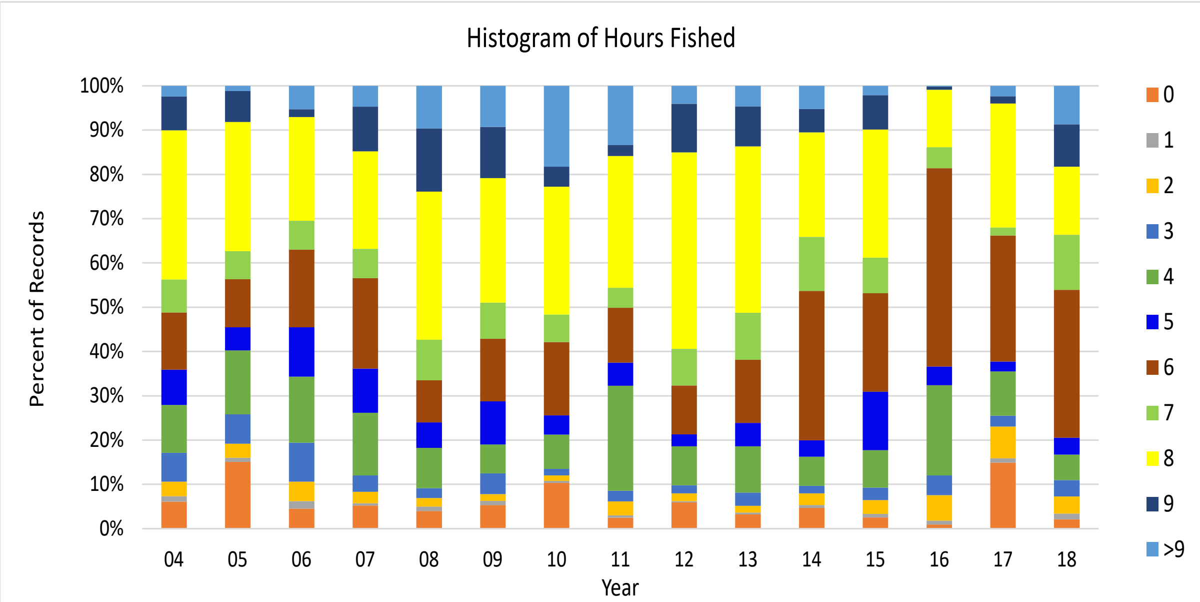


Figure 1-22. Annual comparison of the histogram of the number of hours fished per tender-day for the entire TVH fleet during the six month period February-July. Note, data where the hours fished was not reported have been excluded.

Chapter 2 Estimation of Total Annual Effort in the Torres Strait Rock Lobster Fishery – 2018 update

2.1 TVH Fishery

Data Summary

Catch and effort data for the TVH sector of the Torres Strait rock lobster fishery is recorded in the TRL04 Logbook. The structure of the data is shown in Figure 2-1. 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 was aggregated so that each record refers to the catch for a unique vessel-day, shot, tender and diving method (also known as a tender-set). Between the 2003-04 and 2017-18 fishing seasons (where a season is from 1-December to 31-October the following year) there are a total of 39,956 TVH records or tender-sets. (Note, in the following a season is designated by the main year, e.g. 2018=2017-18 fishing season).

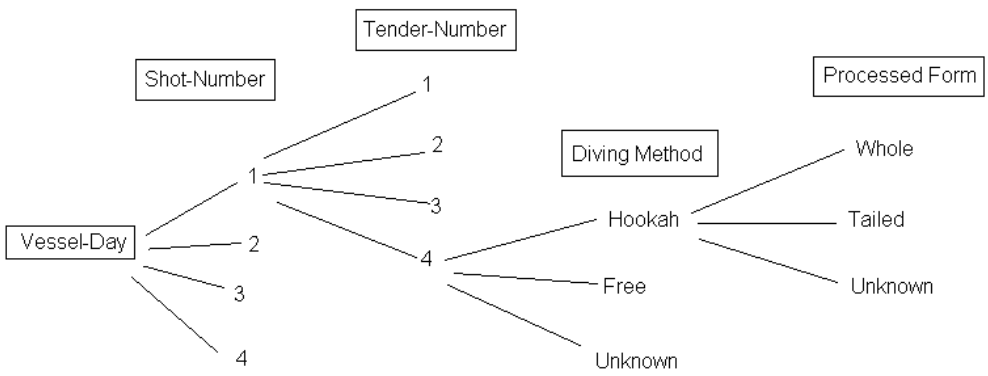


Figure 2-1. Structure of the TVH data

The distribution of these 39,956 records by season and month are given in Table 2-1. It is apparent that there has been little if any effort during October and January since 2006 season.

Effort is recorded as “Hours-Fished” which records the duration of the fishing trip for each tender-set. The distribution of hours fished for all records is shown in Figure 2-2. Unfortunately the fishing effort has not been completed for all tender-sets (c.f. Figure 2-3), with the number of hours fished recorded for only 37,520 (93.1%) of the 39,956 records. The number of recorded hours fished was between 0.15 hours and 96 hours, though the majority were less than 12 hours Of the 337 records where the hours fished was greater than 12, most (315) recorded 24 hours which was assumed to be a day’s fishing. All records where the hours-fished was greater than 12 hours were considered suspect due to possible recording errors and as such only those records where the hours-fished was 12 hours or less were included in the analysis. A further two records where effort was less than 0.5 hours were also excluded. This left a total of 37,183 records (93.1% of all tender-sets) having a recorded effort between 0.5 and 12 hours for further analysis.

Table 2-1. Number of TVH tender-sets by year and month.

SEASON	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
2003-04	176	24	607	712	571	662	761	729	633	395	0	0	5270
2004-05	106	13	662	615	543	519	538	552	533	323	0	0	4404
2005-06	4	0	409	436	361	286	206	349	289	92	0	0	2432
2006-07	0	0	288	427	446	542	489	402	184	91	0	0	2869
2007-08	0	0	133	222	113	161	96	159	175	152	0	0	1211
2008-09	0	0	148	227	174	201	200	125	163	70	0	0	1308
2009-10	0	0	255	333	302	324	292	309	294	253	0	6	2368
2010-11	0	0	286	384	371	322	380	356	310	261	0	0	2670
2011-12	0	0	166	344	371	311	336	318	264	201	0	0	2311
2012-13	0	0	461	383	414	424	324	374	385	243	0	0	3008
2013-14	0	0	357	404	297	433	408	445	274	291	0	1	2910
2014-15	0	0	419	408	441	355	313	253	357	137	0	0	2683
2015-16	0	12	500	444	315	379	349	323	191	141	0	0	2654
2016-17	9	7	397	254	322	383	310	292	277	101	0	0	2352
2017-18	0	10	436	360	335	10	47	308	0	0	0	0	1506
Total	295	66	5,524	5,953	5,376	5,312	5,049	5,294	4,329	2,751	0	7	39,956

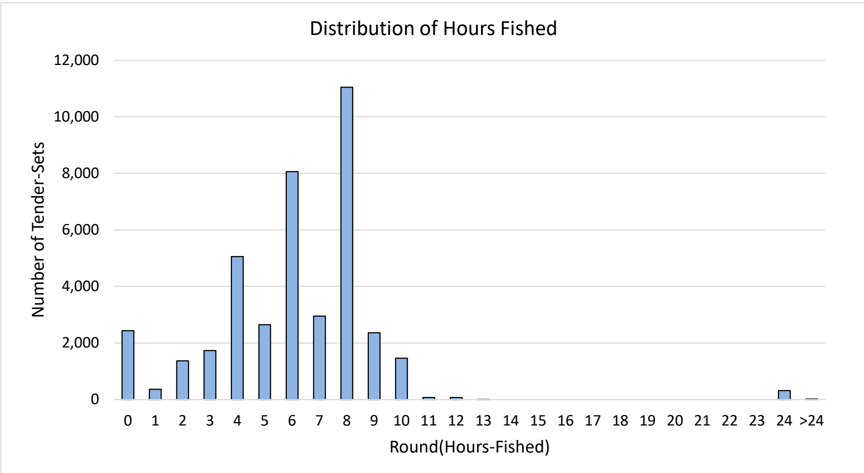


Figure 2-2. Distribution of effort ("hours fished") for the 39,956 TVH records between the 2003-04 and 2017-18 fishing seasons.

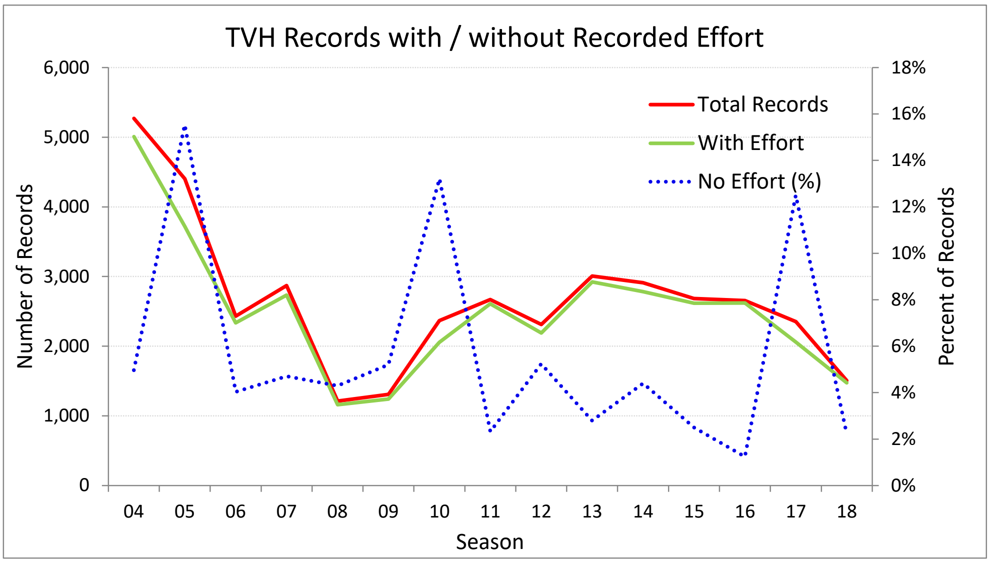


Figure 2-3. The total number of TVH catch records each season and the number of records for which the corresponding effort data is available. The percentage of records for which no effort is recorded is also shown (right hand axis).

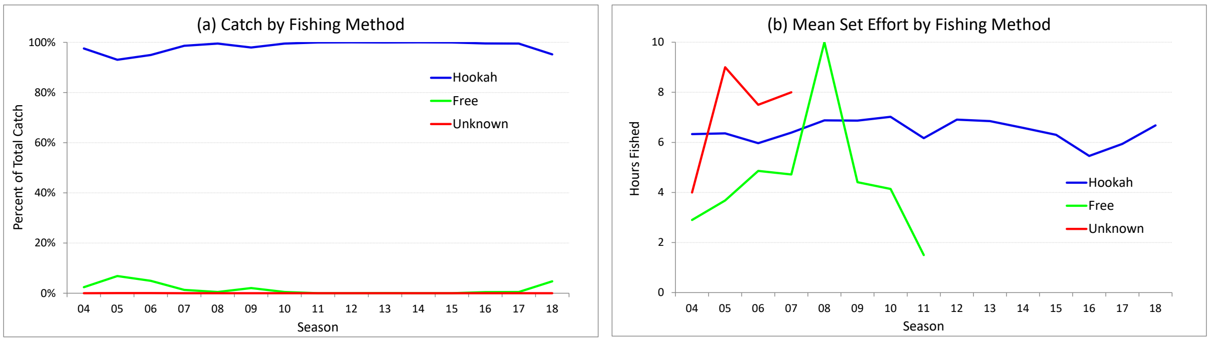


Figure 2-4. (a) The percent of total TVH catch each season caught by each fishing method, and (b) the mean number of hours fished per tender-set for each fishing method.

Finally, the percent of total TVH catch each season (limited to the main months between February and September and where the effort was between 0.5 and 12 hours) caught by each fishing method, and the mean number of hours fished per tender-set for each fishing method are shown in Figure 2-4.

Estimate of Seasonal Effort

Given the above data preparation and filtering the following process was adopted for estimating the total effort each fishing season:

1. First, a seasonal listing of the number of TVH records against the number of hours fished was prepared (c.f. Table 2-2a, Figure 2-5). Records listed against zero hours fished pertain to those where the effort was either not recorded or was outside the 0.5 to 12 hour band used. The total number of tender-sets for each season is also shown in this table.
2. For those records where the hours-fished was recorded, the total number of hours fished for these tender-sets was totalled. This result is shown as the Total Hours in Table 2-2b.
3. To account for those records where the hours-fished was not recorded, the total calculated in the previous section was adjusted as follows:

$$Total\ Hours\ (Adj) = Total\ Hours * \frac{\sum_{i=0}^{12} NumberRecords_i}{\sum_{i=1}^{12} NumberRecords_i}$$

This assumes that the distribution of hours -fished for those records where effort was not recorded is similar to the distribution of hours -fished for those records where effort was recorded. Again, for each season this result is shown as the Total Hours -Adj in Table 2-2b.

Table 2-2. Seasonal listing of (a) the number of TVH records against the number of hours fished – rounded to the nearest integer, and (b) unadjusted and adjusted total number of hours fished.

(a)

	Fishing Season															
Hours-Fished	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
0	265	686	99	138	52	68	435	205	180	88	129	68	33	294	33	2,773
1	63	48	37	14	15	10	10	21	5	15	21	23	32	26	20	360
2	198	134	103	76	24	22	36	88	40	54	75	94	183	184	58	1,369
3	430	300	199	100	34	66	34	58	44	87	64	73	116	71	55	1,731
4	685	633	355	424	129	92	215	610	263	341	201	245	522	254	87	5,056
5	400	231	255	282	86	120	94	145	73	170	124	457	97	53	57	2,644
6	727	482	445	587	128	180	389	464	326	420	970	549	1140	754	502	8,063
7	422	266	182	199	129	132	126	118	187	324	329	195	118	36	187	2,950
8	1622	1292	597	638	375	378	677	728	951	1080	744	747	390	598	230	11,047
9	337	251	37	267	143	127	91	70	207	318	129	186	17	32	146	2,358
10	69	81	123	144	94	113	261	156	30	111	95	44	5	50	88	1,464
11	7	0	0	0	2	0	0	1	4	0	24	1	1	0	29	69
12	45	0	0	0	0	0	0	6	1	0	5	1	0	0	14	72
Total Tender-Sets	5,270	4,404	2,432	2,869	1,211	1,308	2,368	2,670	2,311	3,008	2,910	2,683	2,654	2,352	1,506	39,956
0.5 to 12 hours	5,005	3,718	2,333	2,731	1,159	1,240	1,933	2,465	2,131	2,920	2,781	2,615	2,621	2,058	1,473	37,183

(b)

Total Hours	31,068	23,001	13,792	17,403	7,996	8,484	13,547	15,216	14,721	19,994	18,296	16,464	14,314	12,235	9,774	236,305
Total Hours - Adj	32,713	27,245	14,377	18,282	8,355	8,949	16,596	16,481	15,964	20,597	19,145	16,892	14,494	13,983	9,993	254,066

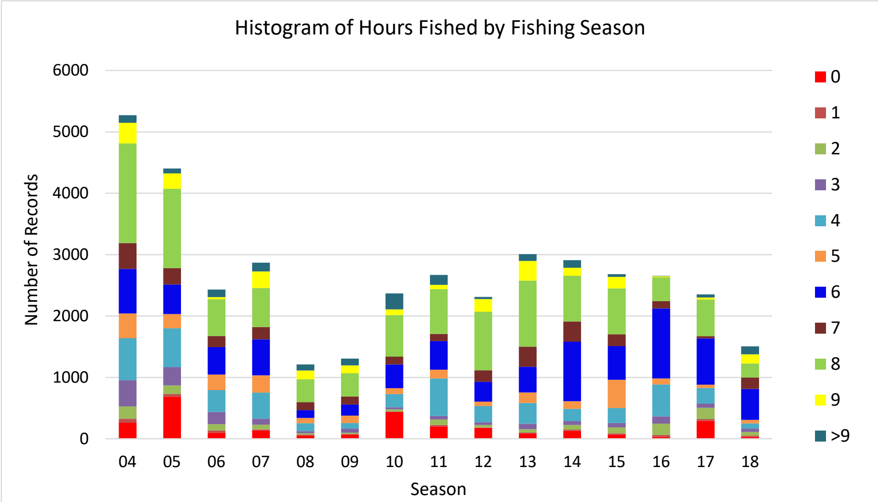


Figure 2-5. Estimates of unadjusted and adjusted total number of hours fished and number of tender-sets for the TVH sector each fishing season.

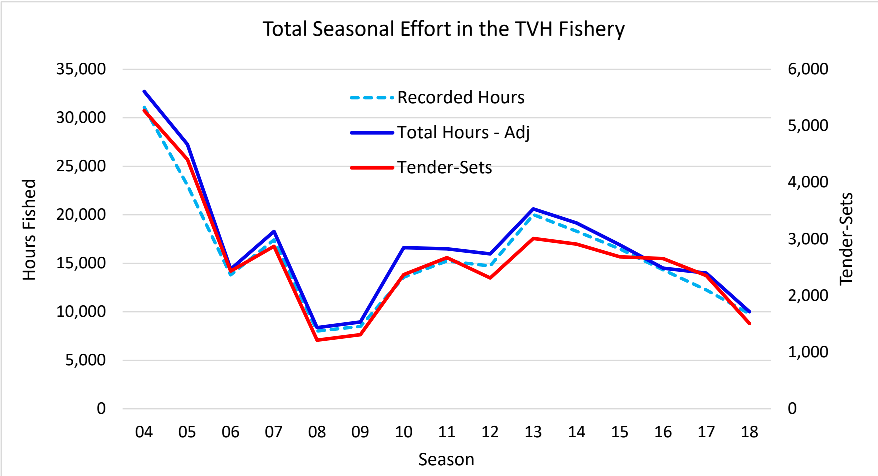


Figure 2-6. Estimates of TRL04 Logbook recorded and adjusted total number of hours fished and number of tender-sets for the TVH sector each fishing season.

The results of the above process are shown in Figure 6-1. Note that the final adjusted effort shown for each season (Total Hours-Adj) is only an estimate as it is difficult to know how accurate the recording of this effort is in the logbook (which is understood to relate to the time away from the primary vessel). Nevertheless, the trends in both the seasonal effort measured in hours fished or number of tender-sets are similar.

2.2 TIB Fishery

Docket-book Coverage

The Buyers and Processors Docket-Book (TDB01), used in the TIB sector of the Torres Strait rock lobster fishery, records the catch sold by fishers (known as sellers on the docket-book) at the end of a fishing trip. However, unlike the logbook for the TVH sector of fishery, which requires catch and effort data to be recorded for individual fishing operations related to each vessel tender, the docket-book requires only aggregate catch and effort data to be recorded at the end of each trip. In particular, the docket-book records the transaction date, the name of the seller together with details of the catch (in weight) and the price obtained. Additional information is also provided regarding the vessel, the number of crew, the number of days fished and the fishing methods used. This information therefore provides a measure of both the catch and effort for a given seller (or fisher) during a fishing trip.

However, there are a number of issues with the docket-book system which create problems with using this data for estimating the total catch and effort in the TIB fishery. These issues include:

i. The requirement that completion of the docket-book is only voluntary,
ii. The fact that catches recorded in the docket-book can also be reported elsewhere, including the TVH logbook,
iii. The fact that processors can also record catches in the docket-book, essentially creating duplicates.

Given the duplication of catch information from both the TVH sector and processors which occurs in the docket-book data, several filters are applied to this data to remove these duplicates. Further to these issues, during some seasons several TIB boats only recorded their catch in the TVH-related logbook (TRL04) and these catch records need to be transferred to the TIB database. Finally, between 2013 and 2016 several processors reported aggregate seasonal catch data as these catches were not being recorded in the TDB01 Docket-Book. Each processor reported the catch for tailed and whole lobsters separately, so that for each season two data records were added to the Docket-Book data for each processor to account for these additional catches.

TIB Summary

Considerable effort has gone into understanding the nature of both the TDB01 Docket-Book and TRL04 Logbook data so as to identify the catch records that should be assigned to the TIB 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). A total of 52,323 catch records have now been attributed to the TIB fishery covering the seasons 2004 to 2018. A few Docket-Book records (37) having a zero catch of lobsters are not included in this total as it is assumed that other species may have been targeted on these trips.

Table 2-3. Number of distinct TIB Record Nos by season and the related catch by data source. Note, PRC relates to the aggregate catch provided by several processors.

	N-Records				% Catch			
Season	TDB01	TDB02	TRL04	PRC	TDB01	TDB02	TRL04	PRC
2004	4058	0	0	0	100.0%	0.0%	0.0%	0.0%
2005	6867	0	0	0	100.0%	0.0%	0.0%	0.0%
2006	3882	0	0	0	100.0%	0.0%	0.0%	0.0%
2007	6212	0	0	0	100.0%	0.0%	0.0%	0.0%
2008	4768	0	114	0	94.5%	0.0%	5.5%	0.0%
2009	3596	0	95	0	94.6%	0.0%	5.4%	0.0%
2010	3033	0	62	0	95.9%	0.0%	4.1%	0.0%
2011	2845	0	0	0	100.0%	0.0%	0.0%	0.0%
2012	1424	0	168	0	79.8%	0.0%	20.2%	0.0%
2013	649	0	183	2	36.7%	0.0%	24.5%	38.9%
2014	2224	0	32	2	65.2%	0.0%	1.2%	33.5%
2015	2652	0	25	2	61.4%	0.0%	0.7%	38.0%
2016	2762	0	0	4	44.8%	0.0%	0.0%	55.2%
2017	3469	0	0	0	100.0%	0.0%	0.0%	0.0%
2018	0	3193	0	0	0.0%	100.0%	0.0%	0.0%
	48,441	3,193	679	10				

The number of catch records and the associated estimate of the total catch of rock lobsters in the TIB sector each season and by data source is shown in Table 2-3 and Figure 2-7. Between 2004 and 2007 all catch was sourced from the TDB01 Docket-Book, and the number of catch records each season varied between 4,058 and 6,867. After this time, and between 2008 and 2015, a portion of the total catch attributed to the TIB sector each season was recorded in the TRL04 Logbook, and while the total related catch was usually small (<10 tonnes) this catch represented over 20% of the total TIB catch in both 2012 and 2013. Finally, between 2013 and 2016 a significant portion of the total TIB catch (between 33% in 2014 and 55% in 2016) was attributed to the aggregate catch data provided by several processors (as this catch was not recorded in the Docket-Book). Whether or not other catches were also not been recorded in the Docket-Book during these or in other seasons remains unknown. Finally, during the 2017 season all catches attributed to the TIB sector were recorded in the TDB01 Docket-Book, while with the introduction of the new TDB02 Docket-Book in December 2017 all catches during the 2018 fishing season where recorded in this latter logbook.

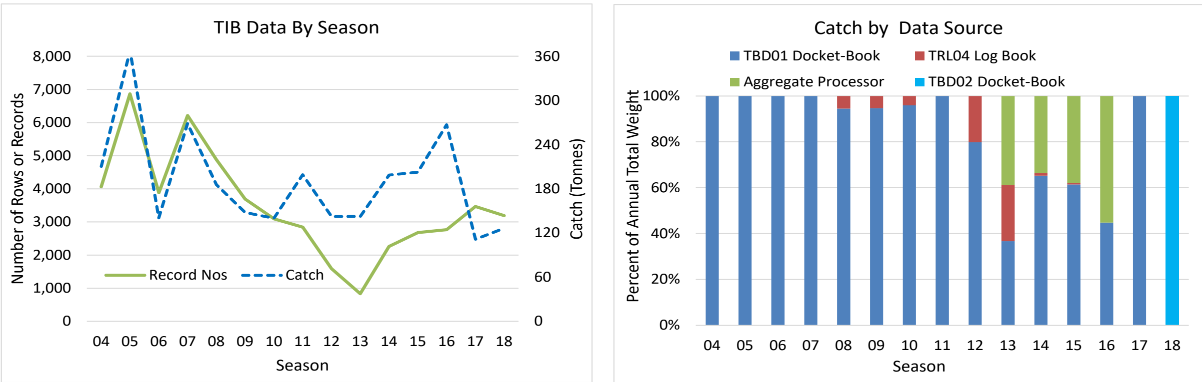


Figure 2-7. Number of TIB data rows, distinct TIB Record Numbers, and associated catch (in tonnes) per fishing season.

Data Preparation

The catch and effort information recorded in each of the TDB01 & TDB02 Docket-Books is associated with a unique Record-No (i.e. the corresponding record number of the page on which the catch and effort data is recorded). While there are usually multiple catch records associated with a given Record-No (given that the catch is separately recorded by process form and perhaps grade), 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 is likely to be due to mis-recording of the date (and possibly other data fields). Whatever the reason, for the following analysis it was assumed that the multiple records for some vessel, date and seller-names is due to the mis-reporting of the date, and that each Record-No indeed pertains to a separate trip for each seller.

Unlike the TVH data where the measure of effort is hours-fished, the measure of effort recorded in the Docket-Book data is coarser, being days-fished. Furthermore, and as noted above, it has been assumed that each Record-No relates to the catch and effort of a single fisher (or seller) during a given trip, i.e. it is assumed that the measure of effort (days fished) associated with each Record-No also pertains to the actual effort expended by that seller in obtaining the recorded catch.

For the TIB attributed catch not-recorded in the Docket-Book there is no corresponding effort information in days fished. However, the TRL04 Logbook allows for fishing effort to be recorded as the number of hours fished. For the 713 TRL04 Logbook records attributed to the TIB sector the hours fished varied between 1 and 11 with a mode at 6 hours (43% of records). If one considers these fishing efforts correspond to a single day's fishing then one could set the effort equal to one day for all these 713 records. However, a comparison of the seasonal CPUE (kg/day) between these logbook records with the CPUE for records in the Docket-Book (where days-fished is also 1) indicates that the former are, on average, three times higher. This indicates that the nature of the operations for these larger TIB vessels is substantially different from those of the typical TIB vessel. The example, more than one tender is often associated with each catch Record for the larger vessels recording their catch on the TRL04 Logbook. As such, for the following analysis the effort for these Records was assumed to remain unknown. Similarly, the number of days fished to attribute to the aggregate seasonal catch data provided by the processors also remains unknown.

Estimate of Seasonal Effort

As with the TVH data, in order to account for the under-reporting of effort relating to all trips in the TIB database, the following process was adopted for estimating the total seasonal effort:

1. First, a seasonal listing of the number of 51,634 TIB Records included in the TDB01& TDB02 Docket-Books against the number of days fished was prepared (c.f. Table 2-4). Note: trips of duration greater than 2-3 days have been recorded and whether these are correct remains uncertain. The associated histogram of the number of days fished is shown in Figure 2-8.
2. For the 45,135 Records where the days-fished has been recorded the total number of days fished was calculated as follows:

$$Total\ Days = \sum_{i=1}^{20} Number\_Records_i * Days\_Fished_i$$

   For each season this result is shown as the Total Days in Table 2-4b.

3. To account for the 6499 Docket-Book Records where the days-fished had not been recorded, the total calculated in the previous section was adjusted as follows:

$$Total\ Days\ (Adj1) = Total\ Days * \frac{\sum_{i=0}^{20} Number\_Records_i}{\sum_{i=1}^{20} Number\_Records_i}$$

   This assumes that the distribution of days-fished for those Records where effort was not recorded is similar to the distribution of days-fished for those Records where effort was recorded. Again, for each season this result is shown as the Total Days-Adj1 in Table 2-4b.

4. Finally, to account to the effort associated with those catches which had not been recorded in the TDB01 Docket-Book (i.e. those catches recorded in the TRL04 Logbook or provided in aggregate form for some seasons by processors), a final estimate of the total number of days fished each season was calculated as follows:

$$Total\ Days\ (Adj2) = Total\ Days(Adj1) * \frac{Total\ TIB\ Catch}{Effort\ Associated\ Catch}$$

   where *Effort Associated Catch* relates to the total catch pertaining to the 51,634 Docket-Book Records included in Step 1. Again, this assumes that for catches not recorded in the Docket-

Book the relationship between catch and effort is similar to those catches recorded in the Docket-Book. The result is shown as the Total Days-Adj2 in Table 2-4b.

Table 2-4. (a) Seasonal listing of the number of Docket-Book Records against the number of days fished. (b). Unadjusted and adjusted total number of days fished each season.

(a)	Fishing Season															
Days-Fished	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
0	683	387	321	458	92	112	15	199	215	563	466	647	751	672	918	6,499
1	2737	5556	3010	5049	4133	2914	2702	2378	881	75	1266	1484	1611	2659	1675	38,130
2	325	422	258	421	317	279	147	78	117	7	215	209	191	66	298	3,350
3	119	204	145	137	123	124	111	59	68	1	116	159	105	31	184	1,686
4	85	101	60	49	39	66	29	44	42	2	70	59	36	13	61	756
5	52	101	51	67	39	51	12	32	25	1	39	49	17	17	32	585
6	10	43	3	6	8	13	3	23	36	0	13	12	12	4	9	195
7	12	27	14	7	9	17	10	12	16	0	21	14	10	5	2	176
8	12	10	9	8	4	5	2	7	10	0	13	9	6	0	2	97
9	12	5	2	2	0	0	0	3	5	0	5	10	23	2	3	72
10	2	5	3	3	1	7	1	8	2	0	0	0	0	0	0	32
11	3	0	0	0	3	5	1	1	7	0	0	0	0	0	0	20
12	0	4	1	1	0	2	0	0	0	0	0	0	0	0	0	8
13	4	1	1	2	0	0	0	0	0	0	0	0	0	0	0	8
14	2	1	1	1	0	0	0	1	0	0	0	0	0	0	7	13
15	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2
16	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total Records	4,058	6,867	3,882	6,212	4,768	3,596	3,033	2,845	1,424	649	2,224	2,652	2,762	3,469	3,193	51,634
(b)																
Total Days	4,825	8,618	4,779	7,097	5,673	4,764	3,630	3,457	2,162	105	2,893	3,192	2,934	3,098	3,473	60,700
Total Days - Adj1	5,801	9,133	5,210	7,662	5,785	4,917	3,648	3,717	2,546	792	3,660	4,222	4,030	3,842	4,874	69,840
Associated Catch	210,383	367,615	140,451	268,689	175,442	139,850	134,353	199,061	113,622	52,249	129,657	124,369	119,756	111,504	126,476	2,413,477
Total Catch	210,383	367,615	140,451	268,689	185,665	147,814	140,039	199,061	142,379	142,522	198,776	202,606	267,135	111,504	126,476	2,851,115
Total Days -Adj2	5,801	9,133	5,210	7,662	6,122	5,197	3,802	3,717	3,191	2,161	5,611	6,878	8,989	3,842	4,874	82,191

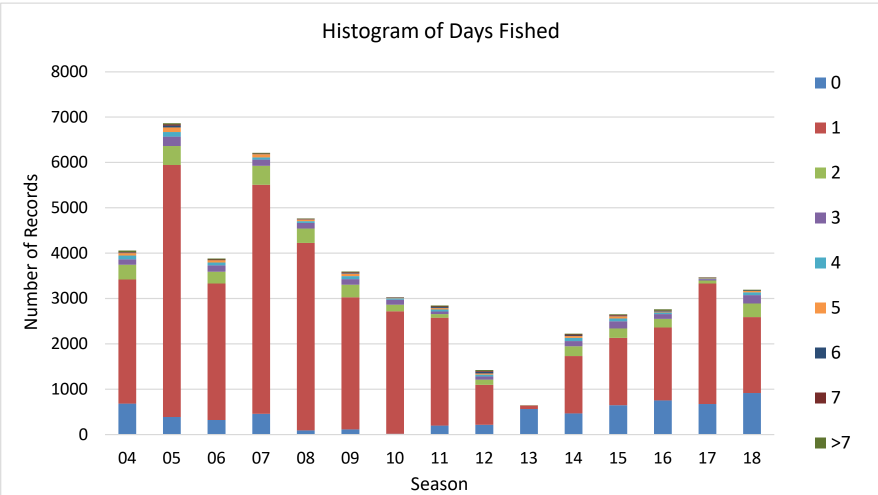


Figure 2-8. Histogram of the number of days fished for TIB related records each season.

The results of the above analyses are shown in Figure 2-9. Note that the final adjusted effort shown for each season (Total Days-Adj2) is only an estimate and it is difficult to know how accurate this estimate is for each season. For example, the relatively low effort estimate for 2013 is no doubt influenced by the small amount of data available for that season – only 86 Docket-Book records had effort recorded, while the high effort estimate for 2016 is influenced by the high proportion (55%) of the catch provided in aggregate form (again for which no effort information was available). Finally, the time-series of seasonal effort is premised on the total TIB catch data being adequately captured by various formats (TDB01 & TDB02 Docket-books, TRL04 Logbook, processors) and if this data is not complete given the caveats on the data mentioned previously then this this will impact on the estimate of total effort for each season.

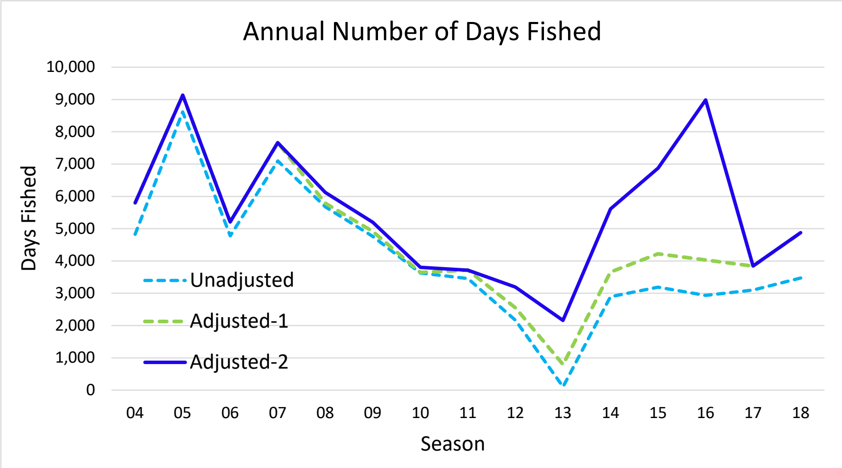


Figure 2-9. Estimates of unadjusted and adjusted total number of days fished each fishing season in the TIB sector.

See also Appendix A this report.

Chapter 3 Use of TVH Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2018 update

3.1 TVH Data

The Torres Strait Tropical Rock Lobster Fishery Daily Fishing Log (TRL04) is used to record the catches taken in the TVH sector of the Torres Strait rock lobster fishery. Logbook data obtained from AFMA consists of 99,267 individual catch records for the TVH rock-lobster fishery for the 25 years from 1994 to 2018. The structure of the data is shown in Figure 3-1. 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 was aggregated so that each record refers to the catch for a unique vessel-day, shot, tender and diving method. This gave 70,283 records.

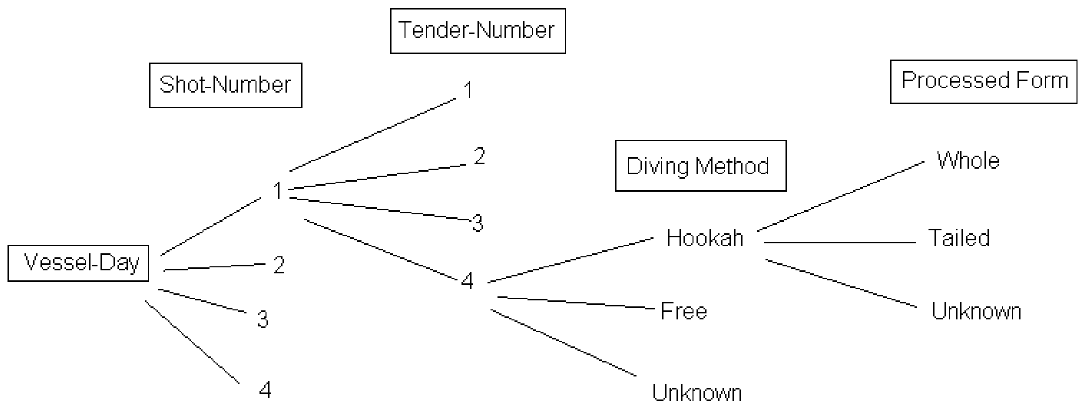


Figure 3-1. Structure of the TVH data.

The distribution of these 70,283 catch records by year and month, diving method, processed state of catch and MSE-area are given in Tables 3-1 to 3-3. There has been little if any effort during October and November before 2006 and since 2006 there has been little effort in the months October-to-January. As such the analysis was limited to the 8 months between February and September. Similarly the analysis was also limited to those records with a known MSE-area (i.e. areas designated A0 and A99 were excluded) though areas 201 and 202 were combined (to provide a better data coverage, and designated as area 110) and area 401 (GBR) was also excluded.

In the past CPUE has been recorded as the catch-per-tender-set. However, as there can be multiple shots-per-day the duration of a tender-set can obviously vary and each tender-set cannot be assumed to be equivalent to a tender-day. The catch data also contains a field “Hours-Fished” which records the duration of the fishing trip for each tender-set and this was deemed to be a better measure of tender effort than assuming each tender-set is equivalent to a day's effort. However, unfortunately this field has not been completed for all tender-sets, with the number of hours fished recorded for only 56,534 (80.4%) of the 70,283 records. (Note, the proportion of records where the effort was not recorded averaged 32% between 1994 and 2005, but has been less than 5% for most years since 2006, but was 13% in 2010 and again increased to 12.5% in 2017, c.f. Figure 3-2). The distribution of hours fished for these records is shown in Figure 3-4. The number of recorded hours fished is between 0.15 hours and 96 hours, though was 12 hours or less for 99.4% of all records. All records where the recorded hours-fished was greater than 12 hours were considered suspect and as such only those records where the hours-fished was 12 hours or less were included in the analysis. The five records where effort was less than 0.5 hours were also excluded. Note, the number of hours fished was recorded as 24 hours for 315 records and was assumed to represent a "day's" fishing.

After applying each of the following filters to the data:

- Exclude MSE-areas 0, 401 and -99
- Exclude Month<2 and Month>9
- Exclude Hours-Fished less than 0.5 hour and greater than 12 hours

the number records included in the data for further analysis was reduced to 51,643. The mean (a) effort, (b) catch and (c) CPUE by fishing method and year for these records are shown in Figure 3-5.

Table 3-1. Number of TVH catch records by year and month.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1994	84	105	236	448	347	364	227	310	270			54	2445
1995	23	116	123	147	185	220	121	239	238	3		220	1635
1996	366	237	447	247	378	264	356	517	411			324	3547
1997	383	232	307	239	598	333	438	538	327	18		598	4011
1998	445	739	551	484	486	587	553	603	493		9	231	5181
1999	117	98	262	242	208	214	161	132	146			235	1815
2000	196	240	349	215	328	370	342	232	99		66	274	2711
2001	375	97	223	65	259	270	206	174	119	9	1	87	1885
2002	26	285	365	295	401	400	360	492	398			89	3111
2003	100	461	488	393	490	518	527	596	413			176	4162
2004	24	607	712	571	662	761	729	633	395			106	5200
2005	13	662	615	543	519	538	552	533	323			4	4302
2006		409	436	361	286	206	349	289	92				2428
2007		288	427	446	542	489	402	184	91				2869
2008		133	222	113	161	96	159	175	152				1211
2009		148	227	174	201	200	125	163	70				1308
2010		255	333	302	324	292	309	294	253		6		2368
2011		286	384	371	322	380	356	310	261				2670
2012		166	344	371	311	336	318	264	201				2311
2013		461	383	414	424	324	374	385	243				3008
2014		357	404	297	433	408	445	274	291		1		2910
2015		419	408	441	355	313	253	357	137				2683
2016	12	500	444	315	379	349	323	191	141			9	2663
2017	7	397	254	322	383	310	292	277	101				2343
2018	10	436	360	335	10	47	308						1506
Total	2,181	8,134	9,304	8,151	8,992	8,589	8,585	8,162	5,665	30	83	2,407	70,283

Table 3-2. Annual number of TVH catch records by diving method and TVH catch by processed state.

	Number of Vessel by -			Diving Method			Total	Catch by Processed State (kg)			Total		
Year	Name	Symbol	Both#	Hookah	Free	Unknown	Records	Tails	Whole	Unknown	Catch	%Tails	%Whole
1994	11	11	11	1,505	136	804	2,445	123,006	0	0	123,006	100.0%	0.0%
1995	14	14	14	947	59	629	1,635	100,407	635	0	101,042	99.4%	0.6%
1996	20	20	20	1,609	87	1,851	3,547	219,045	7,810	0	226,855	96.6%	3.4%
1997	20	20	20	1,890	112	2,009	4,011	273,151	1,880	8	275,040	99.3%	0.7%
1998	23	22	23	2,681	169	2,331	5,181	310,635	18,922	0	329,556	94.3%	5.7%
1999	15	14	15	1,412	38	365	1,815	88,416	6,681	0	95,097	93.0%	7.0%
2000	20	19	20	2,330	114	267	2,711	118,824	10,038	0	128,862	92.2%	7.8%
2001	14	14	14	812	26	1,047	1,885	66,347	2,729	0	69,076	96.0%	4.0%
2002	17	17	17	1,721	10	1,380	3,111	108,216	39,471	0	147,687	73.3%	26.7%
2003	21	21	21	3,958	104	100	4,162	255,447	105,964	0	361,411	70.7%	29.3%
2004	25	24	25	5,045	154	1	5,200	317,467	163,651	0	481,118	66.0%	34.0%
2005	22	23	23	4,101	199	2	4,302	484,497	60,480	0	544,977	88.9%	11.1%
2006	22	20	22	2,307	119	2	2,428	108,909	26,539	0	135,448	80.4%	19.6%
2007	20	20	20	2,829	39	1	2,869	207,463	61,133	0	268,596	77.2%	22.8%
2008	13	12	14	1,205	6	0	1,211	63,378	37,060	0	100,438	63.1%	36.9%
2009	10	10	10	1,281	27	0	1,308	51,322	39,729	10	91,061	56.4%	43.6%
2010	13	12	13	2,356	12	0	2,368	67,817	214,797	0	282,614	24.0%	76.0%
2011	14	13	14	2,668	1	1	2,670	171,469	332,064	0	503,533	34.1%	65.9%
2012	14	13	14	2,311	0	0	2,311	65,282	305,198	2	370,482	17.6%	82.4%
2013	11	12	12	3,006	2	0	3,008	61,631	300,030	0	361,661	17.0%	83.0%
2014	13	13	13	2,910	0	0	2,910	42,105	230,961	120	273,186	15.4%	84.5%
2015	13	12	13	2,682	1	0	2,683	22,479	130,231	0	152,709	14.7%	85.3%
2016	12	11	12	2,642	21	0	2,663	42,714	200,986	0	243,700	14.7%	85.3%
2017	11	12	12	2,340	3	0	2,343	23,885	125,163	0	149,048	14.7%	85.3%
2018	9	9	9	1,434	72	0	1,506	19,159	109,142	22	128,323	14.9%	85.1%
Total				57,982	1,511	10,790	70,283	3,413,071	2,531,294	162	5,944,526	57.4%	42.6%

Table 3-3. Number of TVH catch records by MSE-area.

	Northern	Mabuiag	Badu	Thurs Is.	Central	Warrior	Warraber	Kirkaldie	Adolphus	East TS	East TS	GBR	East Coast	NR	
YEAR	A101	A102	A103	A104	A105	A106	A107	A108	A109	A201	A202	A401	A0	A-99	TOTAL
1994	51	257		11	119		926	64	89	106	177	1		392	2445
1995	106	289	2	41	83		487	111	26	36	32	4		223	1635
1996	620	1152	2	11	51	11	719	41	37	1	32			608	3547
1997	425	1324	21	19	73	100	881	4	21	52	33	3	1	630	4011
1998	463	1681	51	128	107	200	1042	160	16	31	45		2	794	5181
1999	158	457	34	33	66	177	348	177	17	14	30	15		212	1815
2000	137	252	66	48	51	404	605	229	59	7	22	35		370	2711
2001	42	70	5	44	26	329	366	83	40	3	41	44		405	1885
2002	107	278	18	176	44	351	592	718	48		17	16		401	3111
2003	1080	442	112	315	344	396	432	832	96	7	49	4	4	33	4162
2004	1072	612	209	159	551	343	980	970	208	15	51	8		9	5200
2005	803	466	161	194	156	211	511	1680	90	3	18	6			4302
2006	362	267	20	131	187	300	440	351	280	34	48	4			2428
2007	483	293	42	146	120	311	367	980	62	6	28	2			2869
2008	236	58	6	91	52	235	240	206	48	2	31	3		2	1211
2009	268	46	5	80	145	365	231	47	26	23	59	7			1308
2010	564	67	103	103	33	197	206	992	43	12	32	14			2368
2011	389	111	34	83	17	159	430	1406	25		14				2670
2012	417	217		14	46	155	1166	267	18	5	5				2311
2013	718	239	34	16	63	168	469	1267	6	6	21				3008
2014	777	263	15	27	165	268	786	445	47	14	93				2910
2015	176	173	45	5	117	874	661	486	25		121				2683
2016	66	12	62	7	202	681	454	950	18	131	60				2663
2017	726	108	9	43	67	401	461	422	15		74				2343
2018	735	218		34	32	233	164	55			22				1506
Total	10,981	9,352	1,056	1,959	2,917	6,869	13,964	12,943	1,360	508	1,155	166	7	4,079	70,283

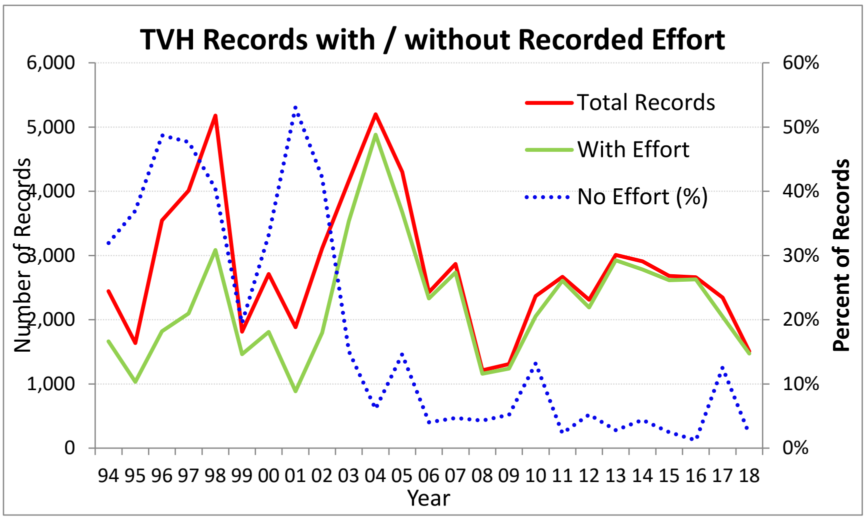


Figure 3-2. The total number of TVH catch records each year and the number of records for which the corresponding effort data is available. The percentage of records for which no effort is recorded is also shown (right hand axis).

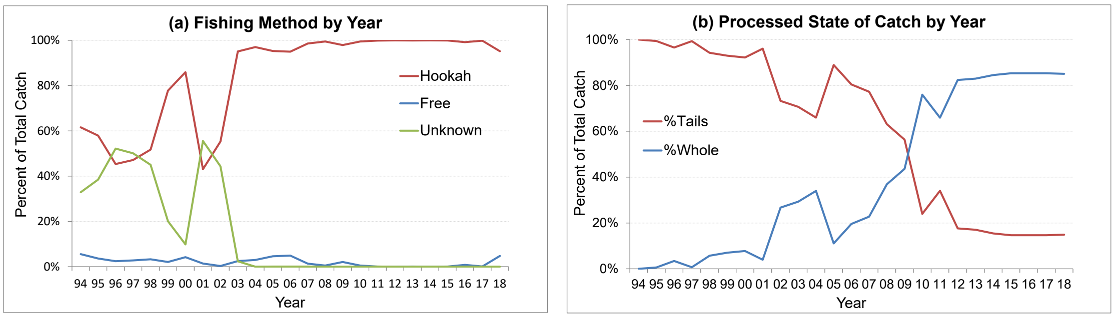


Figure 3-3. The percent of total TVH catch each year (a) caught by each fishing method, and (b) landed as Tails or Whole weight.

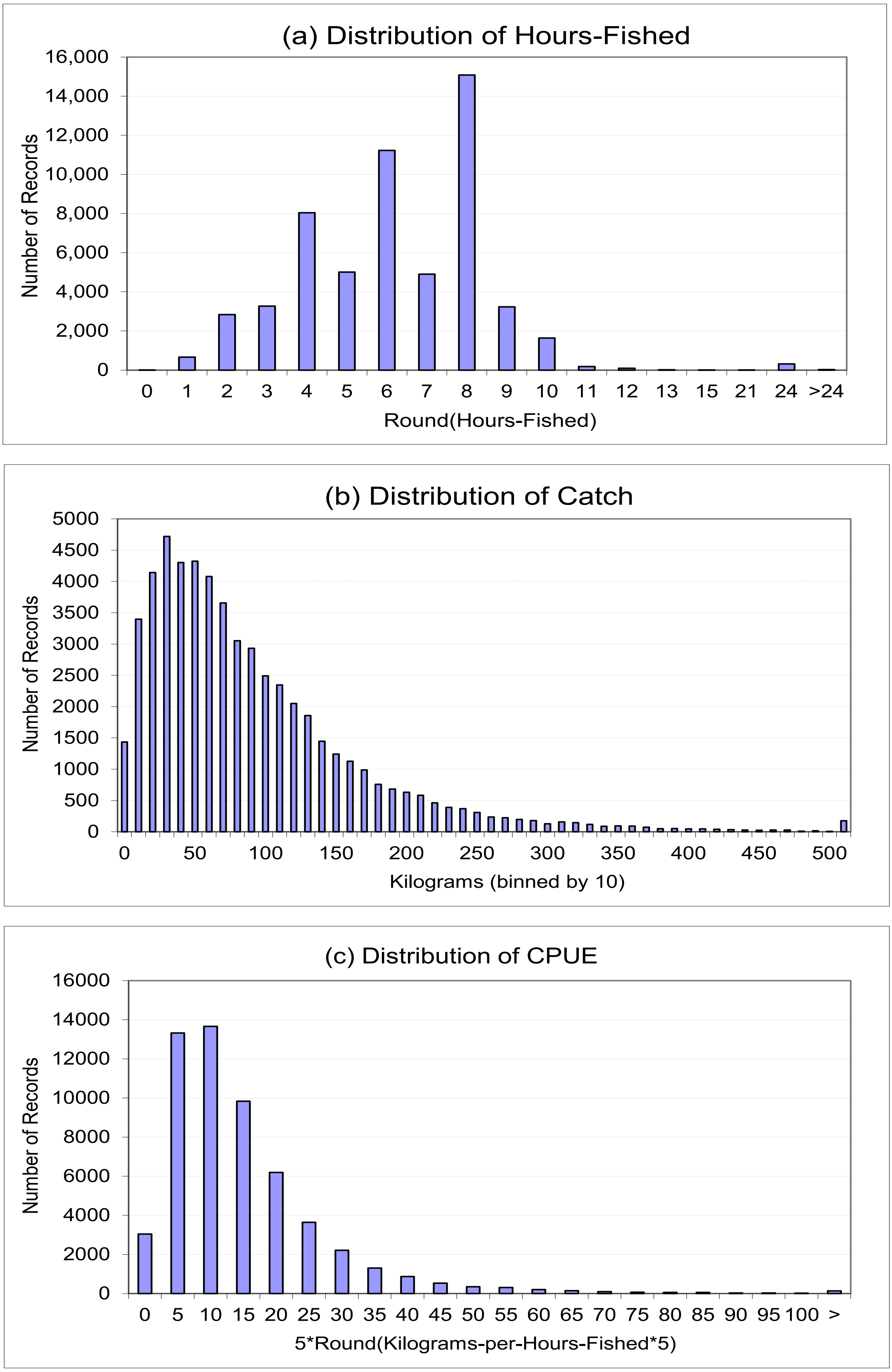


Figure 3-4. Distribution of (a) effort, (b) catch and (c) CPUE for the 56,534 records for which effort was recorded on TVH logbooks.

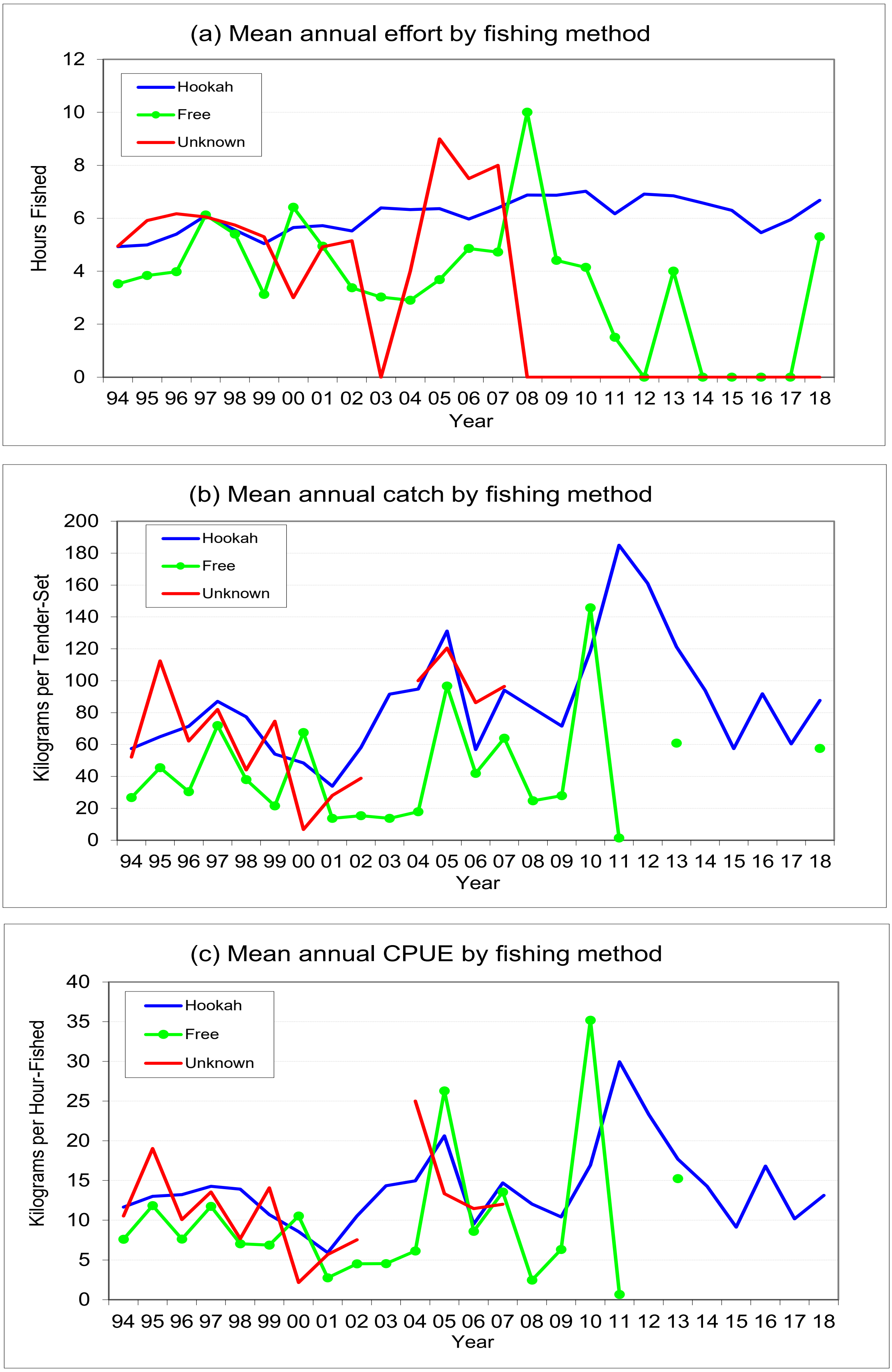


Figure 3-5. Mean (a) effort, (b) catch and (c) CPUE by fishing method and year for the 51,643 unique vessel-day, shot, tender and diving method records for which this effort was between 0 and 12 hours and areas and months restricted as described in the text.

3.2 GLM Analysis

Fitted Data

Of the 51,643 records selected above for analysis it was noted that there were a small percentage of records (618 or 1.2%) where the catch was zero. The inclusion of such records in the GLM analyses can cause problems. The percentage of such records each year is shown in Figure 3-5a and varies from a high of 4.0% in 1998 to a low of 0.29% in 1999. Nevertheless, apart from the four years when this percent was greater than 2% there does not appear to be a trend in the percentage of zero catches in the data over time. As such, and as recommended for the analyses undertaken previously, these zero catch records were excluded from the analyses. Note, to retain the zero-catch records in the analysis a two-stage analysis of the data can be undertaken where one first models the probability of obtaining a positive catch following by a separate analysis where one models the size of the positive catch. The results of each analysis can then be combined to obtain the required standardised CPUE index. Such an approach was not considered appropriate for this data due to the small percentage of zero-catch records in the data.

Further inspection of the data also indicated a number of records having a very high CPUE (kilograms of catch per hour fished) value and which could be considered outliers in the data, possibly due to errors in either the recording of the catch or effort. To exclude these possibilities the 27 records having a CPUE>150 kgs/hour were deleted from the data (cf. Figure 3-6a). Finally, due to the observation that Vessel-Names and Vessel-Symbols are not always matched (likely due to the switching of licences between vessels) a combination of Vessel-Name and Vessel-Symbol was adopted to identify vessels in the data. Of the 94 vessels identified in this manner in the selected data, only the data pertaining to the 48 vessels which had fished for 3 or more years and for which there were 50 or more data records were included in the analysed data (c.f. Figure 3-6b. Note only 4 vessels are selected for 2018). Combined with the other two filters the total number of records remaining in the data for analysis was 45,427.

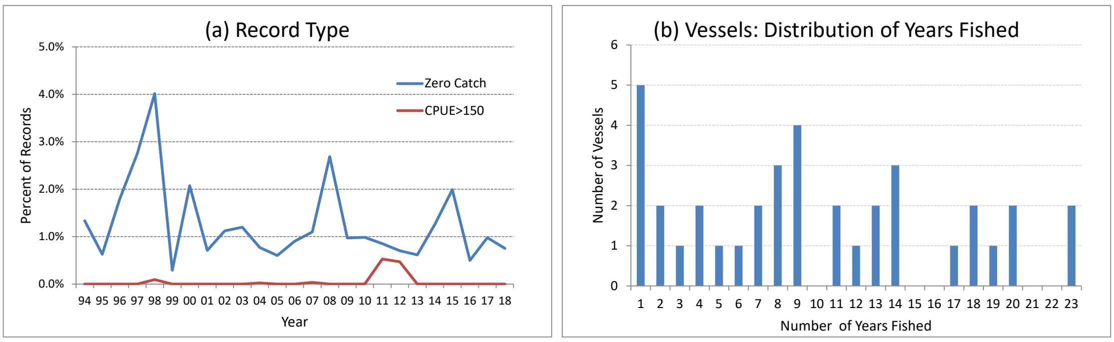


Figure 3-6. (a) Percentage of records in the data, by year, where either the catch is zero, or the CPUE>150 kg/hour, and (b) histogram of the number of vessels (distinguished by vessel symbol) by the number of years they have fished in the fishery.

The number of Area-Month strata fished each year and the number of vessels fishing each year in the data selected for inclusion in the GLM analyses is shown in Figure 3-7 while a bubble plot displaying the number of observations for each vessel each year in this data is shown in Figure 3-8. A summary of the number of observations and nominal CPUE (kilograms per hour) within each Year*Area, Year*Month and Area*Month strata is provided in the Appendix.

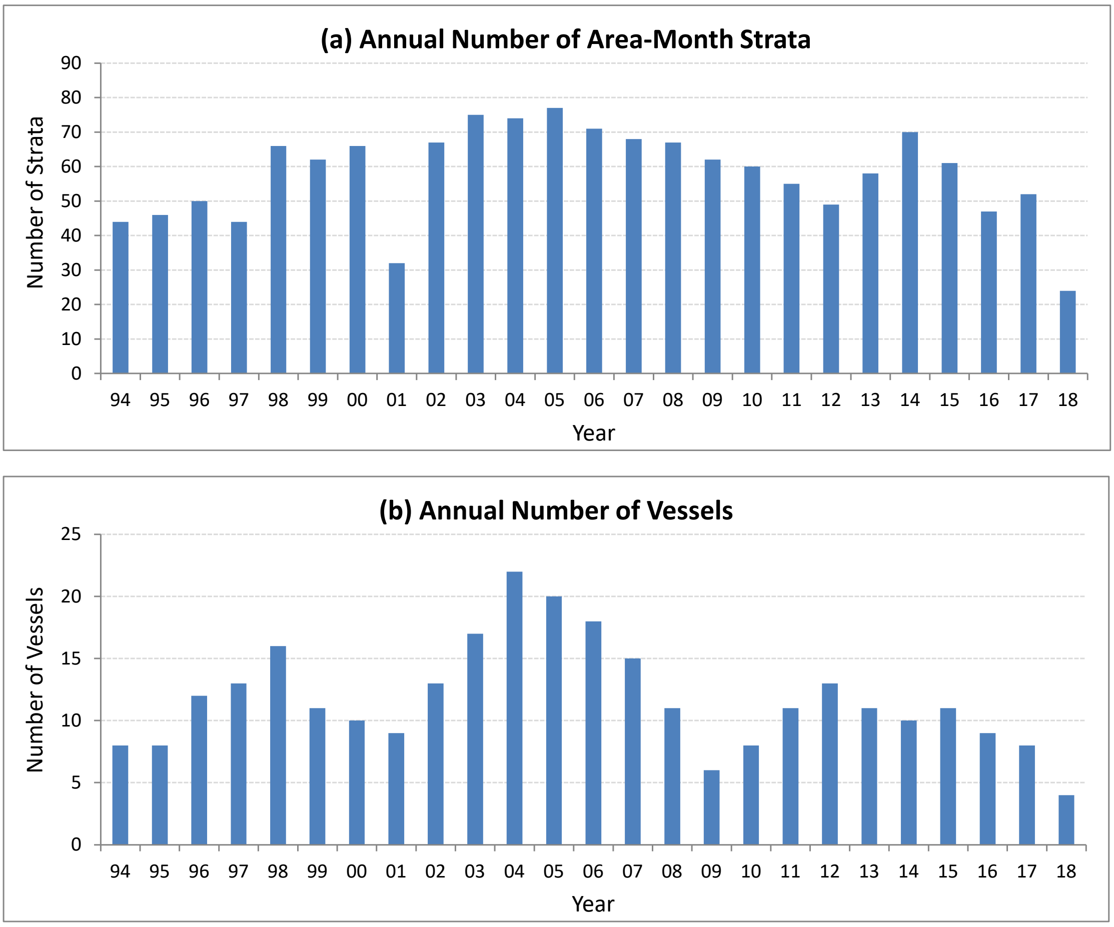


Figure 3-7. (a) Number of *Area-Month* strata fished each year and (b) the number of vessels fishing each year in the data selected for inclusion in the GLM analyses.

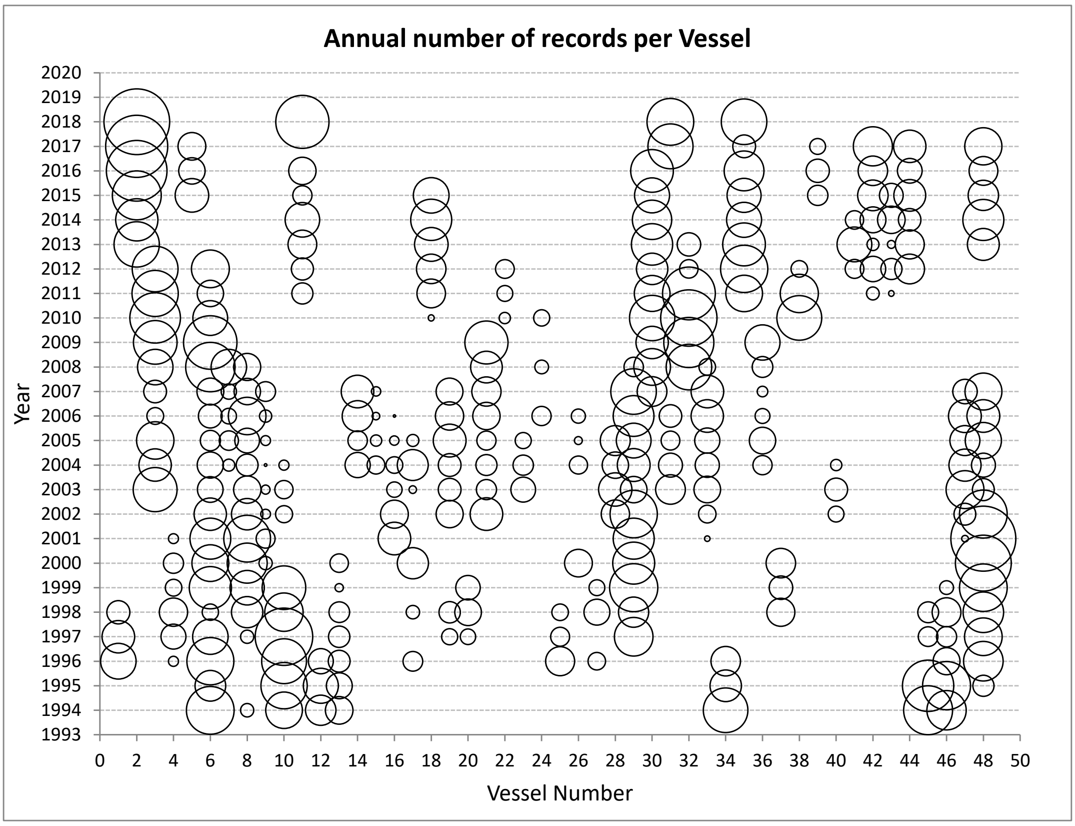


Figure 3-8. Bubble plot displaying the number of observations for each vessel each year in the data selected for inclusion in the GLM analyses.

GLM Models

Several different General Linear Models (GLMs) were adopted for analysing the data in order to obtain a standardised index of stock abundance in each year.

Main Effects Model

In order to explore the impact of each fitted effect, the first set of analyses were based on the following model where no interactions between main effects were included:

CPUE = Intercept + Year + Month +Area + Vessel +Fishing-Method

+ Proportion of Catch Landed as Tails

+ Southern Oscillation Index + Moon-Phase

/ distribution = gamma, link = log

= *I + Y + M + A + V + F + P + SOI + Moon* / dist= gamma, link=log

The SAS GENMOD procedure was used to fit the model. All effects *Year, Month, Area*, *Vessel* and *Method* (Hookah, Free and Unknown) were fitted as class variables except for the SOI index which was fitted as a continuous variable. The *Proportion-Tails* was also fitted as a class variable with each record classified as one of the following five levels: (<20%, 20% to <40%, 40% to <60%, 60% to <80%,

>=80%). The monthly values of the *Southern Oscillation Index (SOI)* were used and *Moon-Phase* was modelled as the number of days (0-29) since the last full moon. A log-gamma distribution was assumed for the distribution of CPUE values. The annual index and abundance was determined using the method described in the section below.

For each of the main effects, a measure of the impact of each level on the modelled CPUE was obtained by taking the exponent of the estimated parameter for each level. The impact of each level was then compared to the impact of a reference level. For each main effect these reference levels were:

Month	September
Area	Eastern Torres Strait
Method	Hookah diving
Vessel	Vessel with the largest number of records
Proportion-tails	>80%

Finally, the annual influence of each of the main effects on the resulting index of abundance was calculated using the method described in Bentley et al (2012).

As shown in Campbell (2004) a bias in the annual abundance index can result when there is an unequal number of observations within each spatial-temporal strata used for calculating the abundance index. In order to overcome this problem a weighting of the observations needs to be incorporated when fitting the data to the GLM. Each observation was therefore weighted such that the sum of the weights for all observations in each of the *Year-Month-Area* strata was the same for all strata. Furthermore, in order to account for the weighting given each observation in determination of the annual influence of each main effect the sum of the weights for all observation within a given level was used instead of just the number of observations.

Interactions Models

The second set of analyses was undertaken in order to explore whether the inclusion of 2-way interactions between the main spatial-temporal effects improved the model fit to the data. Specifically, the following five models were examined:

Int-1:

*CPUE = Intercept + Year +Month + Month*Area*

+ Vessel +Fishing-Method + Proportion-Tails + SOI + Moon

/ distribution = gamma, link = log

Int-2A:

*CPUE = Intercept + Year*Month + Month*Area*

+ Vessel +Fishing-Method + Proportion-Tails + SOI + Moon

/ distribution = gamma, link = log

Int-2B:

*CPUE = Intercept + Year*Area + Month*Area*

+ Vessel +Fishing-Method + Proportion-Tails + SOI + Moon

/ distribution = gamma, link = log

<u>Int-2C:</u>

*CPUE = Intercept + Year*Month +Year*Area*

+ Vessel +Fishing-Method + Proportion-Tails + SOI + Moon

/ distribution = gamma, link = log

<u>Int-3:</u>

*CPUE = Intercept + Year*Month +Year*Area + Month*Area*

+ Vessel +Fishing-Method + Proportion-Tails + SOI + Moon

/ distribution = gamma, link = log

where * indicates an interaction between the related effects. The inclusion in these 2-way interactions allows for the relative distribution of the resource between the different areas and months to be different between years.

ii) Derivation of Annual Index

Using the results from each GLM an annual abundance index was constructed based on the standardised CPUE.

For the model which included the three 2-way interactions the standardised CPUE within each Year-Month-Area strata was calculated as follows:

$$stdCPUE(year = y, month = m, area = a) = \exp(I + Y.M_{ym} + Y.A_{ya} + M.A_{ma} + F_h + V_{ref} + P_{ref})$$

where $Y.M_{ym}$, $Y.A_{ya}$, $M.A_{ma}$, F_h, V_{ref} and P_{ref} are the parameters estimates relating to each of the terms included in the model. Note, due to the over-parameterization inherent in the GLM both F_h=0, V_{ref} =0 and P_{ref}=0 as these respectfully to relate the last levels in each of the *Fishing-Method*, *Vessel* and *Proportion-Tails* factors included in the model. In total there are 1840 (=23 years x 8 months x 10 areas) *Year-Month-Area* strata. As the standardised-CPUE is taken as an index of the density of fish within each strata, an index of the abundance of lobsters across the fishery in each year and month is given by:

$$Index(year = y, month = m) = \frac{1}{\sum_{a=1}^{NA} Area_a} \sum_{a=1}^{NA} Area_a . stdCPUE(y, m, a)$$

where $Area_a$ is the spatial size of each of the *NA Area* effects included in the GLM. Finally, an index of abundance for each year can be obtained by taking the average of the *NM* monthly indices in each year.

$$Index(year = y) = \frac{1}{NM}\sum_{m=1}^{NM}\left[\frac{1}{\sum_{a=1}^{NA} Area_a}\sum_{a=1}^{NA} Area_a .stdCPUE(y,m,a)\right]$$

Finally, a relative annual abundance index, B_y, was calculated such that the mean index over all years equals 1, i.e:

$$B_y = \frac{Index(year = y)}{\frac{1}{NY}\sum_{i=1}^{NY} Index(year = i)}$$

The total spatial size of the each MSE area shown in Figure 3-9 is unlikely to represent suitable habitat for rock lobsters. As such, in order to ascertain the spatial size of each MSE area to be used in the GLM-analysis, the number of 0.1x0.1-degree squares fished (based on the location of the mother ship recorded in the TVH logbook) within each MSE area was determined for each year. For those squares which included more than one MSE area, the square was apportioned between the different MSE areas based on the proportion of records in each area. Across the entire Torres-Strait region the number of squares fished each year between 1994 and 2018 has varied between 29 (in 2018) and 94 (in 2004) with a mean of 49.3 (c.f. Figure 3-10). The size of each MSE area $Area_a$, was set to the mean number of squares fished across all years, and then expressed as a percentage of the combined total across all areas so that $\sum Area_a = 1$.

The derivation of the abundance index based on the GLMs which included less than three 2-way interaction terms is similar to that shown above. However, it can be noted that for those models which do not included an interaction with the Year effect (i.e. the main effects and Int-1 models), the relative abundance index, B_y, reduces to the simpler form:

$$B_y = \frac{\exp(Y_Y)}{\frac{1}{NY}\sum_{i=1}^{NY}\exp(Y_i)}$$

where Y_i , $i=1, NY$ are the parameters estimates relating to the *NY Year* effects included in the model. In these situations the abundance is independent of the relative size of each *Area* effect included in the GLM.

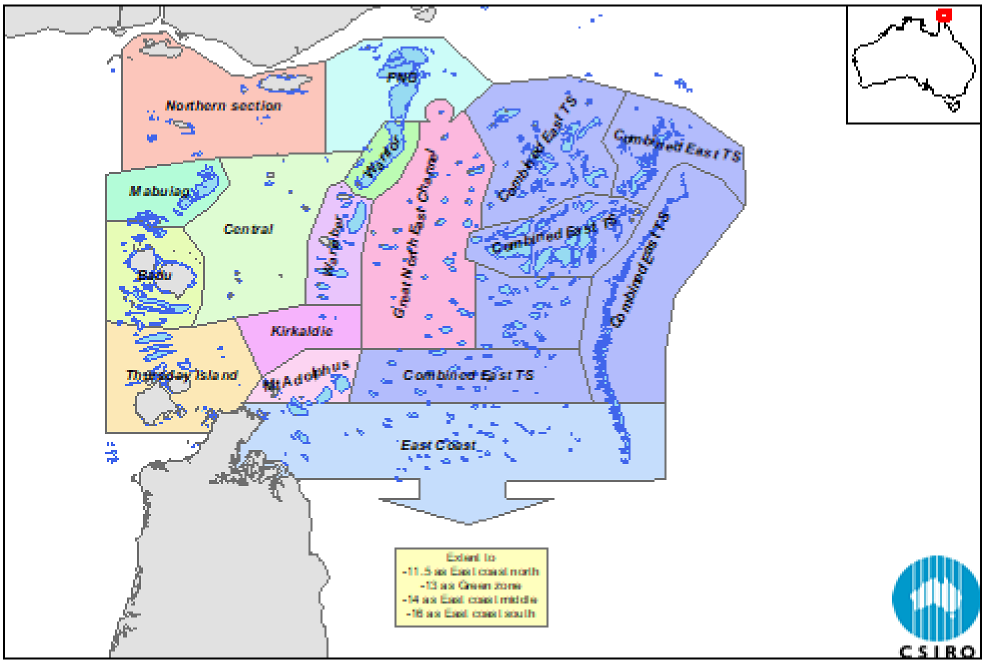


Figure 3-9. Map of the MSE regions used as the area effects in the GLM. Map of the MSE regions used as the area effects in the GLM.

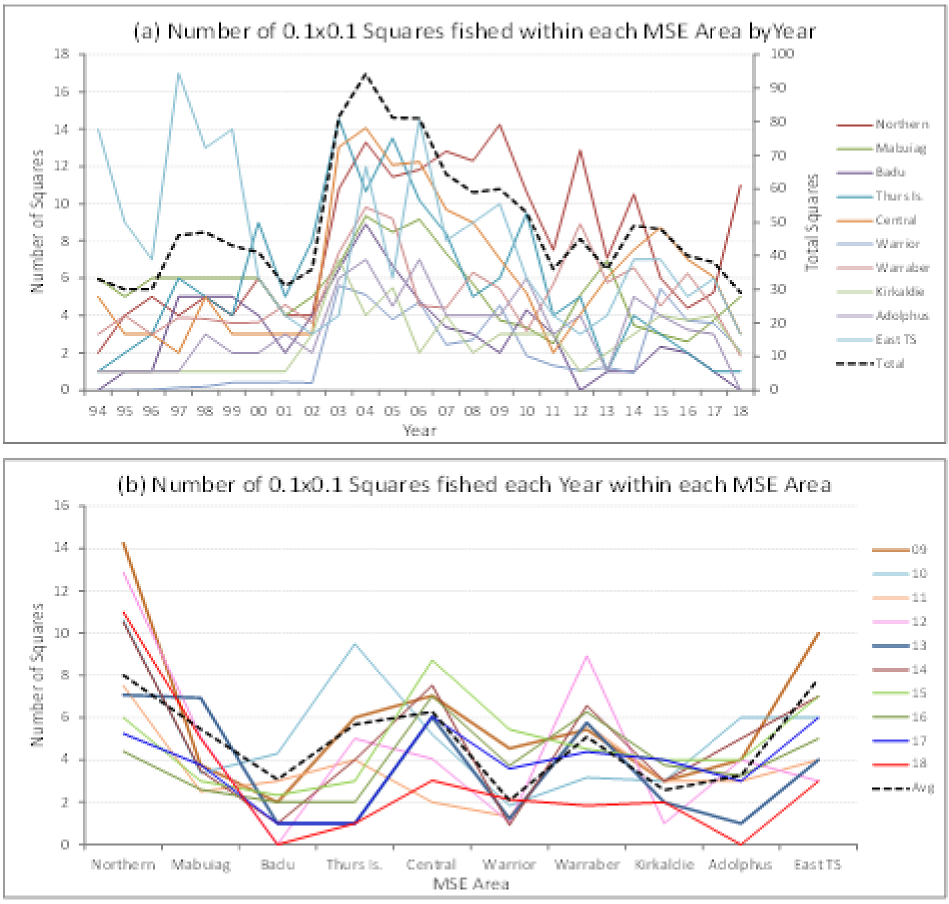


Figure 3-10. Number of 0.1x0.1-degree squares fished (a) within each MSW area by year, and (b) each year within each MSW area between 2009 and 2018. The average over all years (1994-2018) is also shown in both figures.

3.3 Results

Standardising Effects

Statistics for the Type 3 contrasts computed for each fitted effect indicated that each effect was highly significant. The relative impact of each level for all effects fitted to each GLM model is shown in Figure 3-11. For each effect the values have been scaled so that the influence of each level is relative to that of the last level (i.e. Month=Sep, Area=Eastern TS, Method= Hookah & Proportion-Tails >80%). For models which included interactions the Quarter and Area effects were determined by calculating the mean effect across all Year, Month and Area strata respectively.

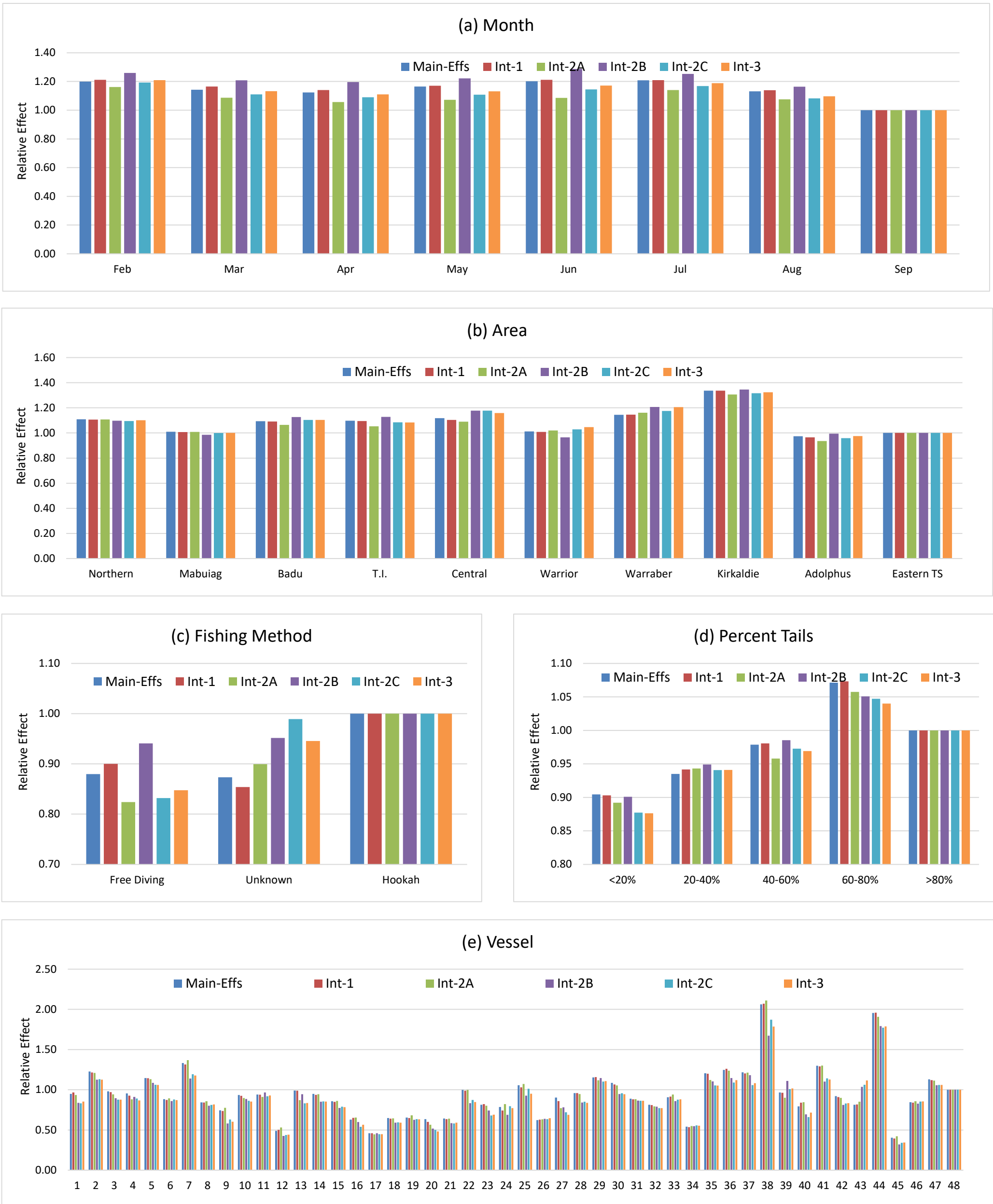


Figure 3-11. Relative impact of each level of the main effects fitted to the each GLM.

Relative CPUE is relatively constant across the eight months of the year and displays only small variation across the six GLM models, though the CPUE in September is the lowest across all models (c.f. Figure 3-11a). Taking the average of the relative effect across the results for the six models for each month indicates that the CPUE is highest during February, June and July (18-21% higher than the CPUE in September) while during March, April and May the CPUE is 12-14% higher than the CPUE in September. The greatest variation (as measured by the standard deviation, σ) between models in the relative CPUE across all months is between the results for the 2Ints-A (σ=0.05) and 2Ints-B models (σ =0.09). For all other models σ=0.07.

The relative CPUE across the various areas included in the GLM also do not display large variation across the six GLM models, though there is some degree of variation across the ten areas (c.f. Figure 3-11b). Taking the mean of the relative effect across the results for the six models for each area indicates that the relative CPUE is, on average, lowest in Mt Adolphus (97%), Eastern TS (100%, the reference area) and Warrior (101%) and highest in Kirkaldie (133%), Warraber (117%) and Central (114%).

Unlike the previous results, the relative CPUE across the three fishing methods displays larger variation across the six GLM models (c.f. Figure 3-11c). For example, the relative effect of the free-diving method relative to hookah diving varies between 82% and 94% while that for the unknown method varies between 85% and 99%. Across all models, the CPUE for hookah fishing is found to be around 13% higher than for free diving and 8% higher than for unknown method. This latter result is to be expected if this fishing method is likely to be a combination of the two other fishing methods.

The relative CPUE across all models is similar for each category of the proportion of the catch which is tails with the relative CPUE generally increasing as the Proportion-Tails increases in the catch (c.f. Figure 3-11d). However, the highest CPUE is found for those catches which include 60-80% tails. Across all models, the relative CPUE within each Proportion-Tails category is 89%, 94%, 97%, 106% and 100% respectively. Finally, there is substantial variation in the relative CPUE across the 48 vessels included in the GLM models, though the relative effect of each vessel is less sensitive to the GLM model used (c.f. Figure 3-11e). Across all models, the relative fishing power across the fleet varies more than four-fold from 37% to 193% of the standard vessel and the distribution of these effects is shown in Figure 3-12.

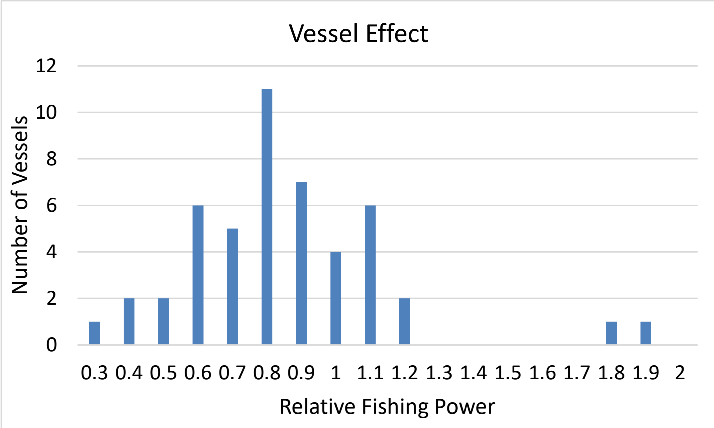


Figure 3-12. Histogram of the distribution of the relative fishing power of the 48 vessels included in the GLM models.

The monthly value of the SOI was fitted as a cubic function and the estimated influence of this effect on CPUE based on the results from three of the fitted GLM models is shown in Figure 3-13a. Note, the influence of SOI on CPUE cannot be estimated for several models as the related parameter is aliased when the GLM model includes a Year.Month interaction term. The influence of the SOI is seen to be similar for the three models shown, with negative values of the SOI (El Nino conditions) decreasing CPUE while positive values of the SOI (La Nina conditions) increasing CPUE. This indicates that oceanographic conditions may have influenced the high CPUEs experienced in the fishery in 2011 (when the mean SOI value was 12.7, c.f. Figure 3-13b) and the low CPUE experienced in the fishery in 2015 (when the mean SOI value was -10.8). However, based on the results shown in Figure 3-13 the influence on CPUE of the conditions prevailing in these years should have been only 6-7%. Further exploration of the influence of this and other environmental variables is warranted.

Finally, the influence of the daily moon-phase across each of the GLM models is shown in Figure 3-13c. The influence is seen to be similar across all models and displays an interesting bi-modal distribution across the days between successive full moons. CPUE is lowest during days near a full moon and also low around a new moon, while CPUE is highest mid-way between these two phases (i.e. around the first and last quarters). During this latter periods CPUE is around 30% higher than at the time of a full moon.

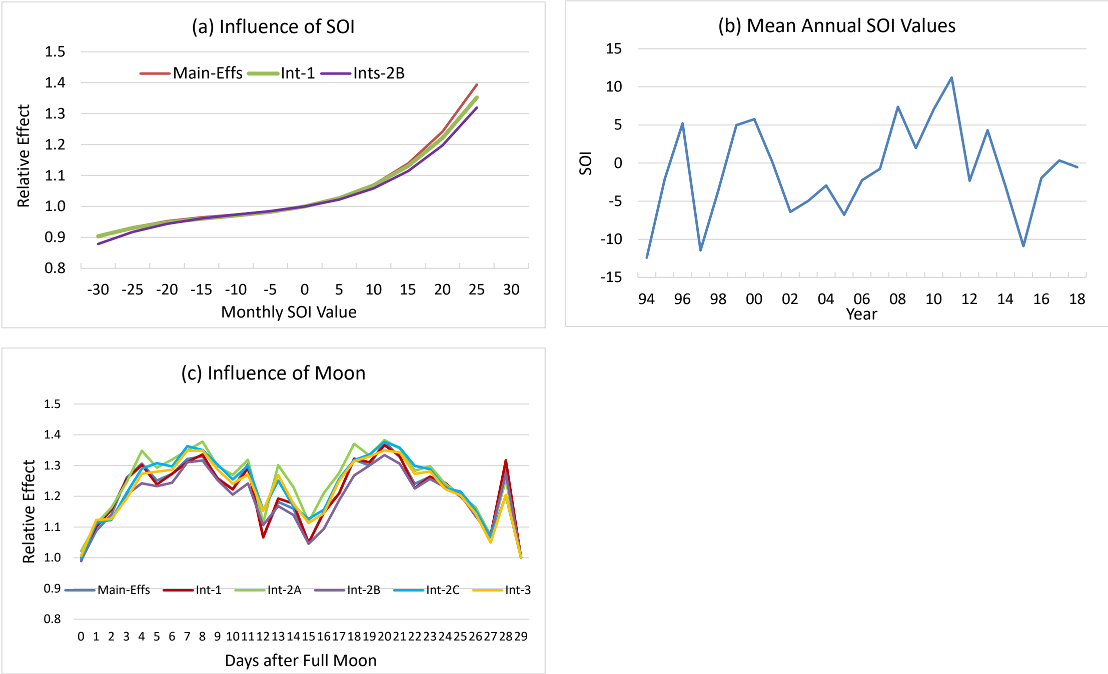


Figure 3-13. (a) Relative influence of the values of the SOI on CPUE and (b) mean annual values of the SOI since 1994. (Note, SOI value for 2017 only mean from Jan to Nov).

Annual Abundance Indices

The relative abundance indices based on each of the six GLM models are listed and displayed in Table 3-4 and Figure 3-14 respectively. Relative to the nominal index, each of the standardised indices is similar but is higher at the start of the time-series and lower after 2012. The reasons for these differences can be investigated using the annual influence of each main effect which is shown in Figure 3-15 for the Main-Effects and Int-1 models. The influence on the annual index is seen to be greatest for the Vessel effect followed by the Proportion-Tails effect, with the influence of each effect showing an opposing trend over time. The change in the influence of the Proportion-Tails effect correlates with the shift from the catch being all tails to now being predominantly whole (c.f. Figure 3-3b), which decreases CPUE (c.f. Figure 3-11d), while the change in the influence of the Vessel effect is most likely due to an (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.

The influence of the other effects is seen to be relatively small. For the Area and Month effects this is likely to be due to the equal weighting given to each Year-Month-Area strata in the GLM model analysis. The small but positive trend in the influence of the Method effect over the time-series also relates to the fact that there may have been a slight increase in the proportion of catches using hookah diving over time which has the highest CPUE (see Chapter 3).

Several criteria for assessing the goodness-of-fit for each of the GLM models are shown in Table 3-5. For each criteria shown (where smaller is better) there is an improvement in the fit between each successive model implying that the model which includes all three 2-way interactions provides the best fit to the data. The Int-3 model has considerably greatly flexibility in accounting for inter-annual changes in the distribution of the resource across the different months and areas in comparison to the Main-Effects model which assumes that these distributions are the same for all years. However, the number of parameters (553) estimated in the full interaction model Int-3 is considerably greater than the number of parameters (128) estimated in the Main-Effects model. A consequence of the increase in the number of parameters is that the number of observations on which some of the parameters rely to be estimated can be small (or in some instances zero). A small number of observations increases the likelihood that the corresponding parameter is poorly estimated.

Figures showing of the number of observations per 2-way strata (for which a separate parameter was estimated) are shown in the Appendix. For 36 (14.4%) of the 250 Year*Area strata the number of observations was less than 10 (with 13 of these strata having zero observations) while only six of the 200 Year*Month strata had less than 10 observations (being zero for five strata, four of which occurred in 2018). On the other hand, the number of observations was greater than 13 for all of the 80 Area*Month strata. For those strata for which the number of observations is zero, the related standardised CPUE for these strata needs to be imputed. (Note, the number of strata for which the standardised CPUE needs to be imputed for each model is shown in Table 3-5.) For this purpose, the corresponding value using the Int-1 model was used as this model allows the standardised CPUE to be calculated within all strata.

For the Int-3 and Int-2C models, the number of Year-Month-Area strata where no observations were available for estimating the related model parameters (which then needed to be imputed) was 126 (or 6.3% of the 2000 number of strata in total). For the Int-2B model the number of imputed strata was 88 (4.4%) while the number of imputed strata for the Int-2A model was 50 (or 2.5% of all strata). While it is can be considered best practice to select an abundance index where no parameters have had to be estimated (i.e. the Main-Effects or Int-1 models), the small number of estimated parameters in the Int-2A model reduces the potential for bias in the corresponding index.

Table 3-4. Annual abundance indices for Torres Strait rock lobsters based on the standardised CPUE from the weighted GLM models. The nominal CPUE is also shown for comparison.

Year	Nominal	Main-Effs	Int-1	Int-2A	Int-2B	Int-2C	Int-3
94	0.89	1.40	1.41	1.32	1.38	1.35	1.35
95	0.97	1.39	1.38	1.30	1.35	1.32	1.33
96	0.94	1.01	1.01	1.01	1.03	1.00	1.01
97	1.04	1.17	1.16	1.11	1.11	1.08	1.08
98	0.98	1.07	1.07	1.07	1.09	1.10	1.09
99	0.77	0.67	0.67	0.68	0.66	0.67	0.67
00	0.62	0.68	0.67	0.74	0.65	0.72	0.73
01	0.44	0.44	0.44	0.43	0.47	0.47	0.47
02	0.77	0.69	0.69	0.66	0.67	0.63	0.63
03	1.03	1.08	1.07	1.03	1.05	1.02	1.01
04	1.09	1.17	1.17	1.16	1.16	1.12	1.14
05	1.49	1.49	1.49	1.42	1.47	1.38	1.40
06	0.68	0.69	0.70	0.68	0.67	0.65	0.65
07	1.08	1.00	1.00	0.97	1.00	0.96	0.96
08	0.87	0.84	0.84	0.87	0.89	0.91	0.90
09	0.62	0.65	0.65	0.64	0.69	0.69	0.69
10	1.24	1.09	1.10	1.24	1.14	1.24	1.27
11	2.11	1.75	1.75	1.93	1.94	2.13	2.09
12	1.64	1.46	1.46	1.43	1.36	1.33	1.30
13	1.27	1.23	1.23	1.28	1.24	1.29	1.30
14	1.04	0.94	0.94	0.93	0.94	0.92	0.92
15	0.63	0.58	0.58	0.56	0.54	0.52	0.52
16	1.19	1.04	1.05	1.09	1.05	1.05	1.08
17	0.75	0.68	0.68	0.66	0.70	0.66	0.64
18	0.88	0.79	0.78	0.79	0.77	0.79	0.78
Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00

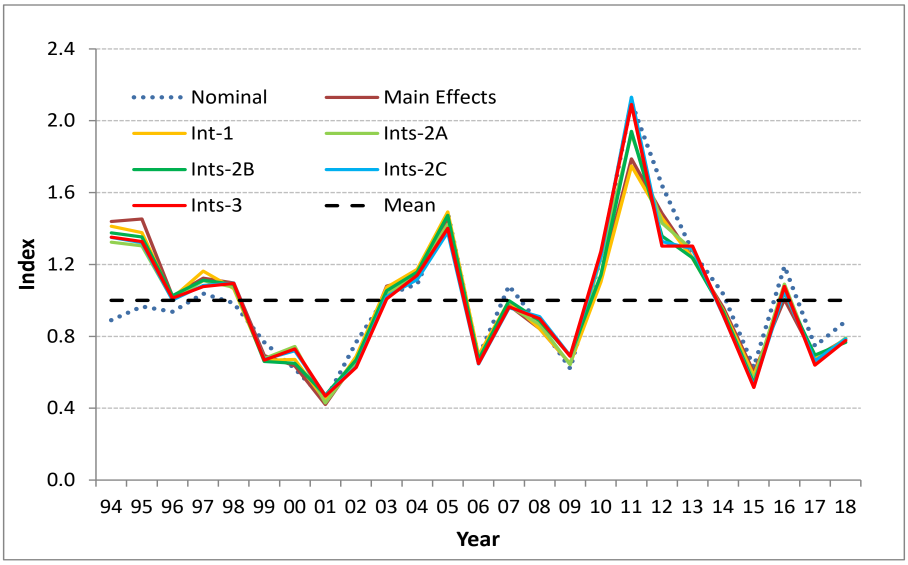
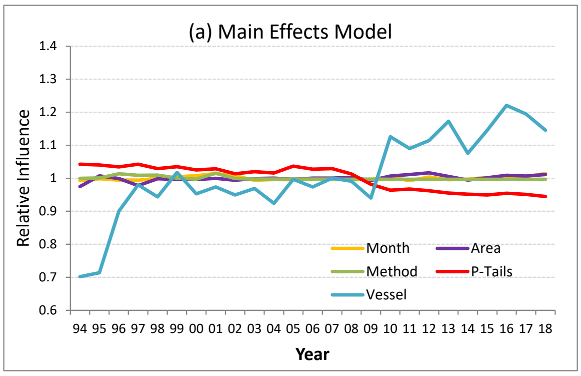


Figure 3-14. Annual abundance indices for Torres Strait rock lobsters based on the standardised CPUE from the Main-Effects and several interaction models. The nominal CPUE is also shown for comparison.



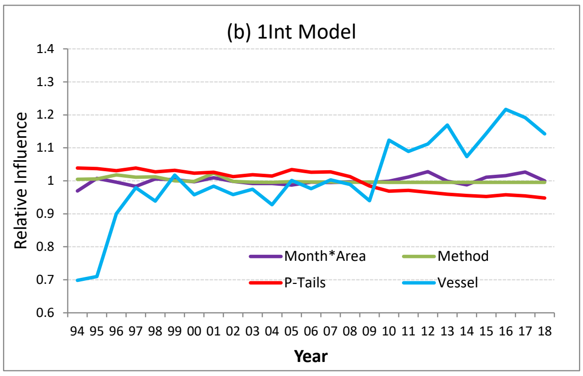


Figure 3-15. Annual influence of the fixed effects fitted to (a) the Main-Effects model and (b) the Int-1 model.

Table 3-5. Criteria for assessing the goodness-of-fit of each GLM.

GLM	Main	Int-1	Int-2A	Int-2B	Int-2C	Int-3
N-records	45,427	45,427	45,427	45,427	45,427	45,427
df	128	188	350	393	490	553
Deviance	20,133	19,810	18,467	17,923	17,084	16,739
Chi-sq	21,313	20,794	18,845	18,038	17,014	16,580
likelihood	-172,861	-172,443	-170,638	-169,874	-168,651	-168,132
AIC	345,975	345,266	341,977	340,534	338,282	337,370
BIC	347,083	346,923	345,030	343,963	342,556	342,194
N-Strata	2,000	2,000	2,000	2,000	2,000	2,000
Imputed	0	0	50	88	126	126

See also Appendix B this report.

Concluding remarks

The above analyses, and the resulting indices of annual abundance, are based on the number of assumptions about the data and how these data describe fishing behaviour in the fishery. In particular, if there are features of the fishery which are not adequately captured by the data used in these analyses then the GLMs will not be able to standardise the CPUE for these particular features.

For example, even though the inclusion of interactions allows the model the freedom to the resolve differences in the distribution of the resource across the different areas within different years, the model has no ability to resolve changes in the fishery which may take place within any given area (or month). In particular, the models used to standardise CPUE assume that within each year the distribution of fishing effort within any area is relatively random or that the pattern of fishing across each area remains relatively consistent over time. However, it is possible that with the introduction of new technologies (such as GPS) that over time fishers have been able to more precisely target their fishing effort to sub-regions of preferred habitat (and higher abundance) within a given area. Such 'effort creep' would result in higher catches and higher CPUE compared to the situation where no new technologies were available. The maintenance of high CPUE in light of reduced resource abundance due to effort creep (known as hyper-stability) ultimately leads to a breakdown of the linear relationship assumed between CPUE and resource abundance.

This can be a particularly critical consideration for an aggregating species such as rock lobsters, when higher CPUE can be maintained when fishers can target known aggregating sites, or the number, size and the distribution of such aggregations within a season can change in response to changes in ambient conditions within a season not related to overall abundance (e.g. oceanographic conditions). It is interesting to note that the area fished across the fishery (as measured by the number of 0.lx0.1-degree squares, c.f. Figure 3-10a) has been decreasing over time, with the area fished reaching a minimum during the current year (2018). However, whether this indicates that the fishing effort was more aggregated during 2018 than in other years remain uncertain, as the location of fishing effort currently recorded in the logbook is the location of the primary vessel and not the associated tenders which can disperse themselves widely from the primary vessel.

While the fitted GLM models used in the analyses described in this report appear to capture increases in the fishing power of the fleet due to changes in the vessels leaving and entering the fishery, continual increases in the fishing power over time for individual vessels that remain in the fishery will not be captured by the available data and fitted models and as such could result in continual biases in the calculated indices of abundance.

To help overcome this problem it would be useful to further investigate whether or not there have been increases in fishing power over time which are not currently captured by the data. With such information in hand one could then decide whether the data currently available adequately captures the strategies used in the fishery. If not, there needs to be a further discussion as to what additional data may need to be collected so that these aspects of the fishery can be taken into account in the statistical analyses used to standardise the data. Of course, this is a discussion that is pertinent to all fisheries.

Finally, the catches and catch-rates achieved in a fishery are also likely to be influenced by changes in oceanographic and environmental conditions which are likely to change on both a seasonal and inter-annual basis. While the current analyses attempt to model the influence of the monthly value of the Southern Oscillation Index (used to distinguish El Nino and La Nina conditions) and the daily phase of the moon on catch rates, the influence of such environmental changes is likely to require a broader understanding of oceanographic processes that impact on the fishery (including those which may influence the aggregation dynamics of the rock lobsters and delayed effects such as those which influence recruitment success or failure and which subsequently propagate through the fishery over time). Again it would be useful to discuss how such processes can be incorporated into these models.

The use of standardised CPUE as an index of resource abundance is an important input to the stock assessments for many fisheries. This is particularly the situation for those fisheries where fishery independent surveys of the resource are not available or feasible (such in fisheries for highly migratory species such as tunas and billfish). However, as noted above the accuracy of these indices is premised on a number of assumptions, particularly the ability of the logbook data used in the analyses to readily capture the important aspects of the fishery which influence catch rates. In these instances, and where possible, it is useful to incorporate fisheries independent data into the stock assessments. In particular, annual indices of resource status based on fishery independent surveys are usually seen as an important adjunct to the fishery dependent data, and where possible their inclusion in the stock assessment is highly recommended. Where such surveys are not available then attention needs to be paid to ensuring that the logbook data from the fishery captures the information necessary to adequately standardise the catch rates in the fishery as discussed above.

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 logbook data from the TVH sector is believed to provide a relatively complete and good source of catch and effort data for this sector, though 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. On the other hand, the data for the TIB sector is considered to be less complete and the measure of effort (days fished) is less accurate and incomplete in many instances. While the utility of these data to provide a useful index of resource abundance has been investigated elsewhere (Campbell et al, 2017), again greater effort needs to be placed on ensuring the completeness and accuracy of these data for such purposes.

Chapter 4 Use of TIB Docket-Book Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2018 Update

Robert Campbell, Eva Plaganyi, Roy Deng

4.1 Introduction

The Torres Strait Seafood Buyers and Processors Docket Book (TDB01), until recently, was used in the TIB sector of the Torres Strait rock lobster fishery to record the catch sold by fishers (known as sellers on the Docket-Book) at the end of a fishing trip. It was replaced on 1 December 2017 by the mandatory Torres Strait Catch Disposal Record TDB02. However, unlike the Daily Fishing Log (TRL04) used in the TVH sector of fishery, which requires catch and effort data to be recorded for individual fishing operations related to each vessel tender, both the TDB01 and TDB02 Docket-Books require only aggregate catch and effort data to be recorded at the end of each trip. Nevertheless, both sets of catch and effort data recorded in each sector of the fishery have proven useful in constructing abundance indices for the fishery, and both are included in the Harvest Control Rule used to help determine an appropriate annual TAC. This document provides the latest update of the data and analyses undertaken for constructing the abundance index based on the Docket-Book data for the TIB sector (see Campbell *et al*, 2017).

4.2 Estimation of Total TIB Catch

A copy of both the TDB01 and TDB02 Docket-Books are shown in Appendix A. Each docket-book records the transaction date, the name of the seller, together with details of the catch (in weight). Additional information is also provided regarding the vessel, the number of crew, the number of days fished and the fishing methods used. This information therefore provides a measure of both the catch and effort for a given seller (or fisher) during a fishing trip and hence can be used to gain a measure of the catch rate (weight of lobsters caught per day fished) during that trip.

However, there were a number of issues with the TDB01 Docket-Book system which created problems with using this data for estimating the total catch and effort in the TIB fishery. These issues included:

i. The requirement that completion of this docket-book was only voluntary,
ii. The fact that catches recorded in this docket-book could also be reported elsewhere, including the TVH logbook,
iii. The fact that processors could also record catches in this docket-book, essentially creating duplicates.

Given the duplication of catch information from both the TVH sector and processors which occurred in the TDB01 docket-book data, several filters have been developed and applied to the data sourced from this docket-book in an attempt to identify and remove these duplicates. Further to these issues, several large TIB boats prior to 2016 only recorded their catch in the TVH-related logbook (TRL04) and these catch records need to be transferred to the TIB database. This occurred because some TIB operators believed the TRL04 Logbook was mandatory, though they later became aware reporting for TIB is currently voluntary.

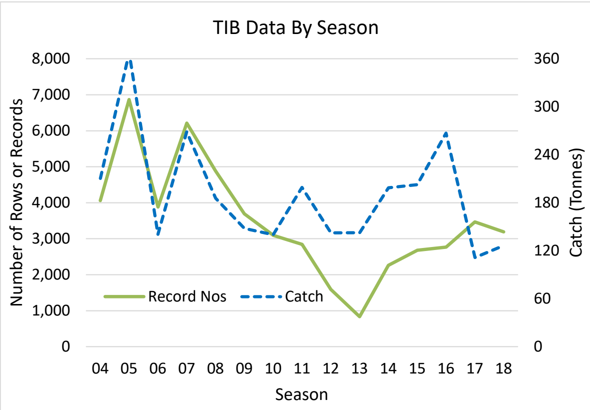
Finally, between 2013 and 2016 several processors reported aggregate annual catch data to AFMA as these catches were not being recorded in the TDB01 Docket-Book. Each processor reported the catch for tailed and whole lobsters separately, so that for each season two catch records were added to the TIB database for each processor to account for these additional catches.

Considerable effort has gone into understanding the nature of both the TDB01 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). For the analyses described in this report, a total of 49,130 catch records have now been attributed to the TIB fishery covering the 2004 to 2017 seasons while an additional 3,193 TIB catch records have been sourced from the TBD02 docket-book for the 2018 season. Note, several (54) Docket-Book records having a zero catch of lobsters are not included in these totals as it is assumed that other species may have been targeted on these trips. Also, a catch record for the purpose of the data summarised in this report pertains to the catch and effort information provided on a single page in either the TDB01/TDB02 Docket-Books or TRL04 Logbook and for which a unique Record-Number (Record-No) is attributed. Within the TIB database there are usually multiple rows of catch information associated with each unique Record-No as the catch is separately recorded by process form and perhaps grade.

The number of catch records and the associated estimate of the total catch of rock lobsters in the TIB sector each season (starting 1-December), and by data source, is shown in Table 4.1 and Figure 4-1. Between 2004 and 2007 all TIB related catch is sourced from the TDB01 Docket-Book, and the number of catch records each season varied between 4,058 and 6,867, while between 2008 and 2015 a portion of the total catch was recorded in the TRL04 Logbook. While the related catch was small in some seasons (<10 tonnes) this catch nevertheless represented over 20% of the total TIB catch in both the 2012 and 2013 seasons. Finally, between 2013 and 2016 a significant portion of the total TIB catch (between 34% in 2014 and 55% in 2016) was attributed to the aggregate catch data provided by several processors (as this catch was not recorded in the TDB01 Docket-Book). For the 2017 season the catch data was sourced entirely from the TDB01-Book data, being the first time since 2007, and this change was likely the result of requests by AFMA for the Docket-Book to be used for the recording all catches. While it has been noted that a substantive portion of the total TIB catch was reported in aggregate form between 2013 and 2016, and which helps to explain the lower number of Record-Nos during this period, the large reduction in Record-No in 2012 and 2013 appears anomalous. Whether or not other catches were also not been recorded in the Docket-Book during these or in other seasons remains unknown. Finally, for the 2018 season all catch data is sourced from the new TDB02 Docket-Book.

Table 4-1. Number of distinct TIB Record Nos by year and the related catch by data source. Note, PRC relates to the aggregate catch provided by several processors.

	Records by Data Source				Total	Catch by Data Source				Total Catch
Season	TDB01	TDB02	TRL04	PRC	Records	TDB01	TDB02	TRL04	PRC	(kg)
2004	4058	0	0	0	4,058	210,383	0	0	0	210,383
2005	6867	0	0	0	6,867	367,615	0	0	0	367,615
2006	3882	0	0	0	3,882	140,451	0	0	0	140,451
2007	6212	0	0	0	6,212	268,689	0	0	0	268,689
2008	4768	0	114	0	4,882	175,442	0	10,223	0	185,665
2009	3596	0	95	0	3,691	139,850	0	7,964	0	147,814
2010	3033	0	62	0	3,095	134,353	0	5,686	0	140,039
2011	2845	0	0	0	2,845	199,061	0	0	0	199,061
2012	1424	0	168	0	1,592	113,622	0	28,757	0	142,379
2013	649	0	183	2	834	52,249	0	34,862	55,411	142,522
2014	2224	0	32	2	2,258	129,657	0	2,456	66,662	198,775
2015	2652	0	25	2	2,679	124,369	0	1,333	76,904	202,606
2016	2762	0	0	4	2,766	119,756	0	0	147,380	267,136
2017	3469	0	0	0	3,469	111,504	0	0	0	111,504
2018	0	3193	0	0	3,193	0	126,476	0	0	126,476
Total	48,441	3,193	679	10	52,323	2,287,001	126,476	91,281	346,357	2,851,115



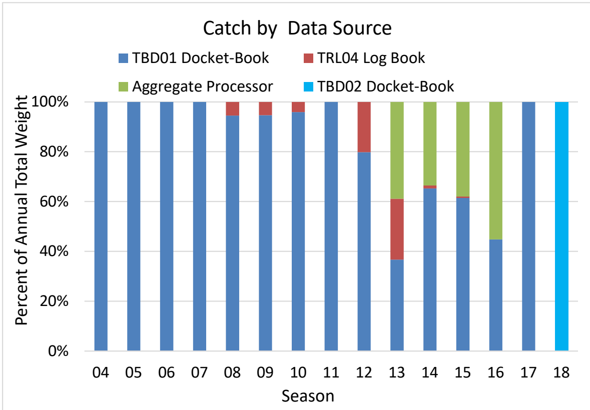


Figure 4-1. (a) Number of distinct TIB catch records and associated catch (in tonnes) by year, and (b) the proportion of the annual TIB catch by data source.

4.3 The TIB Docket-Book Data

The number of distinct vessel-symbols and seller-names associated with the 52,357 TIB catch records identified in the previous section is 1,278 and 2,433 respectively. However these numbers are inflated due to different spellings and mistakes often associated with a single vessel-symbol or seller-name. Attempts have been made to correct these names, and as a result the number of distinct vessel-symbols and seller-names has been reduced by nearly half, to 767 and 1,149 respectively. However, the percentage of all records (and total catch) without a vessel-symbol remains high at 68% (and 71% respectively). On the other hand, only 1.5% of all records (and 3.6% of the total catch) have no associated seller-name.

The frequency of the fishing methods associated with all Record Nos is shown in Table 4.2. Just over 40% of all records, and 39% of the total catch, are associated with hookah-diving, while free diving and lamp fishing are associated with 27% and 4.9% of the total catch respectively. Smaller amounts of the catch are also associated with handlining and trolling, and for around 2.5% of all records the catch is associated with some combination of these five fishing methods. However, the catch method for 12% of all catch records (and 26% of the total catch) remains unknown.

The distribution of all Record Nos (and catch) across each of the 21 TIB areas (shown in Figure 4-2) is given in Table 4.3. Around 42% of the records and slightly over a quarter (27%) of the catch have come from the Thursday Island region, with another 16% and 10% of the total catch coming from the Mabuiag and Badu regions respectively. Eleven of the 21 regions each account for less than one-percent of the total catch over all seasons (and only 2.4% in total). However, across all records the region fished remains unknown (i.e. not recorded) for 8.5% of all records (and 21% of the total catch).

Table 4-2. Number of TIB catch records (and associated catch in kilograms) by fishing method.

METHOD	N-recs	%	Catch	%
HOOKAH DIVING	20974	40.1%	1,111,117	39.0%
FREE DIVING	18633	35.6%	772,128	27.1%
UNKNOWN	6495	12.4%	736,115	25.8%
LAMP FISHING	4903	9.37%	139,958	4.91%
FREE DIVING-LAMP FISHING	493	0.94%	30,698	1.08%
FREE DIVING-HOOKAH DIVING	260	0.50%	27,089	0.95%
DIVING UNSPECIFIED	214	0.41%	15,897	0.56%
HANDLINING-FREE DIVING	141	0.27%	7,182	0.25%
HOOKAH DIVING-LAMP FISHING	37	0.07%	3,422	0.12%
TROLLING-FREE DIVING	44	0.084%	1,293	0.045%
HANDLINING	33	0.063%	842	0.030%
UNKNOWN-HOOKAH DIVING	18	0.034%	933	0.033%
FREE DIVING-HOOKAH DIVING-LAMP FISHING	12	0.023%	1,567	0.055%
HANDLINING-TROLLING-FREE DIVING	18	0.034%	561	0.020%
UNKNOWN-FREE DIVING	13	0.025%	419	0.015%
FREE DIVING-UNKNOWN	12	0.023%	659	0.023%
HOOKAH DIVING-UNKNOWN	3	0.006%	284	0.010%
UNKNOWN-FREE DIVING-LAMP FISHING	3	0.006%	228	0.008%
UNKNOWN-LAMP FISHING	3	0.006%	49	0.002%
TROLLING	3	0.006%	202	0.007%
LAMP FISHING-FREE DIVING	1	0.002%	53	0.002%
FREE DIVING-TROLLING	3	0.006%	51	0.002%
DIVING UNSPECIFIED-LAMP FISHING	1	0.002%	32	0.001%
UNKNOWN-FREE DIVING-HOOKAH DIVING	1	0.002%	18	0.001%
HANDLINING-TROLLING	2	0.004%	22	0.001%
TROLLING-DIVING UNSPECIFIED	2	0.004%	146	0.005%
HANDLINING-FREE DIVING-UNKNOWN	2	0.004%	30	0.001%
FREE DIVING-HANDLINING	1	0.002%	13	0.000%
ROD AND REELING-FREE DIVING	1	0.002%	30	0.001%
HANDLINING-DIVING UNSPECIFIED	1	0.002%	2	0.000%
Total	52,327	1	2,851,041	1

However, as noted by TSRL-RAG23 in May 2018, the Area fished information recorded on the TDB02 docket-book during the 2018 season did not align with knowledge of the main catch regions that season. This discrepancy raised the likelihood that the Area fished information recorded on the TIB Docket-Book records may not be correct in many instances. One possible explanation offered was that it may relate to where the catch was sold instead of where the catch was made. This may account for the high proportion of the catch recorded in the Thursday Island area.

The number of recorded days-fished associated with the above TIB catch records (c.f. Table 4.4) varies between 1 and 20 days, though is only one, two or three days for 74%, 6.4% and 3.2% of all catch records respectively. The days-fished remains unknown (i.e. not recorded) for 12.4% of these records (but for 26% of the total catch).

Finally, the number of crew recorded on the docket-books varies between 1 and 14 (c.f. Table 4.5), though is only numbers one or two for 58% and 27% of records respectively. The number of crew remains unknown for 13% of all records (and 28% of the total catch).

The seasonal percentage of the both the number of TIB catch records and total TIB catch for the various levels (a) fishing method, (b) area fished, (c) days fished and (d) number of crew are shown in Figure 4-3. The seasonal percent of blank (unknown) levels for each data field are also shown. Between 2012 and 2016 there was a significant increase in the proportion of the seasonal catch for which the information relating to these four effort variables remains unknown, and this lack of information impedes the ability to construct indices of resource abundance that represent the distribution of lobsters across the TIB fishery. While this situation has improved in recent seasons, nevertheless there is still room for improving the information recorded on the TDB-02 docket-book (e.g. the area fished and related effort information was still not completed for around 20% of records in 2017 and 2018, cf. Figure 4-3 and Figure 4-4).

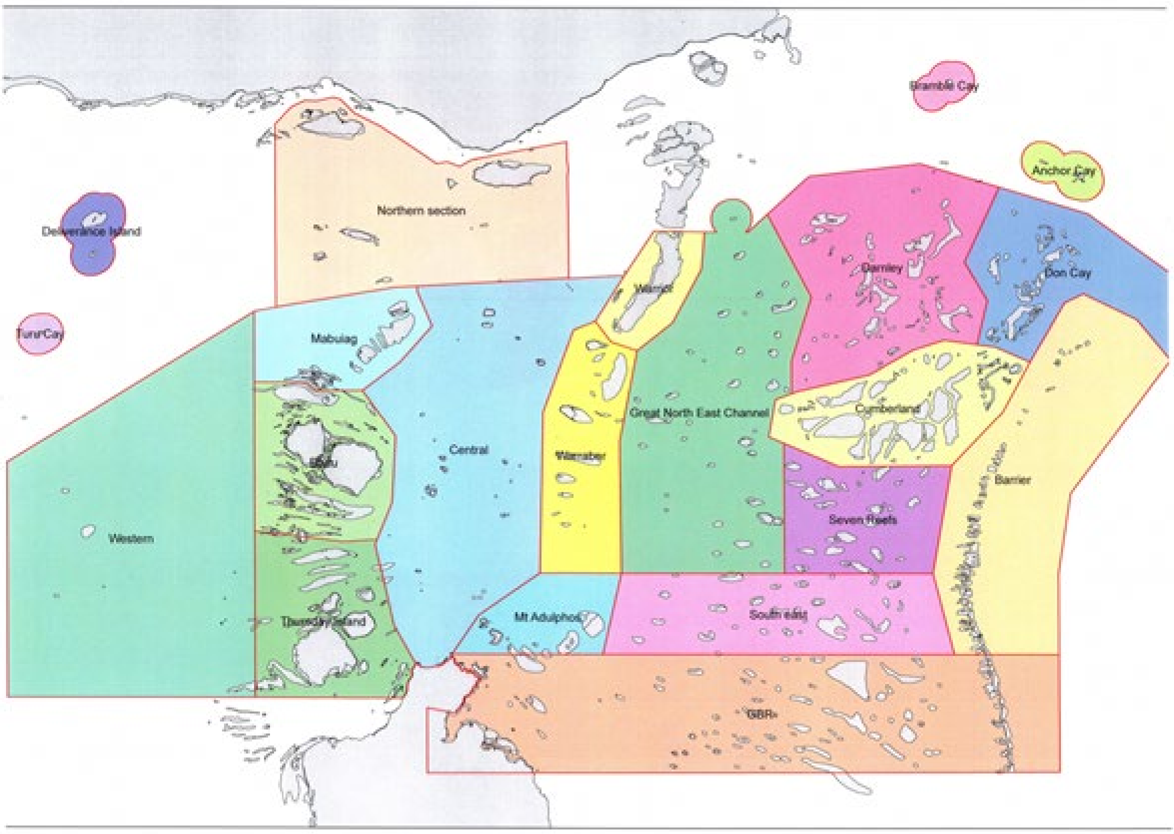


Figure 4-2. Spatial structure of the TIB data.

Table 4-3. Number of TIB records (and associated catch in kilograms) by region.

Area	Area-Name	N-recs	%	Catch	%
9	Thursday Island	21820	41.70%	776,711	27.24%
0	Unknown	4471	8.54%	585,767	20.55%
7	Mabuiag	6177	11.81%	468,239	16.42%
8	Badu	5910	11.30%	293,125	10.28%
12	Warraber	4310	8.24%	197,039	6.91%
11	Warrior	3155	6.03%	175,133	6.14%
14	Great NE Channel	2040	3.90%	103,804	3.64%
13	Mt Adolphus	698	1.3%	54,817	1.9%
17	Cumberland	818	1.56%	45,153	1.58%
16	Darnley	1269	2.4%	44,049	1.5%
10	Central	763	1.46%	39,201	1.37%
3	Northern Section	269	0.51%	28,325	0.99%
1	Turu Cay	248	0.47%	13,569	0.48%
15	South East	118	0.23%	10,947	0.38%
21	GBR	155	0.30%	10,083	0.35%
4	Bramble Cay	19	0.04%	1,481	0.05%
2	Deliverance Island	29	0.06%	1,348	0.05%
6	Western	21	0.04%	1,078	0.04%
18	Seven Reefs	8	0.02%	475	0.02%
20	Barrier	10	0.02%	345	0.01%
5	Anchor Cay	9	0.02%	238	0.01%
19	Don Cay	6	0.01%	189	0.01%
Total		52,323	1	2,851,116	1

Table 4-4. Number of TIB records (and associated catch in kilograms) by the number of days fished as recorded on docket-books.

Days	N-recs	%	Catch	%
1	38,809	74.2%	1,421,609	49.9%
Unknown	6,509	12.4%	747,479	26.2%
2	3,350	6.4%	213,000	7.5%
3	1,686	3.2%	145,597	5.1%
4	756	1.4%	89,535	3.1%
5	585	1.1%	87,664	3.1%
6	195	0.4%	42,048	1.5%
7	176	0.3%	36,776	1.3%
8	97	0.2%	27,252	1.0%
9	72	0.1%	21,032	0.7%
10	32	0.1%	7,306	0.3%
11	20	0.0%	6,792	0.2%
13	8	0.0%	2,086	0.1%
14	13	0.0%	1,329	0.0%
12	8	0.0%	768	0.0%
16	3	0.0%	524	0.0%
15	2	0.0%	192	0.0%
17	2	0.0%	109	0.0%
20	1	0.0%	18	0.0%
	52,324	100.0%	2,851,116	100.0%

Table 4-5. Number of TIB records (and associated catch in kilograms) by the number of crew as recorded on docket-books.

Crew	N-recs	%	Catch	%
1	30,405	58.1%	1,211,089	42.5%
Unknown	6,596	12.6%	793,554	27.8%
2	14,133	27.0%	772,013	27.1%
3	998	1.9%	57,758	2.0%
4	140	0.3%	7,536	0.3%
6	7	0.0%	3,927	0.1%
5	20	0.0%	3,597	0.1%
8	7	0.0%	1,096	0.0%
7	7	0.0%	285	0.0%
12	2	0.0%	99	0.0%
10	3	0.0%	77	0.0%
9	3	0.0%	41	0.0%
14	1	0.0%	37	0.0%
11	1	0.0%	9	0.0%
	52,323	100.0%	2,851,116	100.0%

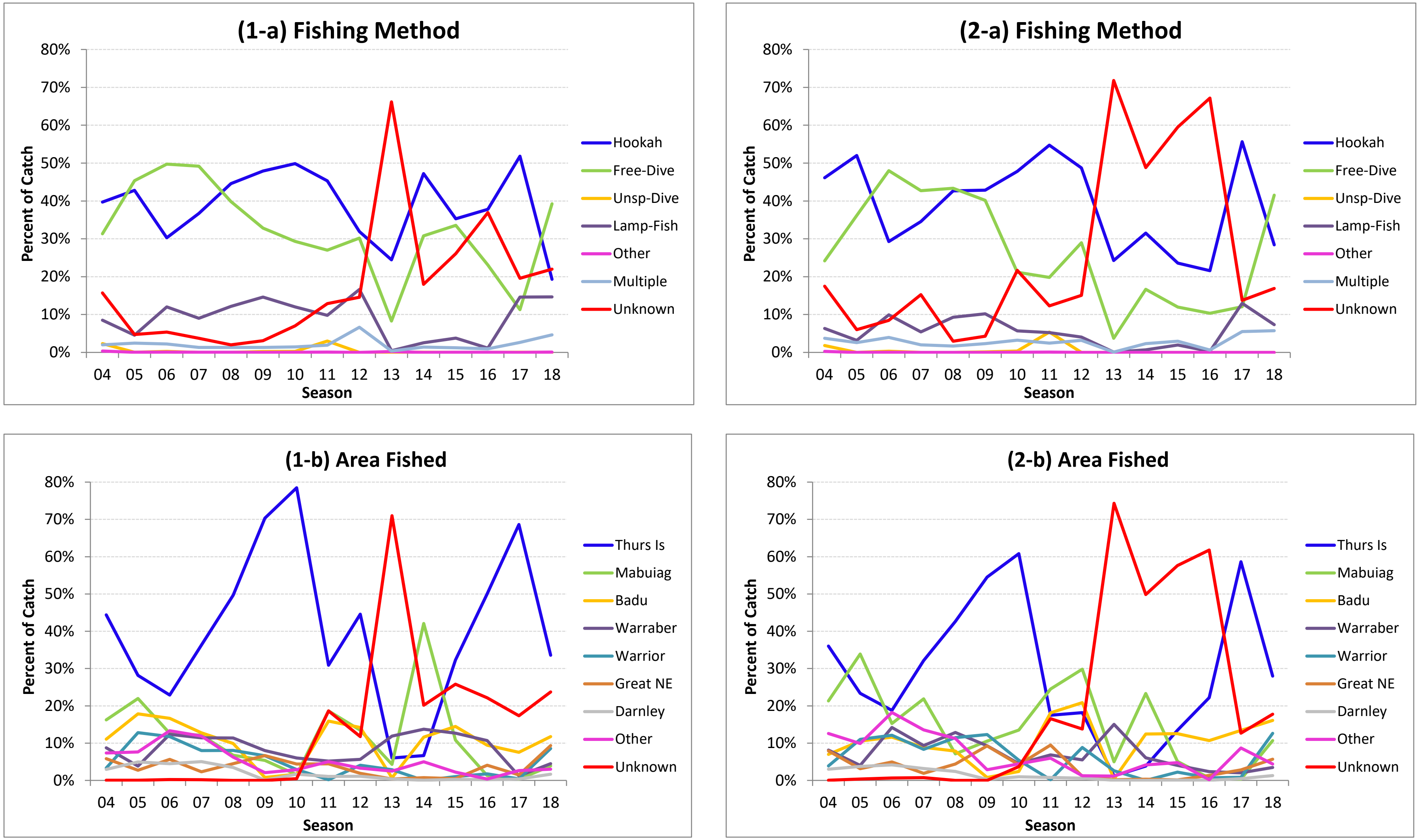


Figure 4-3. Annual percent of (1) number of TIB catch records and (2) total TIB catch for the various levels of: (a) fishing method, (b) area fished in the data. The percent of the annual catch for which each data field was not completed (and therefore remains unknown) is also shown.

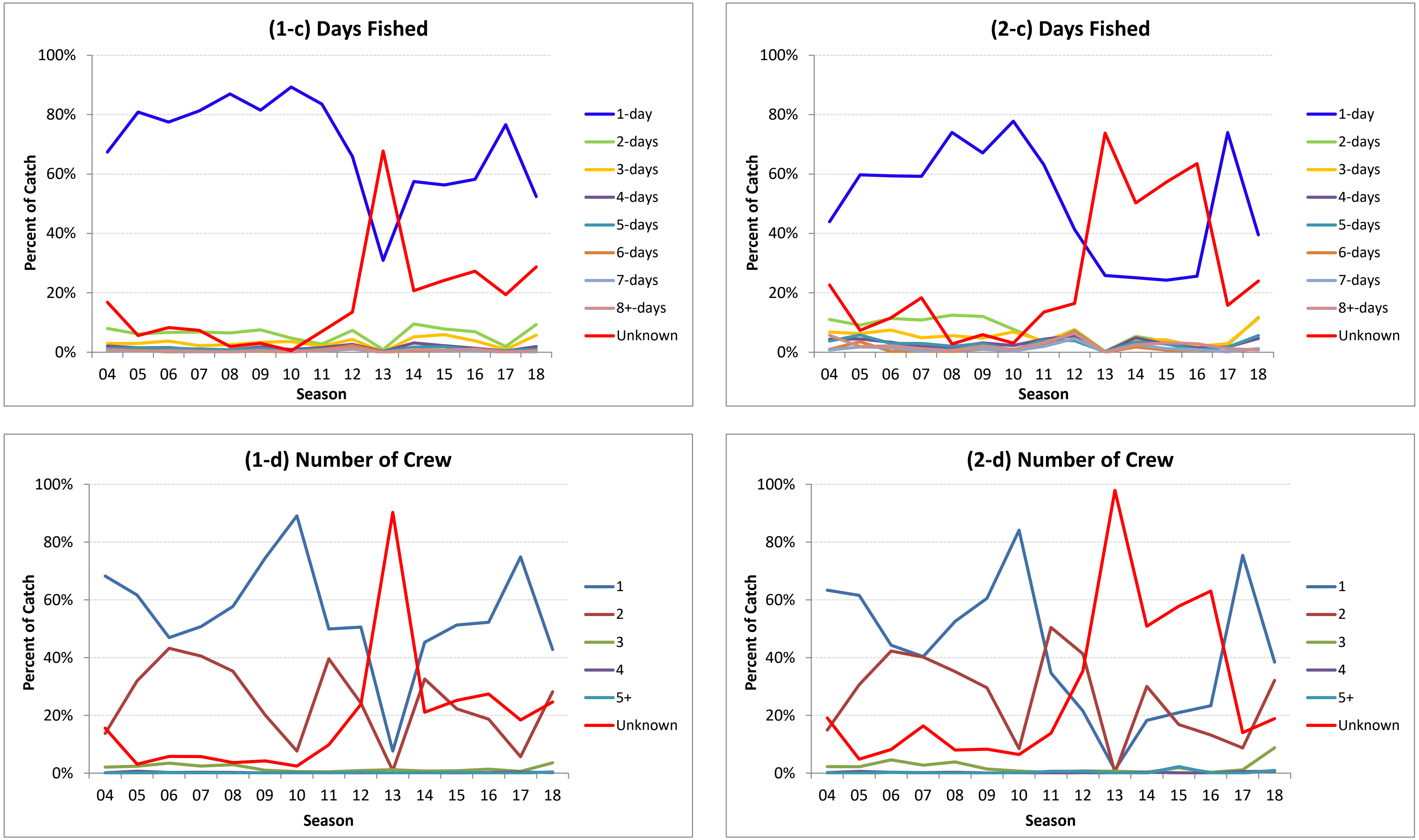


Figure 4-4. Annual percent of (1) number of TIB catch records and (2) total TIB catch for the various levels of: (c) days fished and (d) number of crew. The percent of the annual catch for which each data field was not completed (and therefore remains unknown) is also shown.

4.4 Selection of data used for CPUE analysis

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 identity an appropriate data structure for analysis, the following procedure was adopted 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';
2. Only those records where the first fishing method listed in Table 4.2 was either 'Hookah diving', 'Free diving' or 'Lamp fishing' were selected. This resulted in a total of 43,773 aggregate records (hence-forth known as GLM records);
3. Only those GLM records having a unique Record-No were selected for analysis – accounting for 42,308 (96.7%) of the GLM records identified in the previous step. 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;
4. An additional check was made to ensure that the number of days fished, the number of crew on the boat, the fishing method and the area fished was unique for each Record-No. This was done to help eliminate data errors. Five records were eliminated for having two methods each;
5. Finally, GLM records were also deleted where either the number of days fished was not recorded (1562), the area fished was not recorded (810), the record pertained to the TVH logbook data (704) as the structure of the data for these records was different, or the weight of the catch was zero (26) or greater than 1000 kg (17);
6. Finally, the records for the 2013 season were also deleted due to the small number of records for this season (47) compared to all other seasons (between 1,024 and 5,585). The small number for 2013 was due to the fact that many of the fields on the Docket-Book were left blank.
7. This process resulted in 39,271 GLM records being created and selected.

The number of GLM records, and associated nominal CPUE, within each season, month, quarter and TIB area and the distribution of records per fishing method, days-fished and the percent of the catch which are tailed lobsters are shown in Tables 4.6 & 4.7 (and for each 2-way combination of the season, month and area effects in Appendix B). Due to the small number of records in some TIB areas, these records were combined with the records in an adjacent area so that the minimum number of records in any area was more than 200. This resulted in twelve areas to be used as spatial effects in the GLM analysis. Furthermore, for all records where more than one fishing method was used the fishing method was termed Mixed. Consequently, only four types of fishing methods were in the data. There were also 1,005 distinct seller-names (unknown for only31 records) and 692 distinct vessels (but unknown for 68% of all records).

The substantive decline in the number of Records-Nos since 2010 has been noted earlier, with the average number of catch records per season decreasing from 3,898 between 2004 to 2010 to only 1,518 between 2011 and 2016. However, this situation improved substantially during 2017 with the greater use of the TDB01-Docket-Book when the number of records selected for the GLM analysis again exceeded 2,000 and has remained near this level during the shorter 2018 season.

Table 4-6. Number of GLM records within each year, month and quarter and associated nominal catch rate.

Season	N-Recs	CPUE
2004	2,898	33.1
2005	5,585	39.3
2006	3,263	25.7
2007	5,330	31.1
2008	4,326	30.1
2009	3,240	27.5
2010	2,641	30.9
2011	1,841	51.2
2012	1,024	42.2
2014	1,491	32.5
2015	1,721	24.1
2016	1,513	31.5
2017	2,457	26.6
2018	1,941	27.6
Total	39,271	

Month	N-Recs	CPUE
1	3531	27.5986
2	5578	35.2989
3	6385	36.0666
4	4524	36.1713
5	4300	34.4775
6	3834	34.0037
7	3716	32.1566
8	2611	30.7584
9	1831	27.2811
10	39	23.3836
11	7	21.73
12	2915	26.4867
Total	39,271	

Qtr	N-Recs	CPUE
1	15494	33.8604
2	12658	34.9394
3	8158	30.6149
4	2961	26.4346
Total	39,271	

Table 4-7. Number of GLM records within each TIB area and distribution across each recorded fishing method and days-fished and the associated nominal catch rate.

TIB-Area	GLM-Area	N-Recs
1	6	92
2	6	22
3	6	209
4	16	15
5	16	9
6	6	16
7	7	4810
8	8	5042
9	9	18462
10	10	632
11	11	2432
12	12	3349
13	13	593
14	14	1641
15	15	108
16	16	953
17	17	733
18	15	8
19	16	4
20	15	10
21	15	131
Total		39,271

GLM-Area	N-Recs	CPUE
6	339	44.2613
7	4810	41.7809
8	5042	30.9401
9	18462	31.1478
10	632	32.2396
11	2432	41.1091
12	3349	23.6417
13	593	47.6454
14	1641	31.4873
15	257	43.3771
16	981	30.9084
17	733	36.8099
Total	39,271	

%-Tails	N-Recs	CPUE
<20%	11,759	23.3
20-40%	2,962	35.4
40-60%	2,414	35.6
60-80%	2,137	38.5
>80%	19,999	37.4
Total	39,271	

Method	N-Recs	CPUE
FREE	16255	31.4946
HOOKAH	18293	36.7398
MIXED	4723	23.4807
Total	39,271	

Days	N-Recs	CPUE
1	33,019	33.5
2	2,976	31.7
3	1,497	28.5
4	679	29.7
5	545	29.3
6	176	36.0
7	157	28.0
8	83	36.4
9	66	31.4
10	28	22.6
11	18	27.5
12	6	10.5
13	7	18.5
14	9	5.2
15	2	5.8
16	3	10.9
Total	39,271	

Unlike the TVH data where the measure of effort is hours-fished, the measure of effort for the TIB data is coarser, being days-fished. Furthermore, and as noted above, it has been assumed that each selected GLM record pertains to the catch and effort of a single fisher (or seller) during a given trip, i.e. it is assumed that the measure of effort (i.e. days fished) associated with each GLM record also pertains to the actual effort expended by that seller in obtaining the recorded catch. While the number of days fished for each Record-No in the GLM data is unique, there are instances nevertheless where for the same vessel, date and seller there are multiple Record-Nos where the number of days fished is different. Investigation of this issue undertaken with the AFMA data section indicated that the dates associated with these docket-book forms were most likely not correct (Campbell 2016a).

4.5 General Linear Model Analysis

As with the analysis of the TVH data in previous years, General Linear Models (GLM) were fitted to the TIB data selected in the previous section in order to standardise the CPUE to account for changes in the distribution of records across a number of effects (e.g. Season, Month, Area and Fishing-Method). As mentioned previously, 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 rate associated with each GLM data record, 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 records described in the previous section. All GLMs were weighted as described in Campbell (2018c).

Model-1: Main Effects (labelled Main in the remainder of this report)

CPUE = Intercept + Season +Month +Method + Proportion-Tails + SOI + Moon-Phase

/ distribution = gamma, link = log

Model-2: Main Effects + Area Effect (labelled Main+A in the remainder of this report)

CPUE = Interc + Season + Month + Area +Method+ Proportion-Tails + SOI + Moon-Phase

/ distribution = gamma, link = log

where:

a) *Season* has 12 levels: 2004-2012, 2014-2018 (see below)
b) *Month* has 10 levels: December–to-September.
c) *Area* has the 12 levels as shown in Table 4.7.
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.

All effects were fitted as categorical effects except for SOI which was fitted as a continuous cubic function.

Each of the above models were fitted to the TIB described in the previous section with the following filters: (a) the data for October and November were not included in the GLM due to the small number of records in each month (39 and 7 respectively), (b) the 75 data records where the number of days fished was greater than 9 were excluded as the mean catch rates for these records was substantially below those where the number of days fished was between 1 and 9 days, (c) the 512 records where the catch was less than 1.0 kg or greater than 300 kg as these could also be misreported catches or outliers. This left a total of 38,837 records.

Using the results from each GLM a seasonal abundance index was constructed based on the standardised CPUE calculated for each of the (Season, Month, Area) strata. As the standardised - CPUE is taken as an index of the density of fish within each strata, an index of the abundance of lobsters across the fishery in each season and month is given by:

$$Index(season = s, month = m) = \frac{1}{\sum_{a=1}^{NA} Area_a} \sum_{a=1}^{NA} Area_a . stdCPUE(s, m, a)$$

where *Area_a* is the spatial size of each of the *NA Area* effects included in the GLM. Finally, an index of abundance for each season can be obtained by taking the average across the *NM Month* indices in each season.

$$Index(season = s) = \frac{1}{NM} \sum_{m=1}^{NM} \left[\frac{1}{\sum_{a=1}^{NA} Area_a} \sum_{a=1}^{NA} Area_a . stdCPUE(s, m, a) \right]$$

Finally, a relative annual abundance index, B_s, was calculated such that the mean index over all seasons equals 1, i.e.

$$B_s = \frac{Index(season = s)}{\frac{1}{NS} \sum_{i=1}^{NS} Index(season = i)}$$

For those models which do not included an interaction with the Season effect the relative abundance index, B_s, reduces to the simpler form:

$$B_s = \frac{\exp(S_s)}{\frac{1}{NS} \sum_{i=1}^{NS} \exp(S_i)}$$

where S_i , *i=1, NS* are the parameters estimates relating to *NS Season* effects included in the model. In these situations the abundance is independent of the relative size of each *Area* effect included in the GLM.

No models including an interaction with the *Season*Area* interaction effect were fitted as 22% of the *Season *Area* strata have fewer than 10 records (with 12 having no data records, c.f. Appendix B) and construction of an abundance index from a model including a *Season*Area* interaction would entail the need to impute catch rates for those strata for which the number of records is zero or small (and, hence, maybe unrepresentative). While there was only three *Season*Month* strata having no data records (c.f. Appendix B), no models including an interaction with the *Season *Month* interaction effect were fitted due to the need to know the spatial extent occupied by lobsters within each TIB fishing region (required to construct the abundance index as explained above) and the related uncertainty noted in previous reports about the spatial size of each GLM-area.

Together with the two models described above, a second set of analyses was also undertaken where the Seller-Name (*Seller*) was also fitted as an additional effect to each of the models. To ensure that there was sufficient data for parameter estimation of each *Seller* effect only those sellers which had fished for three or more seasons and for which there were 30 or more data records where included in the analyses. This left a total of 32,360 records for 262 distinct Sellers. A summary of all models fitted in provided in Table 4.8.

Table 4-8. Summary of models fitted to the TIB data.

Model		# Fitted Parameters	# Seller Parameters	Records	AIC
1	Main Effects	63	0	38,837	342,753
2	Main Effects + Area	74	0	38,837	346,966
3	Model 1 + Seller-Name	324	262	32,360	280,371
4	Model 2 + Seller-Name	335	262	32,360	282,956

4.6 Results and Abundance Indices

Standardising Effects

Statistics for the Type 3 contrasts computed for each fitted effect indicated that each effect was highly significant. A comparison of relative influence of each level of the *Month*, *Area*, *Method*, *Proportion-Tails, SOI and Moon-Phase* effects for each model is shown in Figure 4-5. For each effect the values have been scaled so that the influence of each effect is relative to a selected reference level.

Relative CPUE between months is seen to increase at the start of the season from December to March (by 15-20% depending on the model) then remain fairly stable before declining during August before reaching a seasonal low during September (~15% less than at the start of the season).

Relative CPUE varies considerably between the various areas included in the models. There is also considerable variation in the relative effect for a particular area between the different models. For example, for the *Main*-effects the relative CPUE's vary between 158% (for Adolphus) to 91% (for Warraber), while for the *Seller*-effects model, the relative CPUE's varies between 134% (again for Adolphus) to 88% (for Cumberland). However, the uncertainty over the meaning the Area-fished field needs to be taken into consideration.

The relative CPUE of each fishing method also shows some differences across all models, though are similar for the two sets of models with and without the *Area*-effect included. For the two models without the *Area*-effect included, the CPUE for hookah fishing is found to be around 22% higher than for free diving, 19% higher than for lamp fishing, and 7% higher than for mixed fishing. This latter result is to be expected if mixed fishing is a combination of the two other fishing methods.

Finally, the relative CPUE across all models is similar for each category of the proportion of the catch which is tails with the relative CPUE increasing as the *Proportion-Tails* increases in the catch. Across all models, the relative CPUE within each *Proportion-Tails* category is 63%, 86%, 88%, 93%and 100% respectively.

Of the two environmental effects, the results shown in Figure 4-5 (e) indicate that high negative values of the SOI (i.e. strong El Nino conditions) tend to increase CPUE while the influence of high positive values of the SOI (i.e. strong La Nina conditions) is less clear. This result is different from that found when analysing the TVH data. However, there is a high level of uncertainty associated with these results as over the 175 months between January 2004 and July 2018 there have been only 3 months where the mean monthly value of the SOI has been less than -20 and 6 months where this value has been greater than 20, and between these values the influence of the SOI is seen to be relatively small. The influence of the Moon-Phase on CPUE, shown in Figure 4-5 (f), is seen to be similar across all models, and while displaying a degree of variability indicates a bi-modal distribution across the days between successive full moons similar to that found with the TVH analysis. CPUE is lowest during days near a full and new moon, while CPUE is highest mid-way between these two phases (i.e. around the first and last quarters). Average across all models, during this latter periods CPUE is around 30% higher than during the periods of lowest CPUE.

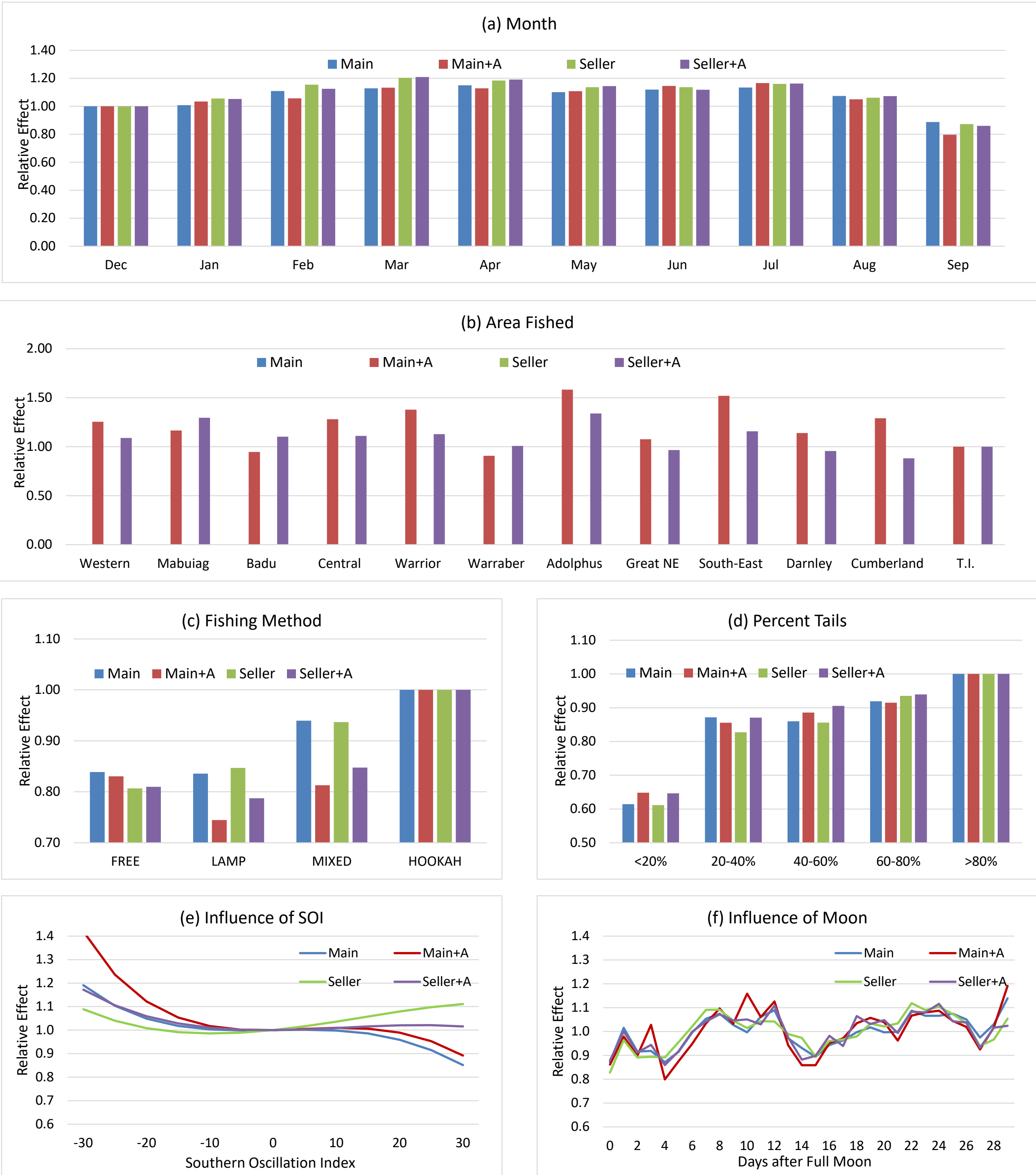


Figure 4-5. Comparison of relative influence of each level of the Quarter, Area, Method and Percent-Tails effects for each fitted model. Results are shown for both model runs. Note, for each effect the values have been scaled so that the influence of each effect is relative to that of the last level of each effect (i.e, Qtr=1, Area=T.I., Method= Hookah and %-Tails= '>80%').

Table 4-9. 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 the all seasons is equal to 1.

Season	Nominal	Main+A	Main	Seller+A	Seller
2004	0.98	0.85	0.90	0.93	0.94
2005	1.16	0.94	0.99	1.04	1.05
2006	0.82	0.74	0.78	0.78	0.78
2007	0.97	0.90	0.88	0.91	0.87
2008	0.95	0.85	0.85	0.85	0.83
2009	0.93	1.02	0.93	0.96	0.90
2010	0.98	1.01	0.95	1.05	0.99
2011	1.52	1.37	1.40	1.35	1.36
2012	1.11	1.13	1.21	1.22	1.26
2013					
2014	1.00	0.97	1.01	0.99	1.08
2015	0.76	0.88	0.85	0.89	0.92
2016	1.09	1.22	1.14	1.19	1.15
2017	0.82	1.12	0.99	0.95	0.91
2018	0.89	1.00	1.10	0.89	0.94
Mean	1.00	1.00	1.00	1.00	1.00

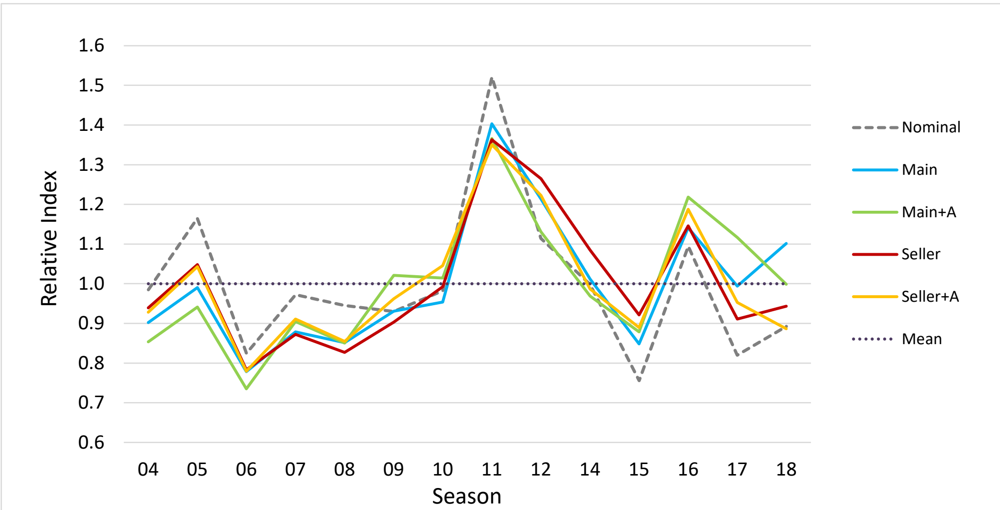


Figure 4-6. Relative indices of resource availability based on each the models fitted to the catch and effort data for the TIB fishery.

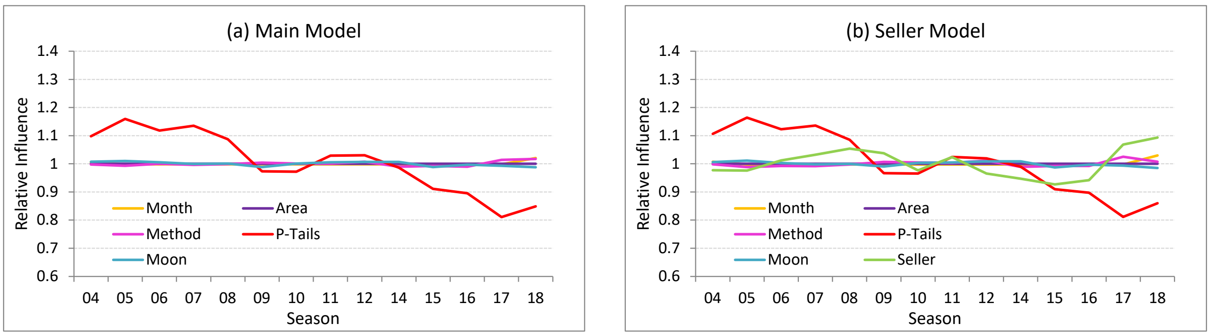


Figure 4-7. Annual influence of the fixed effects fitted to (a) the Main-Effects model and (b) the Seller-Effects model.

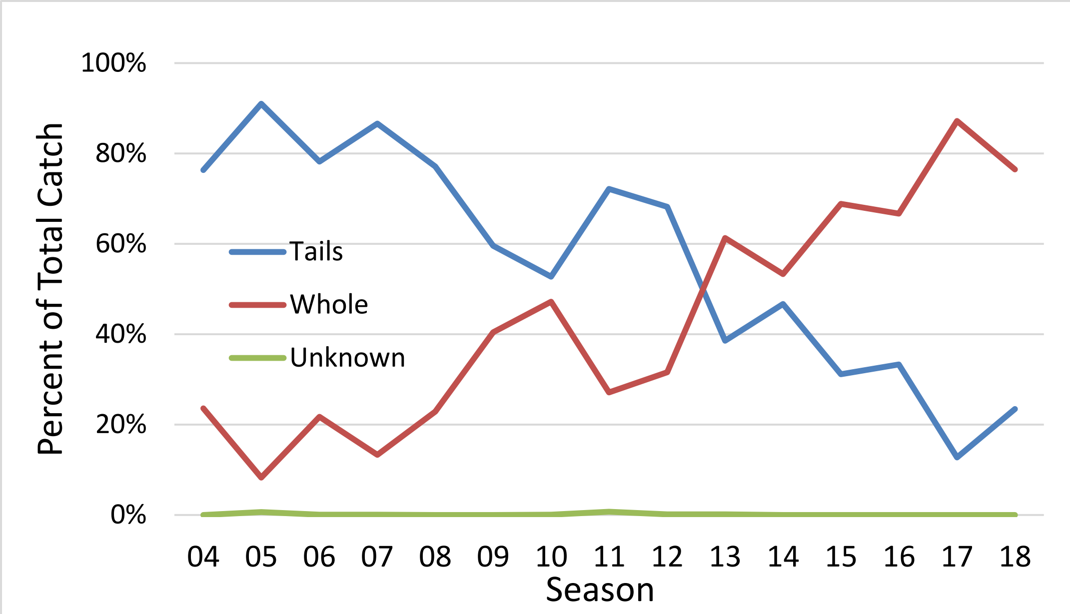


Figure 4-8.Percent of total annual catch (whole weight) by processed form

Annual Abundance Indices

The seasonal abundance indices based on each of the four GLM models listed in the previous section are listed and displayed and in Table 4.9 and Figure 4-7 respectively. Relative to the nominal index, each of the standardised indices displays a number of 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).

The reasons for these changes can be investigated using the seasonal influence of each main effect which is shown in Figure 4-8 for the Main and Seller models. The influence on the seasonal index is seen to be greatest for the *Proportion-Tails* effect, and the decreasing trend observed over time is correlated with the shift from the catch being predominantly tails to now being predominantly whole lobsters (c.f. Figure 4-8), with the latter process type decreasing CPUE (c.f. Figure 4-5(d)). The other effect having a substantive influence on the annual index is the *Seller* effect, and while displaying a variable influence over time the influence of this 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 standardising model leads to a decrease in the standardised CPUE. 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. The annual influence of the other effects included in the standardising models is seen to be negligible, likely due to the fact that there has been no systematic shift in the relative degree of fishing within each level of these effects over time. For example, the proportion of fishing during each level of Moon-phase is likely to have remained unchanged over time (likely being relatively equal each season).

Using the Akaike Information Criteria (AIC) as a measure to select the relative quality of the different statistical models fitted to a given set of data (where a lower value is better), then based on the results shown in Table 4.8, and across the two sets of models (i.e. Main vs Seller), the models without the *Area* effect included are found to provide a better fit to the data. Although using an *Area* effect would usually be seen as a good explanatory variable to account for changes in CPUE due to the spatial variation in the distribution of the lobster resource, this otherwise unintuitive result may be influenced by the poor quality of the data related to the Area fished recorded on the TIB docket-books. Furthermore, and while not shown in Table 4.8, the AIC measure also indicates that between the two models with and without the *Seller*-effect included and fitted to the same set of data as Model 3 (i.e. 32,360 records) that the model including the *Seller*-effect provides the better fit (AIC=280,371 vs 287,500). Based on these observations, Model 3 is therefore seen as the preferred model.

4.7 Comparison with other indices

A comparison of the TIB abundance indices with two of the preferred indices based on the standardised CPUE from the TVH fishery is shown in Figure 4-9 while the Pearson correlation, ρ, between each of these indices is shown in Table 4.10. A number of differences are seen between each set of indices. In particular, the standardised TIB indices each display a considerably flatter trend over time than the TVH indices. Despite this, the peaks and troughs in each of the TIB and TVH indices generally coincide. For example, local maximum occur for the 2005, 2011 and 2016 seasons while local minimum occur for the 2006, 2009, 2015 and 2017 seasons. This similarity is also reflected in the relatively high correlation (ρ =0.8) between the TIB index (*Seller*) and the two TVH indices. As both the TIB and TVH fisheries are fishing the same resource, this result should not be unexpected. The reasons for the flatter trend in the TIB indices remain uncertain and warrants further investigation, but may be due to the nature of the data collected from this fishery, in particular the courser scale measure of effort collected from the TIB fishery (day) in comparison to that collected in the TVH fishery (hours). There is also a problem with the substantive amount of data which is not included in the analyses for the TIB fisher in some seasons, and its more limited spatial extent. Some form of hyper-stability in catch rates in the TIB-sector also cannot be ruled out.

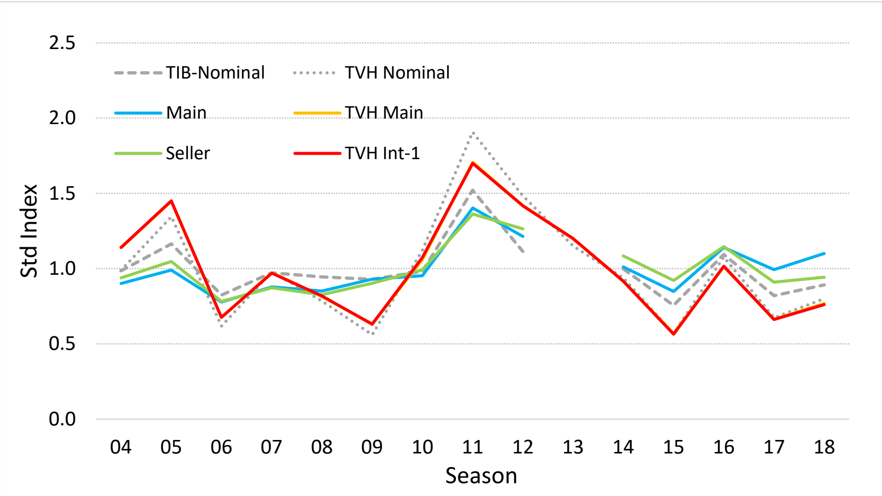


Figure 4-9. Comparison of the selected TIB and TVH resource indices.

Table 4-10. Pearson correlation between the various TIB and TVH-based indices.

Model	TVH-Main	TVH-Int1
Main	0.71	0.70
Main+A	0.54	0.53
Seller	0.80	0.80
Seller+A	0.80	0.80

See also Appendix C this report.

4.8 Concluding Remarks

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 eta al, 2018). 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. On the other hand, the data for the TIB sector is less complete and the measure of effort (days fished) is less accurate and incomplete in many instances. 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 actually occurred and whether there are differences between the different sellers and trends over the years. Also of concern is the likely lack of accuracy of the data related to the Area fished being recorded in the docket books, as this is likely to be highly influential variable in helping to account for the annual variability in catch rates across the fishery.

Finally, it has been noted that either the Docket-Book or many of the fields in the Docket-Book were not completed in recent seasons, though there were improvements in 2017 and 2018. With the introduction of the new Torres Strait Catch Disposal Record (TDB02, shown in Appendix A) it is hoped that the improvements seen in data recording will continue. While the recording of several data fields (e.g. Fisher Name, Fisher Type, Boat Symbol, and catch details) will be mandatory in the new form, it is also essential that the other fields in the voluntary sector of the form (e.g. detailing fishing effort and methods) are completed if the required information is to be available for standardising the TIB catch and effort data. As with the TVH data, continued effort needs to be placed on ensuring the completeness and accuracy of these data if they are to be used on a continuing basis.

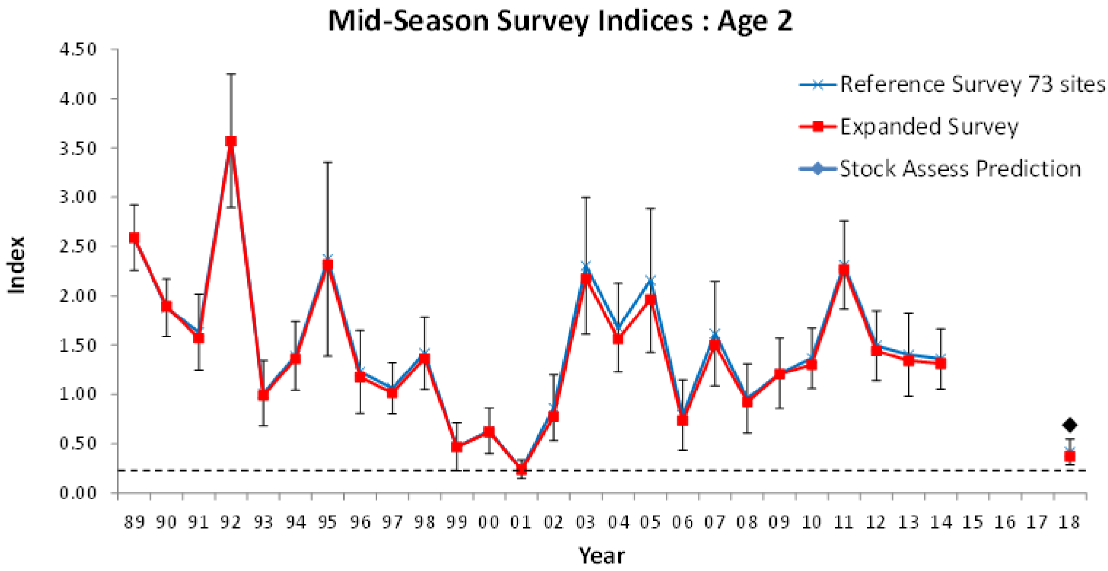
Chapter 5 Midyear Survey 2018

Abstract

The 2018 Midyear survey of the Torres Strait lobster population was conducted between 28th June - 9th July 2018 using the mothership Wild Blue (Gladstone) and CSIRO tender. The survey has shown convincingly that the original scientific results and recommendations hold, i.e. the observed 2018 2+ survey index is NOT significantly different to the stock assessment model-predicted value. The survey results therefore recommend no increase in this year's RBC based on the process agreed at the May 2018 TRLRAG: "The RAG recommended a review of the RBC be undertaken if the results of the 2018 mid-season survey 2+ survey index falls outside the 95% confidence interval associated with the model forward prediction based on the November 2017 pre-season survey 1+ index, in relation to directly comparable sites (e.g. sites sampled in both surveys only)." The survey result suggests that the 2+ stock abundance (being the cohort that will contribute to spawning) is lower than predicted based on forward projections (it's the 2nd lowest index after the 2001 minimum value), and hence that a low precautionary RBC is warranted (Fig 5.1).

The survey suggested that the incoming 1+ recruiting cohort is slightly above average and hence preliminarily suggests that next year will be a much better year. The 1+ index is higher than would have been predicted by the Preseason 0+ index. However previous analyses acknowledged that the 0+ index was negatively biased and the stock assessment model downweighted it based on the high associated standard deviation. This year's November 2018 Preseason survey will be able to corroborate the Midyear 1+ index, which is a key input for computing next year's RBC. Previous analyses showed that the relationship between recruiting (1+) lobster indices recorded from mid-year and pre-season surveys in the same years was highly significant ($R2=0.97$), which isn't too surprising given that the surveys were conducted only four months apart (June and November).

The midyear survey index has provided a valuable basis for calibrating this year's CPUE, but we won't be able to start those analyses until we have the entire year's CPUE data analysed. The full report containing the detailed analyses of the survey data will be circulated before the next TRLRAG meeting.



Key summary figure showing July 2018 Midyear standardised survey index relative to historical values and compared with the stock assessment prediction (based on the 2017 Preseason survey).

5.1 Introduction

The May 2018 TRLRAG recommended the following: “that a mid-season survey be conducted as soon as practically possible, to be facilitated by industry and PZJA agencies, for the purposes of:

providing further data on the abundance and spatial distribution of all age classes in the current season to input to the 2018/19 stock assessment, noting that CPUE data for the current season is now biased by management changes and may be unusable should the Fishery close early this season;

providing further data to validate the 0+ and 1+ indices of abundance from the November 2017 pre-season survey, noting the 0+ index may not have been reliably estimated from the November 2017 pre-season survey and the model was unable to satisfactorily fit this index;

providing a 2+ index of abundance to more accurately inform on stock status and for comparison with CPUE data;

provide a preliminary prediction of the expected 1+ lobster recruitment for the 2018/19 season (0+ lobsters in November 2017 pre-season survey) to provide forewarning on the likelihood of another low RBC for the 2018/19 season.

The survey will consist of 77 pre-determined sites expressly selected to provide for comparison with previous mid-season surveys.

The RAG further recommended that CSIRO work with industry to ensure areas fished in the current season are adequately represented in the sites sampled in the mid-season and future pre-season surveys.”

Annual fishery-independent monitoring of the Torres Strait ornate rock lobster *Panulirus ornatus* population has been carried out between 1989 and 2018. Midyear surveys were conducted for all years 1989-2014, with the 2018 survey extending this series. Pre-season surveys have been conducted for years 2005-2008 and 2014-2017. These surveys provide the only long-term information on the relative abundance of recruiting (1+) and fished (2+) lobsters, since there was no comprehensive monitoring of commercial catch and effort prior to 2003. The survey sites are distributed throughout most of the fished area to provide representative abundance estimates. The relative abundance indices and age composition data are used in the TRL fishery model for assessments of the status of the stock, and to inform management regulations.

The 2018 Midyear survey of the Torres Strait lobster population was conducted between 28th June - 9th July 2018 using the mothership Wild Blue (Gladstone) and CSIRO tender (Figure 5-1). A total of 78 sites were surveyed by divers and each site was re-located accurately using portable GPS. Seventy-three sites corresponded to the 2017 Preseason survey, whereas 5 additional sites that were surveyed corresponded to the hotspot area fishers have focussed on during 2018 (Figure 5-2). The selection of the 5 additional sites was circulated to TRL RAG members and fishers for comment prior to the survey with agreement from those that responded that these sites were representative of the hotspot area for the 2018 season. The four scientific divers involved in the survey ranged in experience with two divers having more than 10 surveys experience while the other two had completed 2 or 3 TRL surveys. The two dive teams were split based on experience with a less experienced diver coupled with a more experienced diver. Measured belt transects (500 m by 4 m) were employed as the primary sampling unit, as they were found to give the greatest precision (p=SE/Mean) of lobster abundance. Transect distance was measured, to the nearest metre using a Chainman® device. At the completion of each transect divers recorded: the number of lobsters caught, the number and age-class of those observed but not caught, depth, visibility, distance swum, numbers of pearl oyster (*Pinctada maxima*), crown of thorns starfish and holothurian species observed, and percent covers of standard substratum and biota (including seagrass and algae species) categories. The sampled lobsters were measured (tail width in mm), sexed and moult staged to provide fishery-independent size-frequency data.

At the commencement of the survey the ‘Wild Blue’ experienced a hydraulic pump breakdown however the crew were able to quickly rectify the situation and minimise delays. The weather and underwater conditions for the survey were generally good. There were some strong winds (20-25 knots) for the first 7-8 days, dropping to 15-20 knots over the last 3 days. The visibility was good, averaging 2.5-3m. The lowest recorded visibility was 1.5m.

As previously, diving operations were limited by a Marine Park Permit to take only 5 lobsters per site from 6 sites located within the Great Barrier Marine Park Zone in the SE region of the fishery. Restrictions included: collection of no more than 30 juvenile lobster (≤ 90mm carapace length) from the 6 sites per year and no more than 5 collected per site per year.

Figure 5-1. Vessels used for 2018 midyear survey: mothership Wild Blue and a 5m CSIRO naiad.

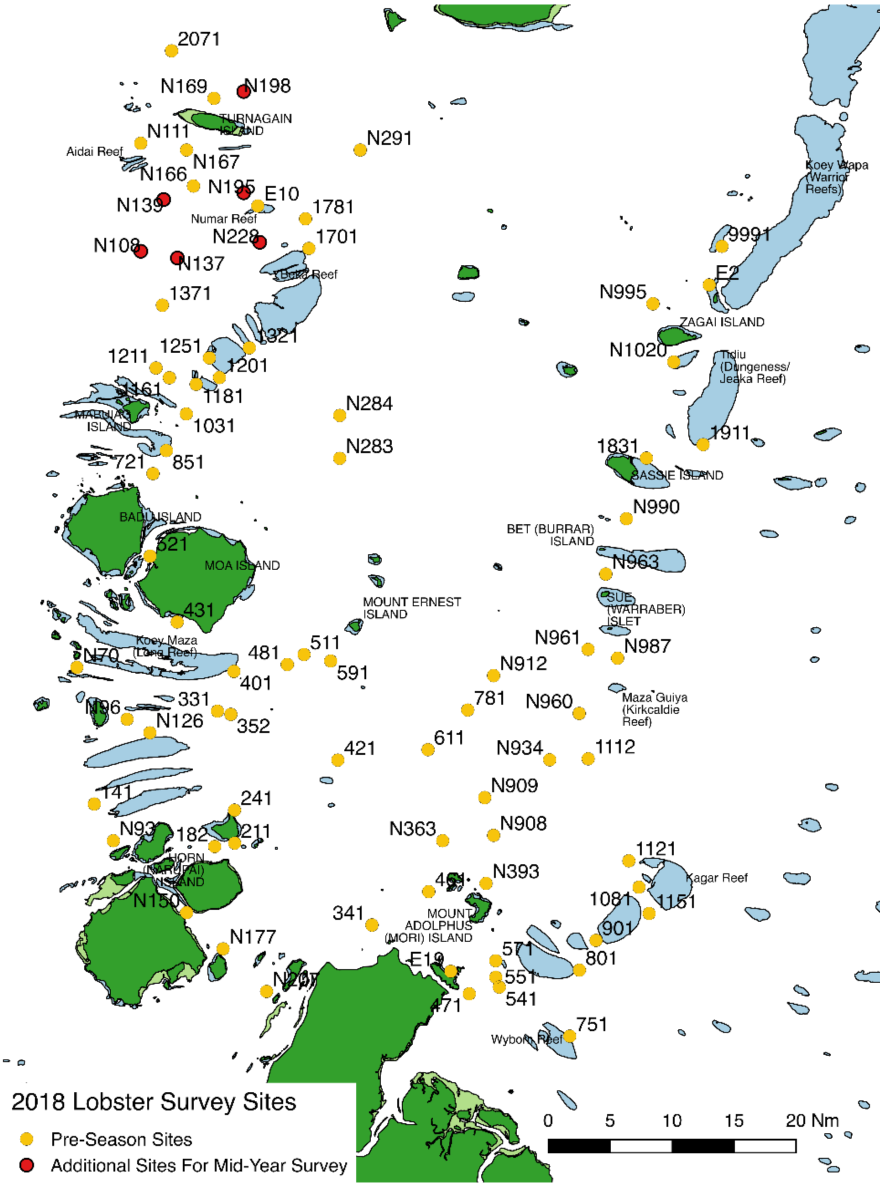


Figure 5-2. Map of western Torres Strait showing sites surveyed during the 2018 TRL midyear population survey. Sites marked in yellow are the same sites as surveyed in the 2017 Preseason survey whereas the red marks indicate additional sites added to the Midyear Survey

Fishing Effort: Previous midyear surveys have been conducted during the fishing season. There was concern that the 2018 midyear survey might be positively biased due to reduced fishing effort this year because of a low RBC, plus concern that the fishery might close before the start of the survey if the RBC was reached, and because of a hookah ban implemented mid-season.

The 2017/18 total RBC is 299t. Following a recent agreement between Australia and PNG on the allocation of the 2017/18 recommended biological catch (RBC) for the Torres Strait Tropical Rock Lobster Fishery (TRL Fishery), there will be no cross endorsement and hence the final Australian catch share is 254.15 tonnes. This is an increase from 190.65 tonnes. The sustainable catch limit for the

Australian sector for the 2017/18 fishing season is thus 254.15 tonnes and the total reported catch as at 12 July 2018 was 228.12 tonnes, with 24 t taken from 1-12 July. If the PNG catch as at 12 July was 45t, this suggest the total catch up until the end of the midyear survey was approximately 273t.

Other fishery restrictions this year have included additional moon-tide closures and a hookah ban for a short time period. However, the use of hookah gear was again permitted from 2-9 July 2018, and hence it can be assumed that the total level of fishing effort preceding and during the time the midyear survey was conducted was not overly anomalous. However, there are indications from the data and from anecdotal reports from fishers that the fishing effort has been locally concentrated this year, and hence high fishing pressure in the Mabuiag stratum could influence results.

5.2 Results

TRL distribution and abundance

The distribution of recruiting (1+) lobsters observed during the 2017 Preseason survey was compared with the 2+ lobster abundance (given they have grown into the next age class) during the 2018 Midyear survey (Fig. 3). Both survey indices suggested low abundance of the (1+) lobsters in November 2017 and the same cohort (2+) in June/ July 2018 across most strata. Buru stratum had one of the higher 2+ indices from the 2018 Midyear survey which contrasted with the very low 1+ abundance index observed for this stratum in the November 2017 preseason survey. The South East stratum which had an average 1+ index in November 2017, had a low Midyear 2+ index indicating the expected northward movement of lobsters as they grow and prepare for migration around September. In general, there were plenty of sites with empty dens where one might have expected 2+ animals if the abundance was high.

The 2018 recruiting class (1+) suggests a more even distribution of recruits than was the case last year (Fig. 3). The Midyear survey indicated that all strata had reasonable numbers of 1+ recruits however the north-western stratums (Buru and Mabuiag), and the South-East stratum had higher indices compared to the others.

Annual indices of abundance for 1+ and 2+ lobster

As the 2015, 2016 and 2017 pre-season surveys involved a reduced number of transects (77) from previous surveys (>130, e.g. 2014), several alternative methods have been used to calculate annual pre-season indices of abundance between 2005 and 2017. Previous analyses indicated that transitioning to smaller scale pre-season surveys would not interrupt the time series collected to date. Moreover, analyses were done to cross-check the reliability of using subsets of the survey data, such as selecting for analysis of the Preseason survey index, only those sites also common to the earlier Midyear surveys. As the Preseason survey becomes more extensive, more recent additions to the survey could be included in the standardised index. The 2018 Midyear survey used mostly the same reference sites (73) as per the 2017 Preseason survey but also included an additional 5 sites in the Mabuiag stratum where most fishery catches were being reported from. There were therefore 4 alternative methods (Table 5.1) used to analyse the 2018 Midyear survey index relative to previous years. The first involved using the same method as was used to obtain the Reference Case Preseason 1+ index from the 2017 Preseason survey (using 68 common sites), being the series that was input to the stock assessment model. The second method involved using all 73 sites as used in the Preseason survey. The third method used all 78 sites, i.e. including the additional 5 sites. The fourth used only sites common to all years.

The 2018 midyear abundance index for 2+ lobsters is significantly lower than the previous 8 midyear survey indices and is the second lowest value on record (Fig. 4). The 2018 index is 26% of the average survey indices over the period 1989-2004 (Fig 4). The overall pattern of a low 2018 index is very similar across all methods examined.

The (1+) recruiting index is much more positive and is at approximately the average historical level, suggesting that the next fishing season will be improved relative to the current fishing season (Figure 5-4).

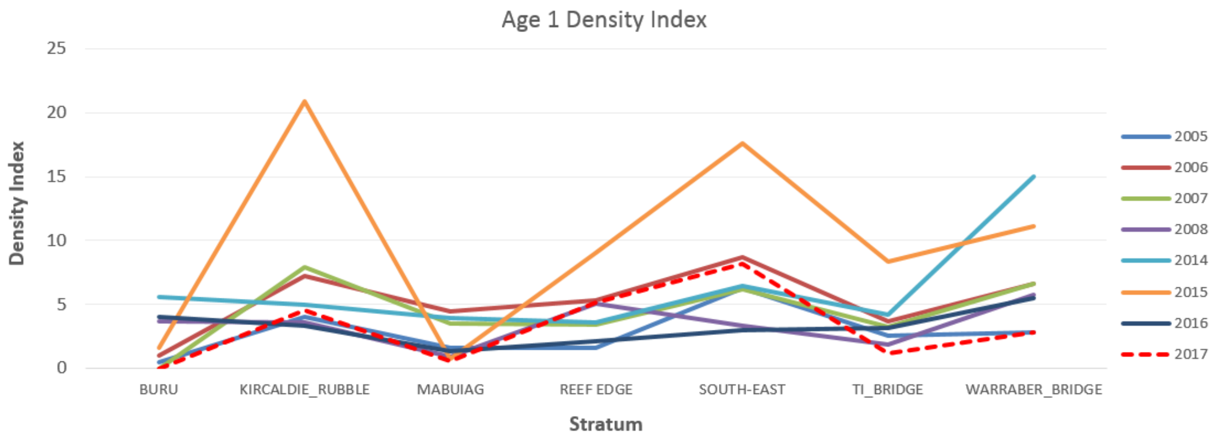
Figure 5-5 compares the standard errors (SE) of the alternative survey indices, highlighting the improvement (i.e. reduction in standard error) in the precision of surveys with substantially more sites (e.g. 34 vs 73 sites) but only a small change in precision associated with adding a few more sites. The 2018 coefficient of variation (SE/mean) for both the 2+ and 1+ indices was similar to the average of the historical series, supporting that the 2018 midyear survey was adequately precise.

Table 5-1. Description of the four options used to estimate ornate rock lobster (Panulirus ornatus) abundance indices from the 2018 Midyear population survey conducted in Torres Strait.

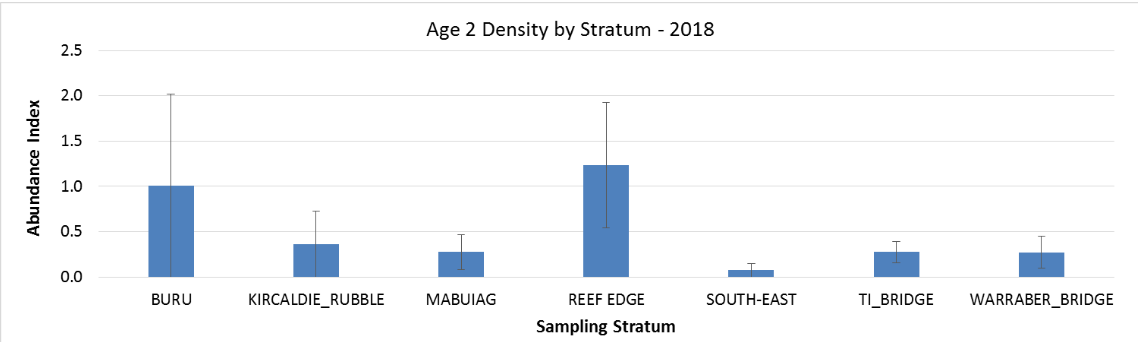
Midyr Index Option	Number of Transects in 2018	Total Number of Transects in series	Description
1. 73 Reference Sites	73	73#	The 73 Reference Sites used in the 2018 survey
2. Reference Index used in Stock Assessment Model	68	73#	Historically selected reference sites : Sites common to those in the 2002 and 2006 surveys
3. Expanded survey	78	83	Sites used in Option 2 plus the additional sites in the 2018 survey
4. MID_YEAR ONLY SITES-common across all years	34	34	Sites common to surveys across all years

Of the 73 sites included in options 1 and 2 above, 68 sites are common to both options while 5 sites are particular to each option.

November 2017 Preseason Survey



July 2018 Midyear survey



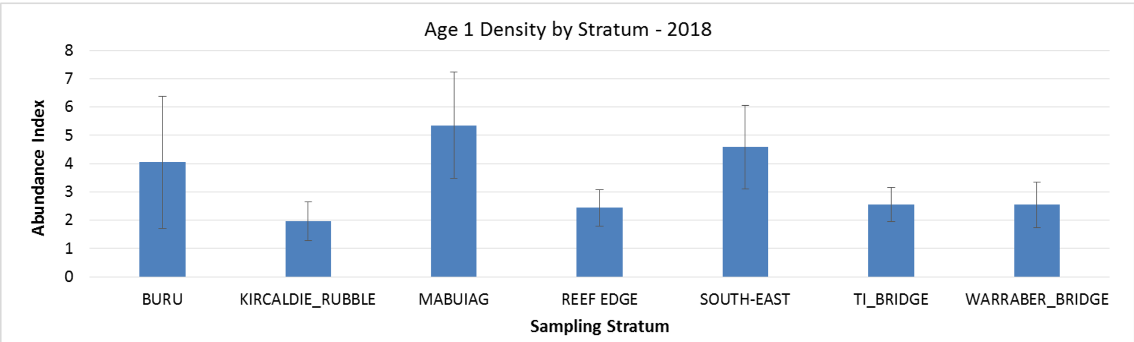
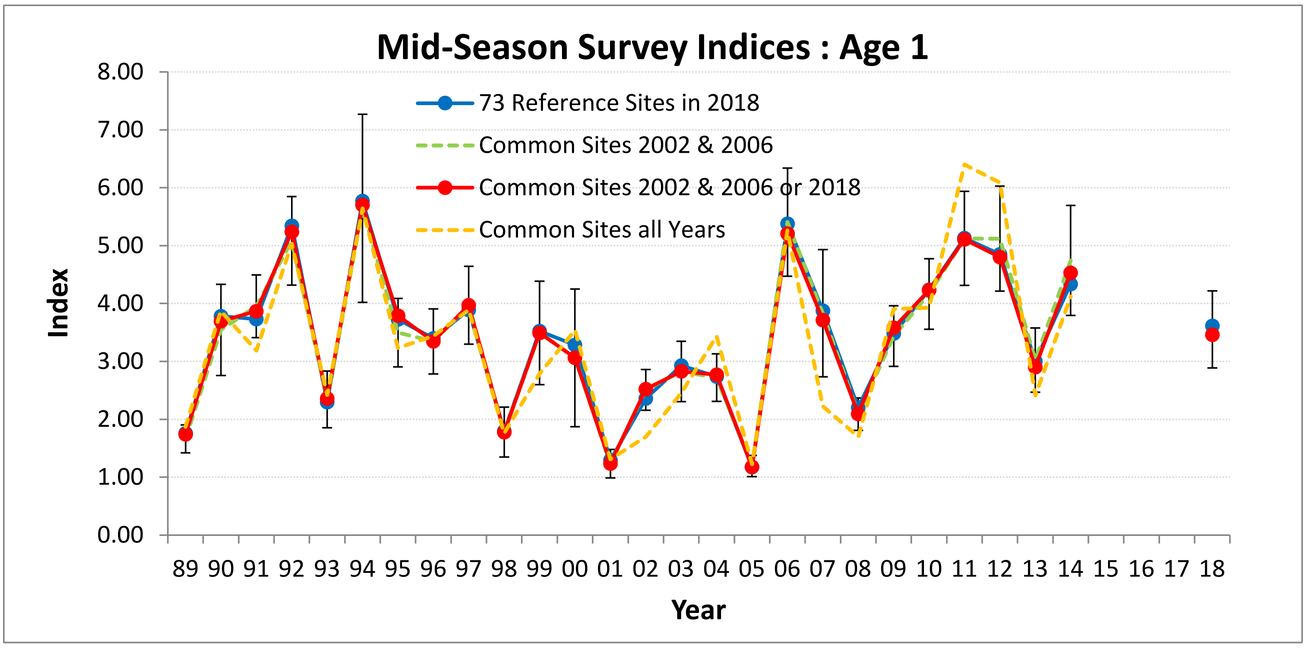


Figure 5-3. Comparative indices of abundance of recruiting (1+) ornate rock lobsters (Panulirus ornatus) recorded in each sampling stratum during pre-season surveys in Torres Strait between 2005 and 2017 (note surveys were not done during 2009-2013), compared with results (based on all 78 sites) obtained during the July 2018 Midyear survey



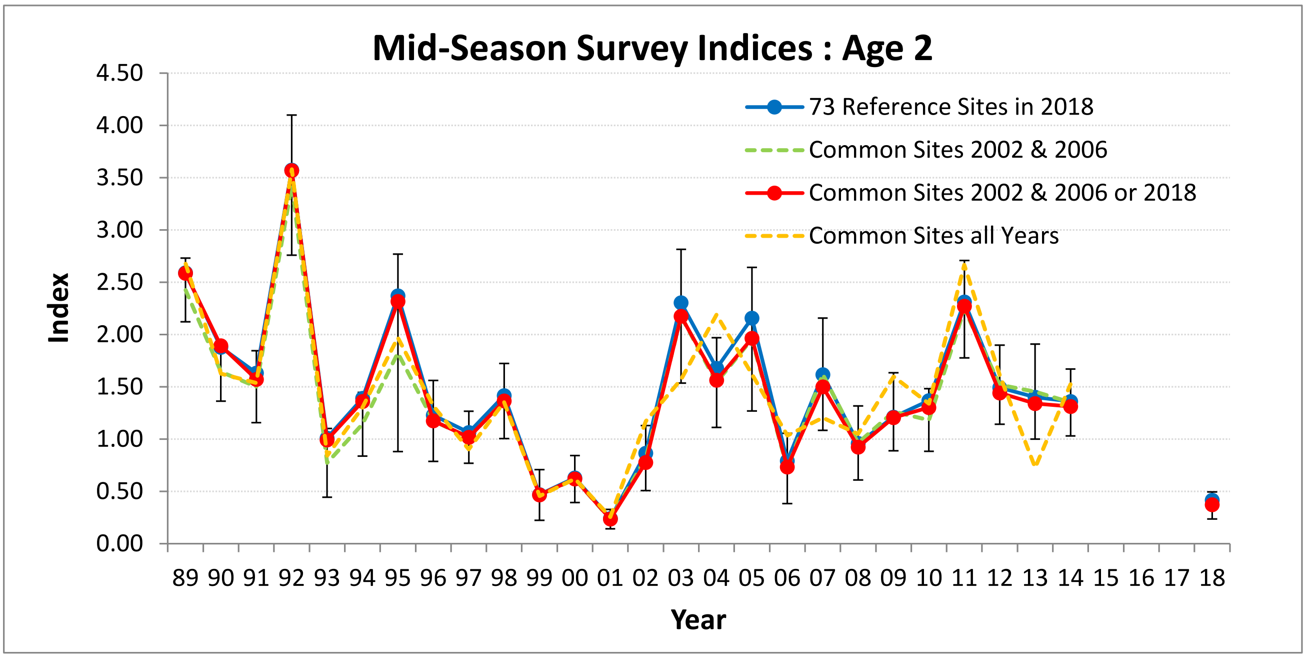
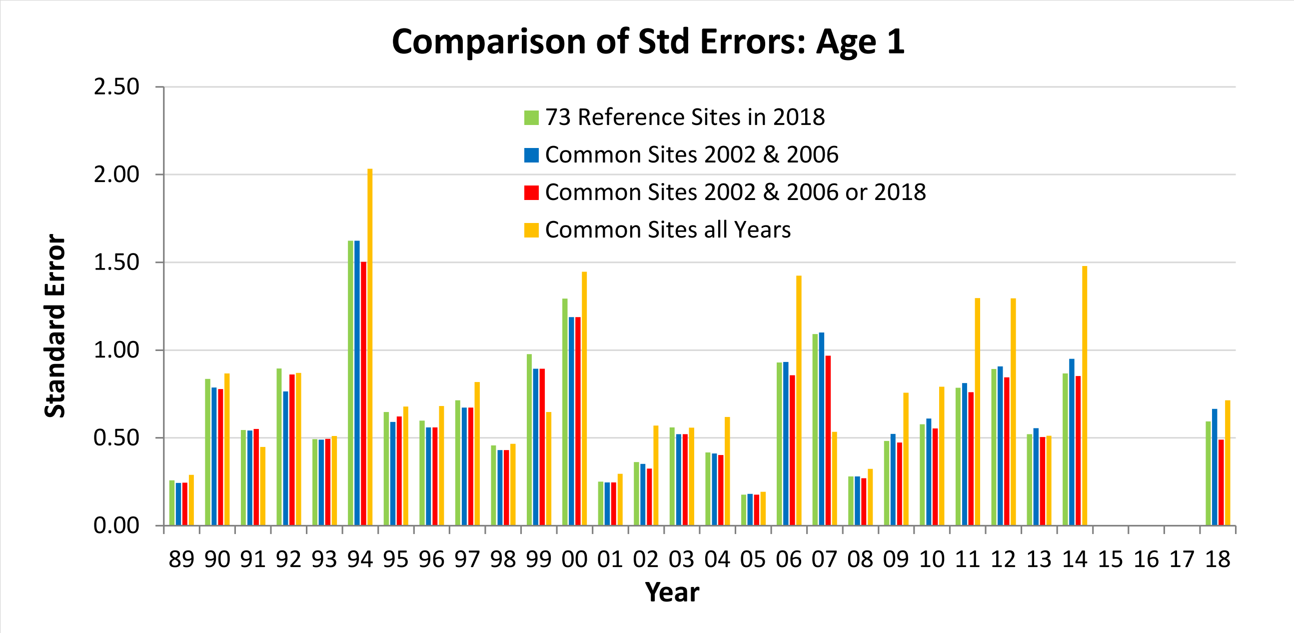


Figure 5-4. Four comparative indices of abundance of recruiting (1+) and fished (2+) ornate rock lobsters (Panulirus ornatus) recorded during midyear surveys in Torres Strait between 1989 and 2018 (note midyear surveys were not done during 2005-2017). Error bars of MYO indices represent standard errors.



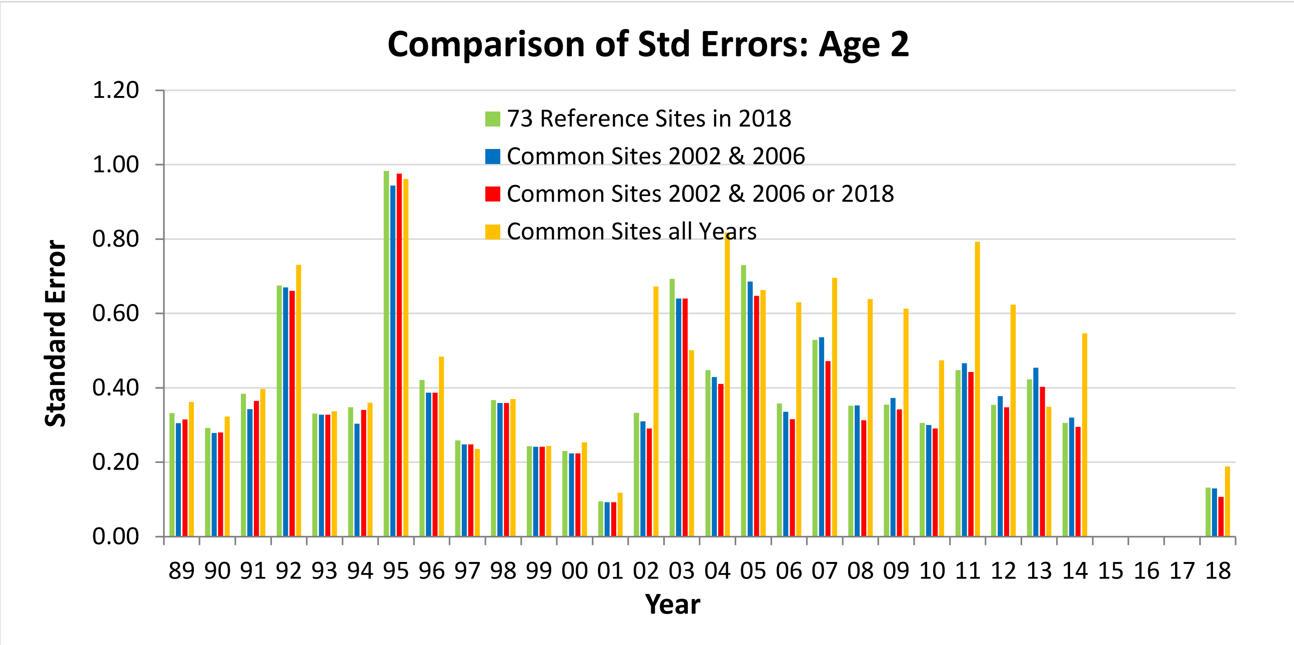


Figure 5-5. Comparative standard errors for four indices of abundance of recruiting (1+) and fished (2+) ornate rock lobsters (Panulirus ornatus) recorded during midyear surveys in Torres Strait between 1989 and 2018 (note midyear surveys were not done during 2005-2017).

Evaluating Results relative to predictions based on the 2017 Preseason survey and Stock Assessment Model Predictions

The TRLRAG May 2018 meeting noted the following regarding at what point the mid-season survey may trigger a review of the RBC for the TRL Fishery: "*The AFMA member advised that there would need to be a significant variation between the results of the November 2017 pre-season survey and the 2018 mid-season survey to trigger a review. Such an "anomalous" result is considered unlikely at this point given indications from available data for the Fishery to date. The CSIRO scientific member supported this view and suggested an anomalous result be defined as a 2018 mid-season survey 2+ survey index that falls outside the 95% confidence interval associated with the model forward prediction based on the November 2017 pre-season survey 1+ index. This is given uncertainties in available data and the fact that a mid-season survey has not been conducted since 2014. The RAG noted that a 95% confidence interval sets a high bar but agreed that this would be appropriate.*"

As shown in Table 5.2 and Figure 5-6, the midyear 2+ index falls within the confidence limits associated with the stock assessment model prediction and is slightly lower than predicted. As per the greed process for evaluating results, this therefore suggests that no increase in the RBC is warranted.

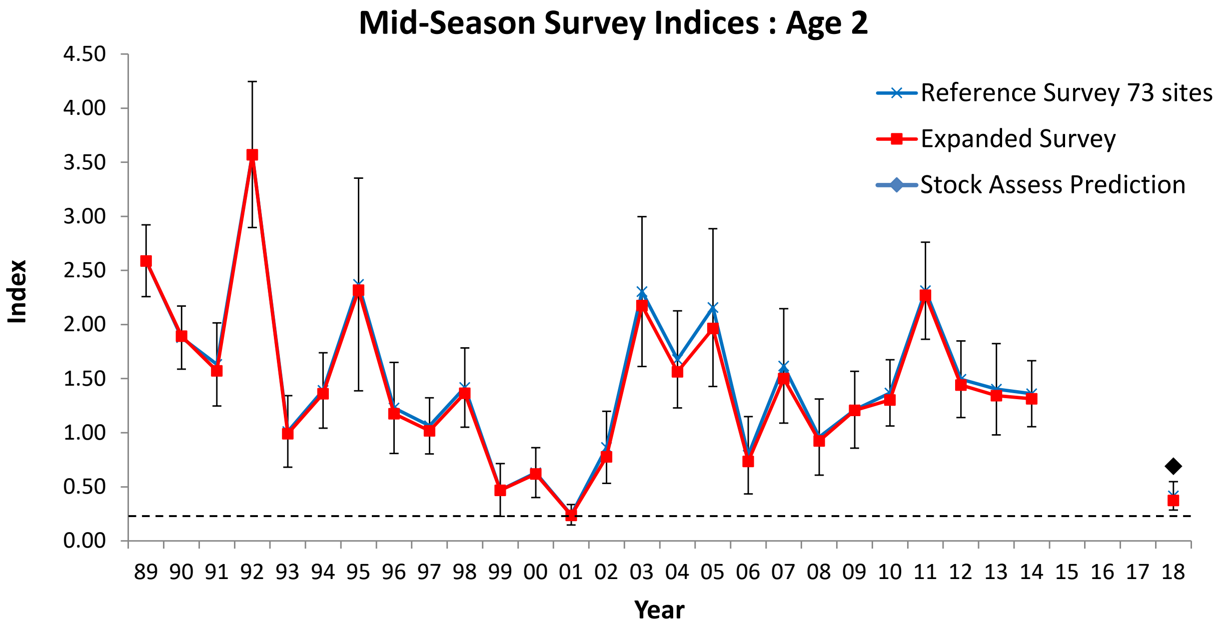
The midyear survey also provides an early indication of the recruiting (1+) age class, which is helpful given the 0+ index is considered unreliable. As evident from table 5.2 and Fig. 6, the 1+ index is slightly higher than the upper 95% limit associated with the model prediction and is seen to be at approximately the average historical value, suggesting a more positive outlook for next year.

Table 5-2. Stock assessment model (Dec 2017 Reference Case version) prediction of 2018 Midyear survey expected relative numbers (i.e. equivalent to survey index) of 1+ and 2+, shown with lower and upper 75% and 95% confidence limits, compared with actual Observed values from 2018 Midyear survey.

	Observed	Predicted Value	lower95%	upper95%	lower75%	upper75%
1+	**3.56**	2.69	1.84	3.54	2.10	3.47
2+	**0.37**	0.69	0.34	1.04	0.44	0.93

Comparison with additional sites added to the index

The additional 5 sites were added to the Mabuiag stratum given information that the stock distribution has shifted this year and fishing has been concentrated in this stratum. It was therefore anticipated that the absence of these sites in the 2017 Preseason survey may have biased results negatively, and that the bias could be evaluated by comparing with results from an index including additional sites in the "hotspot" area. As shown in Fig. 8, a difference in the stratum-specific indices is therefore only expected for the Mabuiag stratum. However, in contrast to the expected results, the index for the Mabuiag stratum decreased slightly when adding the additional 5 sites. This could be partly because the lobsters are very spatially concentrated in this stratum and the survey has underestimated overall abundance because the survey is designed to provide a larger scale representative index. Alternatively, this suggests that the earlier "hotspot" concentrations of lobsters in this stratum have now been fished and the index is reflecting the fishing pressure that has been exerted in this area. In summary though, this suggests that there is no basis for concluding that lobster abundance is significantly higher than indicated by the survey and hence that the RBC should be increased.



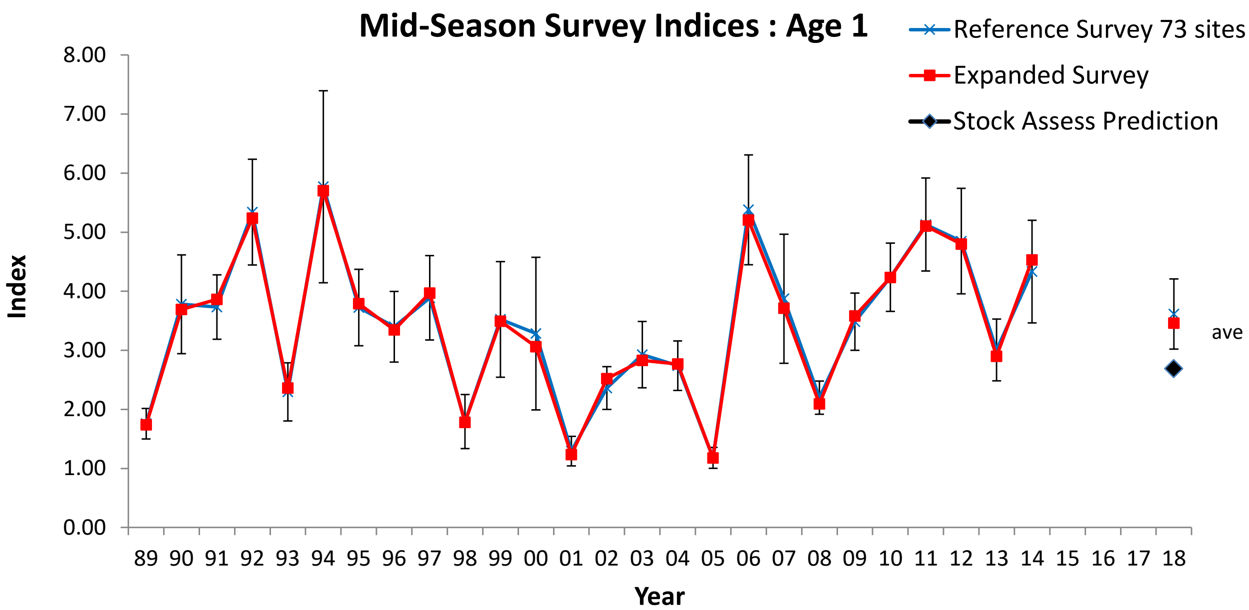
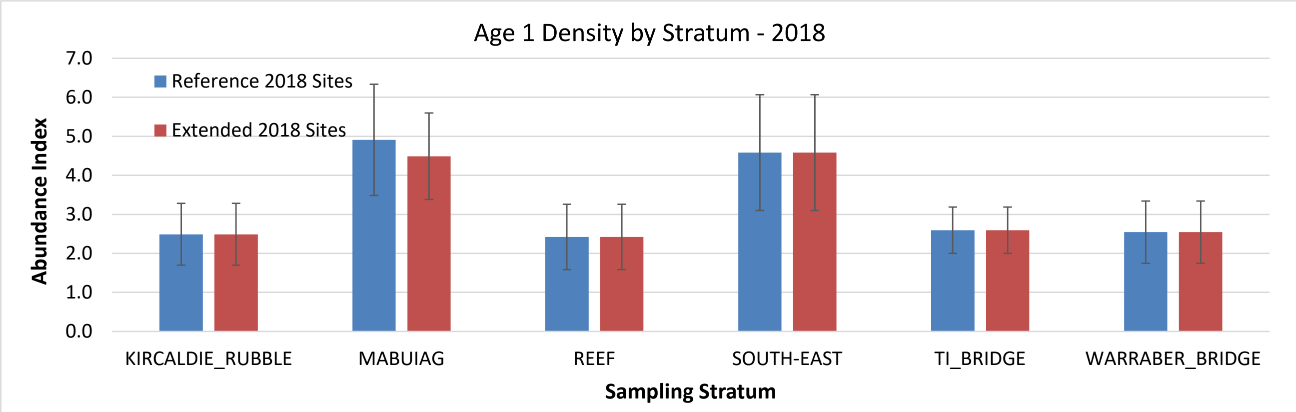


Figure 5-6. Comparison of the Reference and Expended Survey indices of abundance of recruiting (1+) and fished (2+) ornate rock lobsters (Panulirus ornatus) recorded during midyear surveys in Torres Strait between 1989 and 2018 (note midyear surveys were not done during 2005-2017), shown together with the stock assessment model-

predicted values that were based on the model fitted to the Preseason 2017 survey data. Error bars represent standard errors.



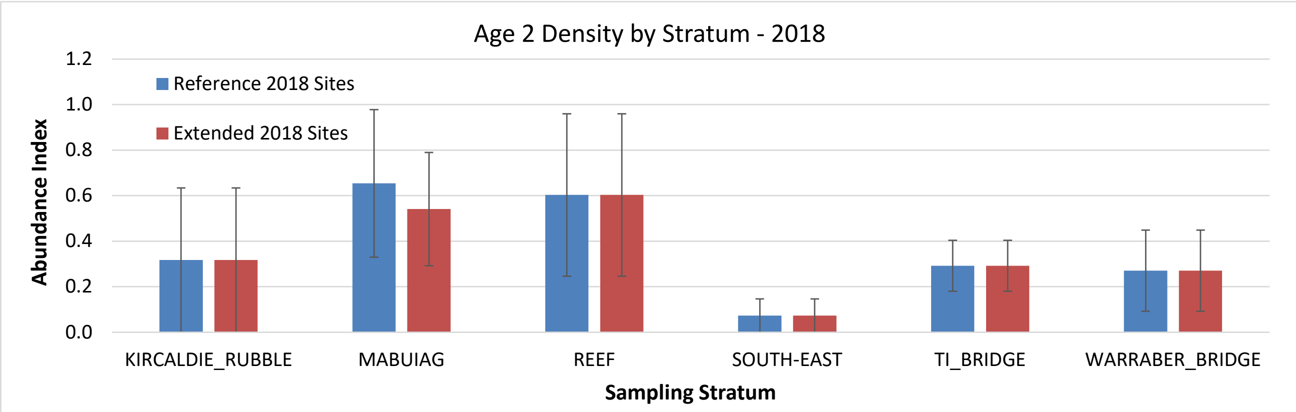


Figure 5-7. Comparison of 2018 Midyear survey results per stratum as shown.

The midyear survey index has provided a valuable basis for calibrating this year's CPUE, but we won't be able to start those analyses until we have the entire year's CPUE data analysed. The full report containing the detailed analyses of the survey data, including length frequency information, will be circulated before the next TRLRAG meeting.

Acknowledgements

We wish to sincerely thank the master (Rob Benn) and crew (Joseph Harland) of the Wild Blue for excellent assistance in all aspects of the mid-year dive survey in Torres Strait, and in logistic support prior to and after the field survey. We also thank Tim Skewes for stepping in to assist with the diving and sharing his extensive experience from decades of involvement in TRL research. We are grateful to Darren Dennis for comments which helped improve the analyses. Finally, we thank all TRL RAG members and observers for their constructive inputs. We gratefully acknowledge funding support for the survey from AFMA and CSIRO

Chapter 6 Pre-Season Survey 2018

Mark Tonks, Robert Campbell, Nicole Murphy, Kinam Salee, Steven Edgar, Eva Plagányi, Judy Upston, Mick Haywood

6.1 Introduction

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been engaged by the Australian Fisheries Management Authority (AFMA) to undertake annual pre-season stock assessments of *Panulirus ornatus* (Ornate or Tropical Rock Lobster (TRL)) within a defined region of the Torres Strait and determine the Recommended Biological Catch (RBC) for the respective fishing season. To undertake the stock assessment, relative abundances of the TRL must be determined. Divers complete a census of lobster along transects at pre-determined sampling sites, with a subset of lobster collected for additional measurements.

A benchmark survey was undertaken in 1989 to scope the fishery's habitats and lobster abundance. Initially, Midyear surveys (June/July) were used to assess stock status, however this has recently (since 2015) shifted to pre-season surveys (November) to monitor lobster recruiting to the fishery as close to the start of the fishery as possible. Because of a low RBC for the 2018 fishing season (in part an outcome of low 2017 pre-season survey abundance indices) and locally high reported catches of lobster in the north-western region, a midyear survey was conducted in July 2018. To further investigate the reported higher catches of lobster in the north-western region, five additional sites were included to identify lobster distribution and abundance within this region. Outcomes of the Midyear survey were communicated to TRLRAG in October 2018 and were consistent with the 2017 preseason survey which supported the low abundance of recruiting (1+) lobster.

The 2018 TRL Pre-season Population Survey (the survey) was conducted between 11th and 23rd November. The mothership "Wild Blue" (Rob Benn Holdings Pty Ltd) and a 5 metre CSIRO naiad (Figure 6-1) supported the CSIRO TRL Dive Team (Mark Tonks, Nicole Murphy, Kinam Salee and Steven Edgar). Conditions during the 12-day survey varied with winds ranging between 15-25 knots for the first week and dropping to 5-10 knots for a majority of the second week. Visibility averaged between 2.5-3m with neap tidal flows allowing for a good visual census and collection of lobster. Ninety percent of dives had more than 2m visibility. A total of 82 sites were surveyed (Figure 6-2), 77 of these were long-term repeated TRL survey sites and 5 were additional sites recently included in the July 2018 Midyear survey (as well as in earlier Midyear surveys). The lobster abundance data were used to calculate age-class abundance indices for input to the TRL stock assessment and to inform an RBC for the 2019 fishing season.

Figure 6-1. Vessels used for 2018 pre-season survey: mothership Wild Blue (left) and a 5m CSIRO naiad.

6.2 Methods

Survey permits

Three research permits are required to conduct research associated with TRL population surveys. These include:

- Protected Zone Joint Authority Permit
  - Collect no more than 400 lobster per survey within the area of Australian Jurisdiction in the Torres Strait Tropical Rock Lobster Fishery
- Queensland General Fisheries Permit
  - Collect lobster 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 30 juvenile lobster in total (≤90mm carapace length) per year from 6 sites from within the Great Barrier Reef Marine Park Zone (Fig. 2, green dots), and
  - Collect no more than 5 juvenile lobster collected per site per year from within the Great Barrier Reef Marine Park Zone.

Site survey

Using a portable Garmin GPS, the CSIRO TRL Dive Team accurately located the pre-determined 82 survey sites. At each site, divers employed the standard 2000m2 belt transect method (2 divers per site each scanning 2m by 500m) with transect distance measured to the nearest metre using a Chainman® device.

Divers swam along the 500m transect, counting TRL by age-class and collecting specimens where possible. At the completion of each transect, divers recorded:

- The number and age-class of lobsters observed, but not collected;
- The number of lobsters collected per age-class;

- The size (tail width in mm), sex and moult stage of the collected lobsters;
- Maximum depth;
- Visibility; and
- Distance and direction swum from site co-ordinate.

In addition, species of interest were counted, and the seabed habitat characterised. Species of interest include the pearl oyster (Pinctada maxima), crown-of-thorns starfish and holothurian species. While seabed habitat composition (percent cover of sand/mud, hard substrate (consolidated rubble or limestone pavement), seagrass or algae) was estimated. The presence of bleached coral was also noted, where applicable.

Data analysis

Upon completion of the dives, the data were entered into the project's Microsoft Access database and verified for accuracy. Post survey data analyses are undertaken using R statistical analyses software, or similar to calculate the abundance indices for each lobster age-class. The output of the results is discussed below. The TRL abundance data are also used as an input to calculate the Recommended Biological Catch. The outcomes of those analyses are documented within the CSIRO Torres Strait Rock Lobster (TRL) 2018 Stock Assessment report.

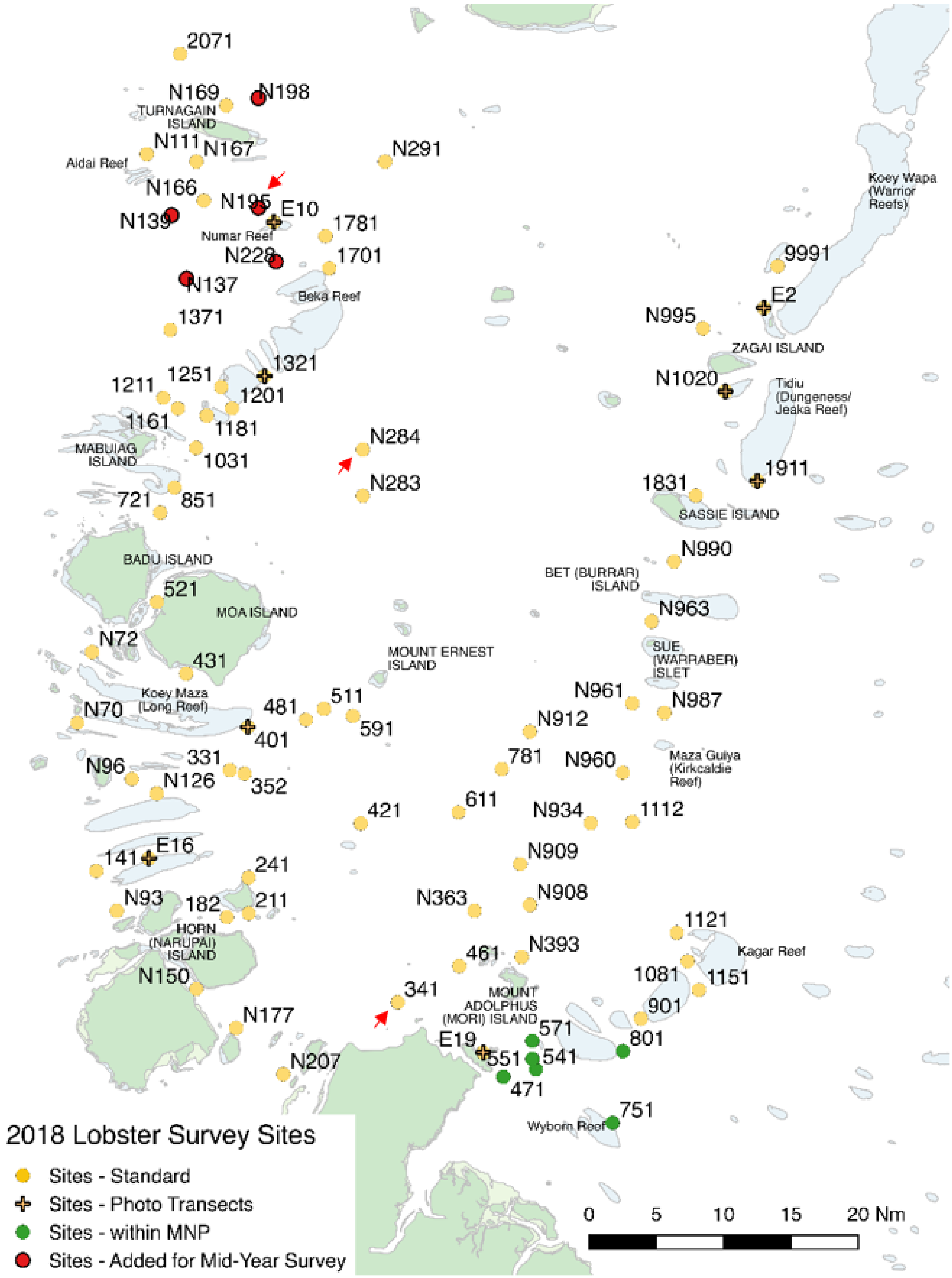


Figure 6-2. Map of western Torres Strait showing sites surveyed during the 2018 TRL pre-season survey. The 5 additional sites surveyed are included in red (north-western region). Sites where coral monitoring photo-transects were conducted in 2015-2018 are marked with +. Sites in green represent those which are in the Great Barrier Reef Marine Park Zone and red arrows indicate sites with and observed sand incursion.

6.3 TRL Results

A total of 306 TRL were observed and categorised into age-classes over the survey period. The age-classes were defined as: recently-settled (Age 0+), recruiting (Age 1+) and fished (Age 2+). Of the 306 TRL observed, 171 were collected, measured (TW) and their moult stage and sex determined. With respect to total numbers per age-class the following was recorded:

- Recently-settled - 0+ (66);
- Recruiting - 1+ (234);
- Fished - 2+ (6).

The number of recently-settled lobsters observed in 2018 (66) was considerably higher than the 19 observed in the 2017 pre-season survey and was more like the numbers observed in 2015 (82) and 2016 (89). Similarly, recruiting lobster numbers (234) were considerably higher compared to 2017 (138) and 2016 (148) pre-season surveys. As expected, fished (2+) lobsters were rarely observed, as most of these lobsters have been shown to emigrate from Torres Strait during August/September to undertake the breeding migration.

Total Lobster Counts per Site

A plot of the total counts of lobster at each of the 2018 pre-season survey sites illustrates the abundance and high variability of lobster observed across the survey area (Figure 6-3). The greatest abundance of lobsters was observed at sites in the western region, particularly at sites south of Long Reef, from north to east of Mabuiag and north-west of Turnagain Island.

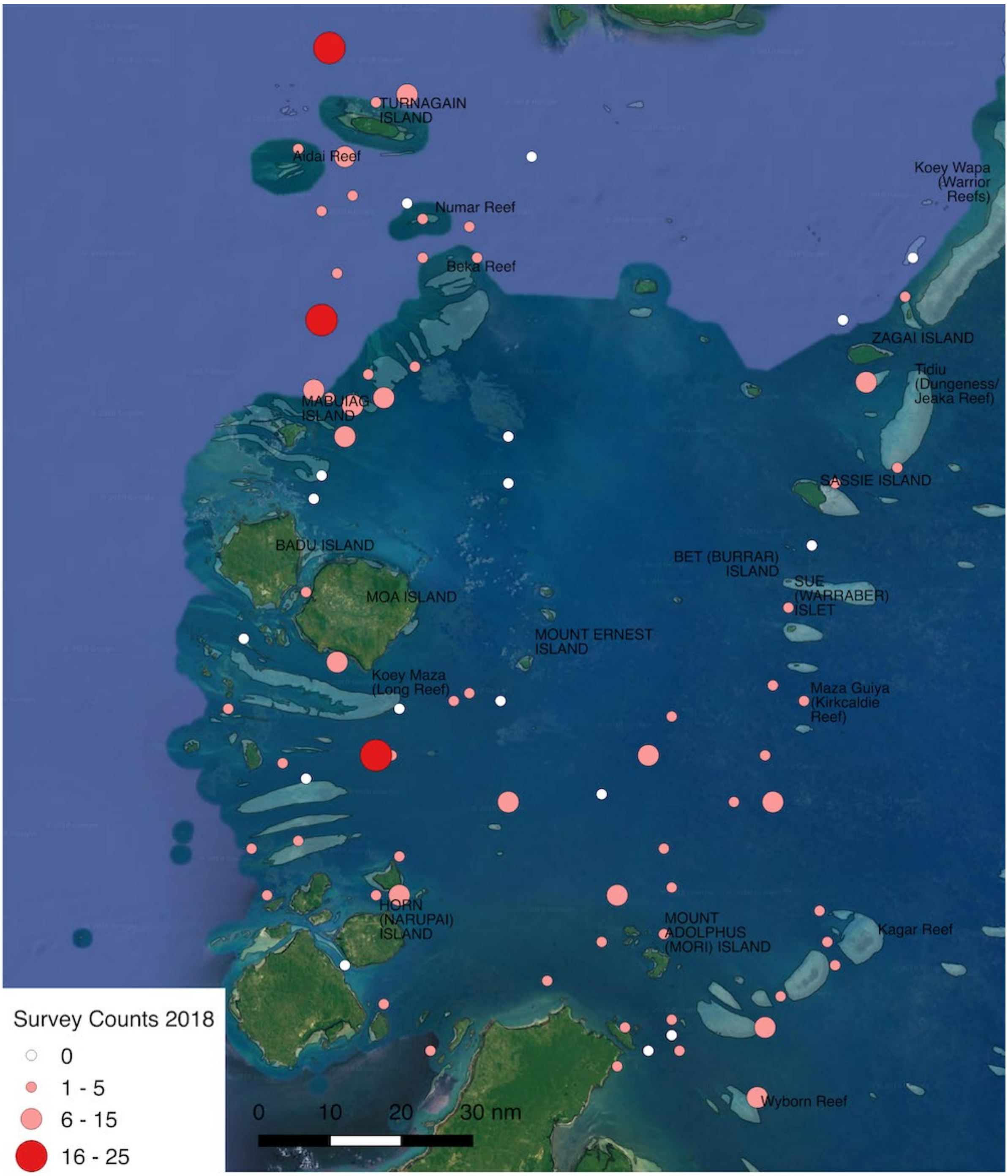


Figure 6-3. Total counts of tropical rock lobsters (Panulirus ornatus) at each site for the 2018 pre-season survey. The counts represent a sum of all age-classes.

Abundance Indices

As the 2015 to 2018 pre-season surveys involved a reduced number of transects (73-77) from previous surveys (>128 for 2005-2014)), four alternative methods were used to calculate annual indices of abundance between 2005 and 2018. The four index options are described in Table 6.1 below. This enabled an assessment of the likely impact of the reduced sampling on accuracy and precision of the indices. This is demonstrated by the general increased precision of the abundance indices generated using 'All Sites' in comparison to the 'Mid-Year Only' (MYO-Sites) indices for the years 2005-2008 (Figure 6-5). As seen in Table 6.2, between 2005-2018 there is a substantial decrease in the number of transects included in the calculation of the four abundance indices. The recruiting lobster index of relative abundance was calculated after applying an area weighting factor. The same approach was used for the recently-settled lobster index.

Table 6-1. Description of the four options used to estimate ornate rock lobster (*Panulirus ornatus*) abundance indices from pre-season population surveys conducted in Torres Strait between 2005 and 2018.

Pre-season Index Option	Number of Strata	Description
1a. All sites	7	All transects for all years utilised
1b. All sites, excluding Buru	6	All transects for all years utilised, excluding those from the Buru stratum
2a. Mid-year only sites	7	All mid-year transects (76) utilised
2b. Mid-year only sites-common across all years	6	All common transects utilised; equal number in each year

Table 6-2. Number of transects included in the calculation of each of the four abundance indices during each survey year.

	sites All	All sites, excl. Buru	MYO sites	MYO sites -common
Year	**1a**	**1b**	**2a**	**2b**
2005	153	142	71	64
2006	143	132	74	64
2007	150	148	75	64
2008	147	137	76	64
2014	129	125	75	64
2015	73	70	73	64
2016	73	70	73	64
2017	74	71	74	64
2018	77	74	76	64

The 'Mid Year Only' (MYO sites) abundance index is used as the primary index in the 2018 TRL stock assessment and is based on sampling of 76 MYO transects (i.e. Table 6.1, Index 2a). To determine the impact of including the additional 5 sites (in the north-western region of the fishery), the 'MYO (82)' index was also calculated (Figure 6-4). When comparing the two indices, the MYO site index yields a slightly higher index for 2018 pre-season survey than the MYO-82 site index. This is consistent with indices comparisons reported for the 2018 Midyear survey (not reported here). The 5 additional sites were added in response to stakeholder concerns as to whether the index was biased due to not adequately sampling a localised area that was considered to have high catches. However, the addition of these sites did not significantly alter the abundance index and hence this addressed the specific question the additional sites were included to address. The TRLRAG decided not to continue including these sites as a default approach given that a more statistically defensible approach to extending the survey is preferred to an ad hoc approach.

Recruiting 1+ lobster abundance

By comparing the recruiting lobster indices through time, high annual variability in recruitment is observed. In 2017, the lowest abundance index was recorded since the commencement of pre-season surveys in 2005. In contrast, the 2018 index has increased significantly relative to 2017, recording the second highest index in the last 9 pre-season surveys. The 2018 index for recruiting lobster is approximately three times greater than the index recorded for 2017. However, the standard error of the 2018 index indicates that the number of lobsters observed between sites was highly variable (Figures 6.4 and 6.5).

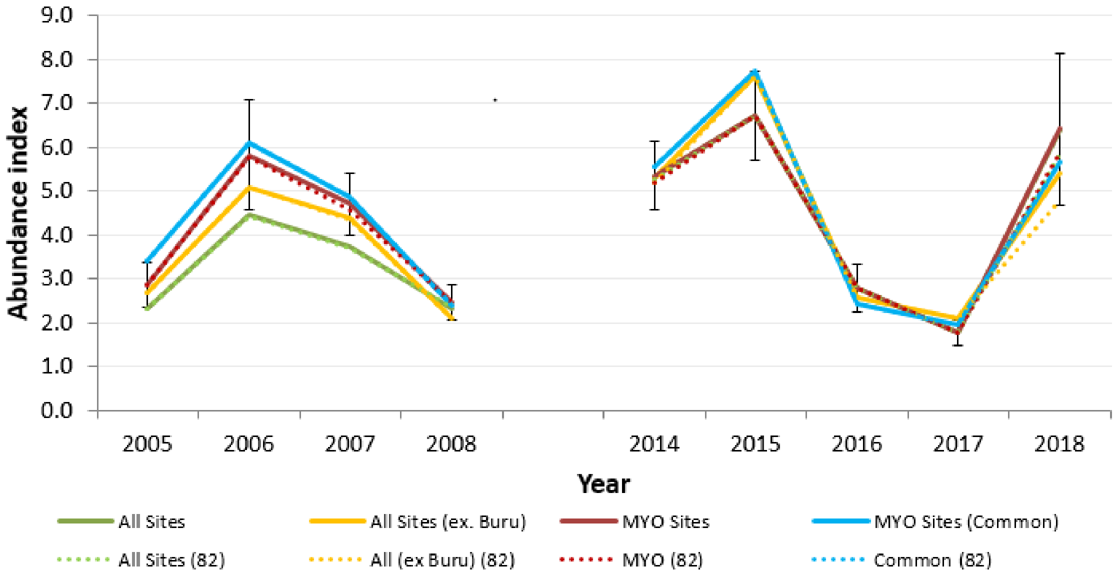


Figure 6-4. Abundance indices of recruiting 1+ ornate rock lobsters (Panulirus ornatus) recorded during pre-season surveys in Torres Strait between 2005 and 2018. The data represents abundance indices for all sites as well as reduced series including Midyear-Only Sites (MYO). Error bars of MYO indices represent standard errors. (Note: pre-season surveys were not conducted between 2009-2013, inclusive).

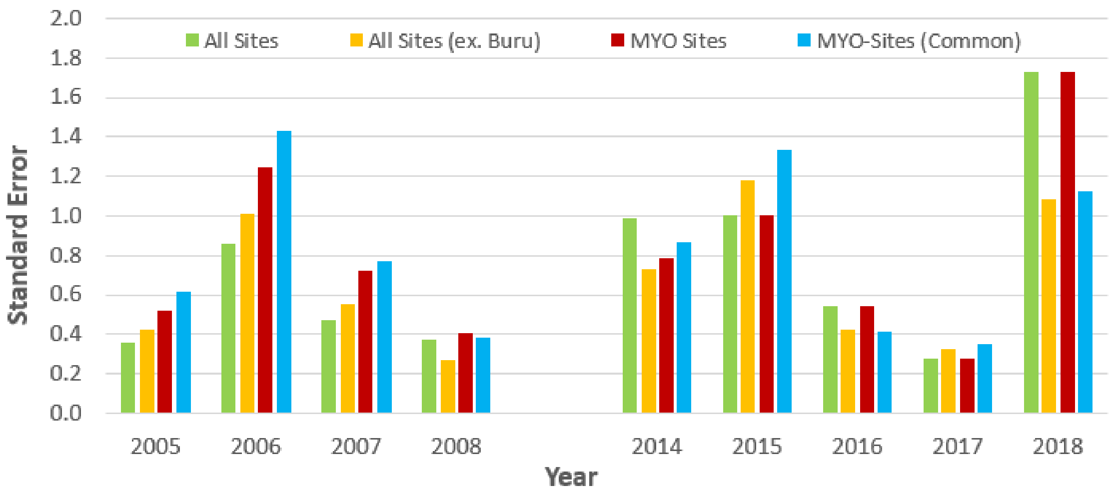


Figure 6-5. Comparative standard errors for four indices of abundance of recruiting 1+ ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2018 (Note: surveys were not conducted between 2009-2013, inclusive).

Recently-settled 0+ lobster abundance

Like the recruiting lobster index, the recently-settled lobster index increased from a record low in 2017 (Figure 6-6). While the 2018 index was lower than average it was not significantly different from indices recorded in 2006, 2007, 2015 and 2016. The comparative standard errors for the four indices are shown (Figure 6-7).

Figure 6-6. Abundance indices of recently-settled 0+ ornate rock lobsters (Panulirus ornatus) recorded during pre-season surveys in Torres Strait between 2005 and 2018. The data represents abundance indices for all sites as well as a subset including Midyear-Only Sites (MYO). Error bars represent the standard error for MYO indices. Note: pre-season surveys were not conducted between 2009-2013, inclusive.

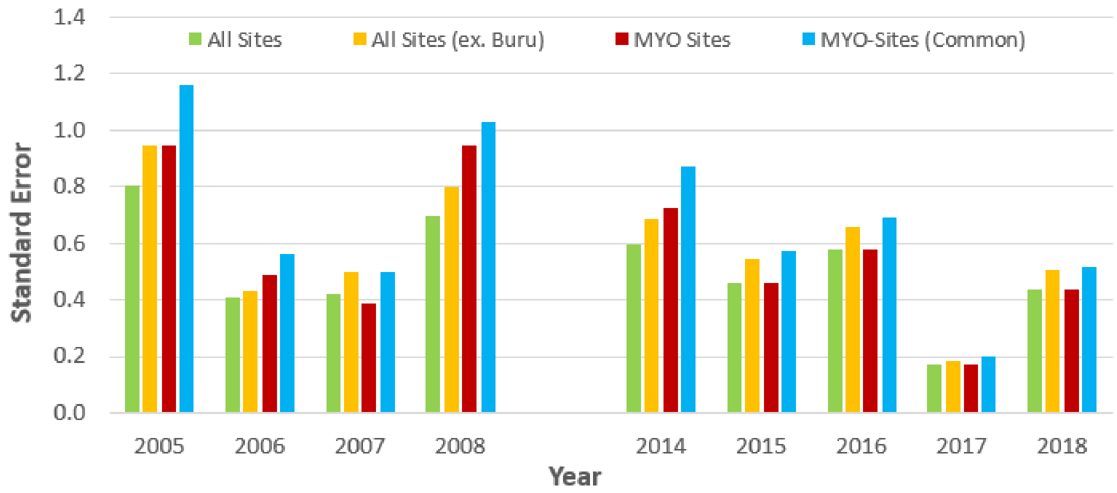


Figure 6-7. Comparative standard errors for four indices of abundance of recently-settled 0+ ornate rock lobsters (*Panulirus ornatus*) recorded during pre-season surveys in Torres Strait between 2005 and 2018 (Note: surveys were not conducted between 2009-2013, inclusive).

Lobster Distribution

Recruiting 1+ lobster distribution

The 2018 abundance of recruiting lobster was observed to be higher and more consistent across the survey area in comparison with 2016 and 2017 (Figure 6-6). Abundance was observed to be highest in the western regions, particularly at sites north of Twin Island, south of Long Reef, east of and on adjacent reefs north of Mabuiag, Dabangai Deeps and north-west of Turnagain Island. In comparison to 2017, the 2018 lobster counts were lower in the south-eastern region.

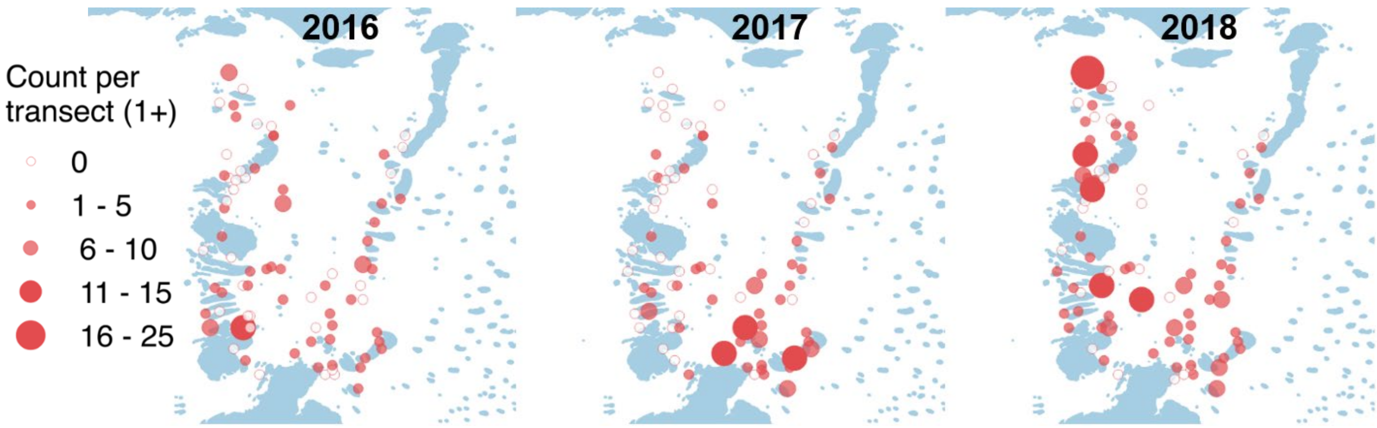


Figure 6-8. Total counts of recruiting 1+ ornate rock lobsters (Panulirus ornatus) recorded in each sampling site for the 2018 pre-season survey.

The abundance index for recruiting lobster for each stratum, indicates that recruitment to the fishery is widespread and consistent across most stratums (Figure 6-9). Buru and Mabuiag recorded the highest levels of recruitment, while Warraber Bridge reported the lowest. However, the large standard error for Buru indicates that the number of lobsters recorded at sites within this stratum were highly variable.

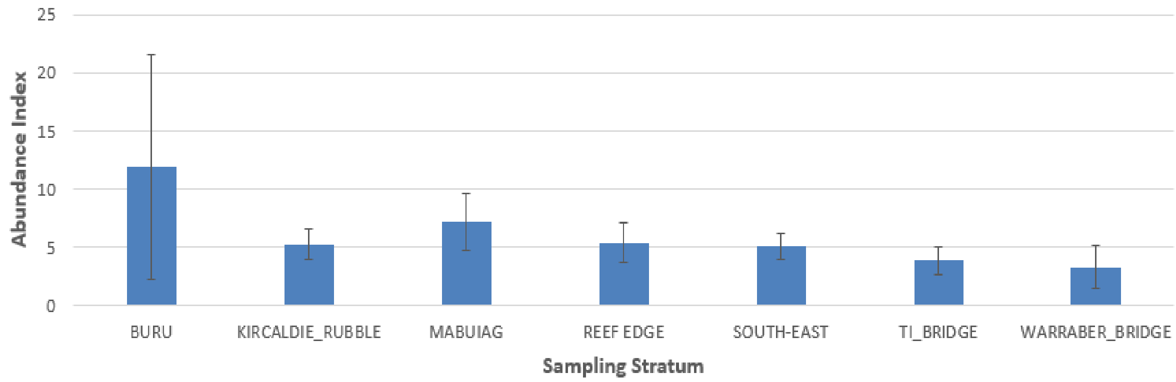


Figure 6-9. Abundance indices of recruiting 1+ ornate rock lobsters (Panulirus ornatus) recorded for each stratum for the 2018 pre-season survey.

A comparison of the recruiting lobster abundance indices for each stratum over the last 9 surveys indicates that Buru and Mabuiag have recorded their highest indices in 2018, with a large increase for Buru (Figure 6-10). The remaining stratums recorded average indices except for Warraber Bridge which indicates below average recruitment.

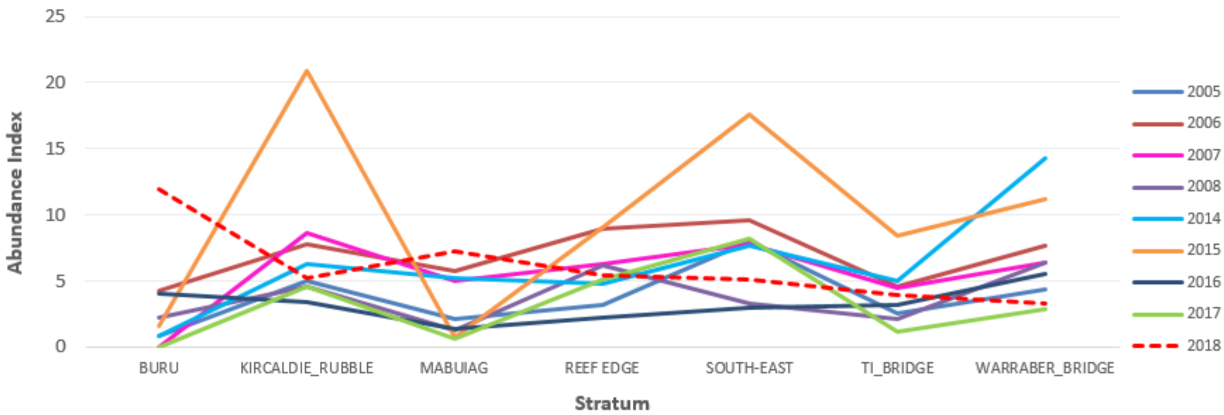


Figure 6-10. Abundance indices of recruiting 1+ ornate rock lobsters (Panulirus ornatus) recorded for each sampling stratum during pre-season surveys in Torres Strait between 2005 and 2018. (Note: Pre-season surveys were not conducted between 2009-2013, inclusive).

Recently-settled 0+ lobster distribution

In 2018, recently-settled lobster recruited mostly to western Torres Strait with the largest site counts observed in the north-western region between Mabuiag and north of Turnagain Island

(Figure 6-11). This general pattern of recruitment was like 2016, however there was less recruitment near Turnagain Island and more at sites in the south-western region compared to 2018. In contrast, 2017 was an anomalous year where low abundance of the recently-settled lobster were identified in limited areas of the south-eastern and north-western regions only. Further, there was little to no settlement of lobster outside of these regions.

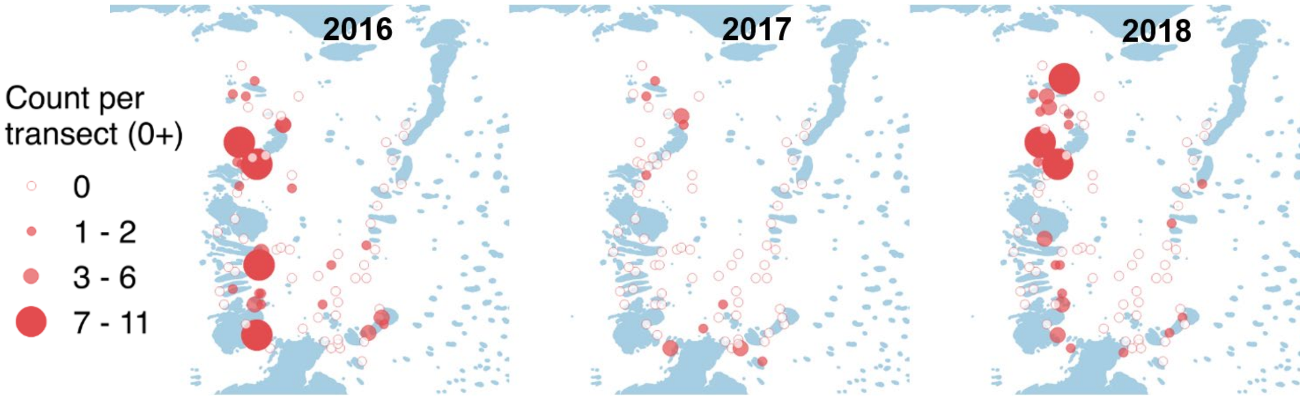


Figure 6-11. Total counts of recently-settled 0+ ornate rock lobsters (Panulirus ornatus) recorded at each sampling site for the 2018 pre-season survey.

The abundance index for recently-settled lobster for each stratum, indicates that recruitment is highest in the western regions and lowest in the eastern regions of the survey area (Figure 6.12). Mabuiag and TI Bridge recorded the highest indices.

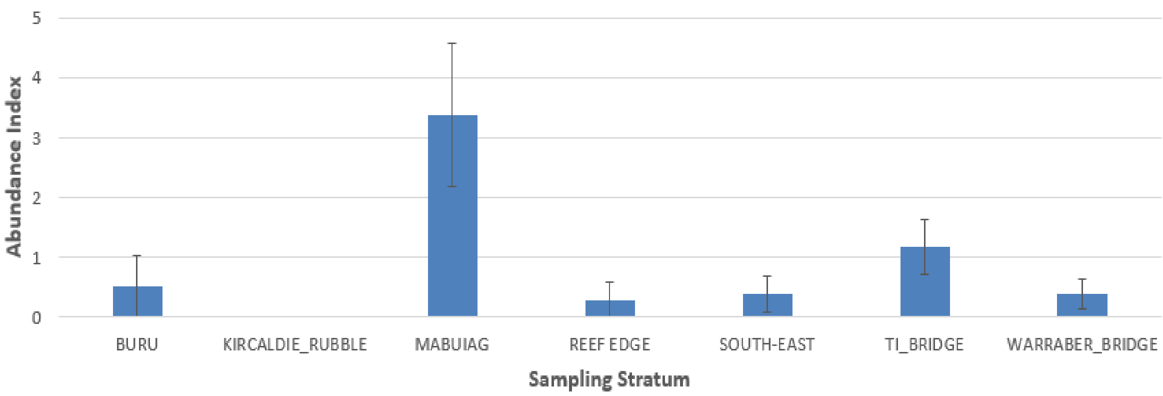


Figure 6-12. Abundance indices of recently-settled 0+ ornate rock lobsters (Panulirus ornatus) recorded for each sampling stratum for the 2018 pre-season survey.

Recently-settled lobster abundance indices were highest at Mabuiag and TI Bridge stratums and lowest at Kircaldie, Reef Edge, South East and Warraber Bridge (Figure 6-13). When comparing indices over the last 9 surveys, 2018 indices for each stratum are relatively low.

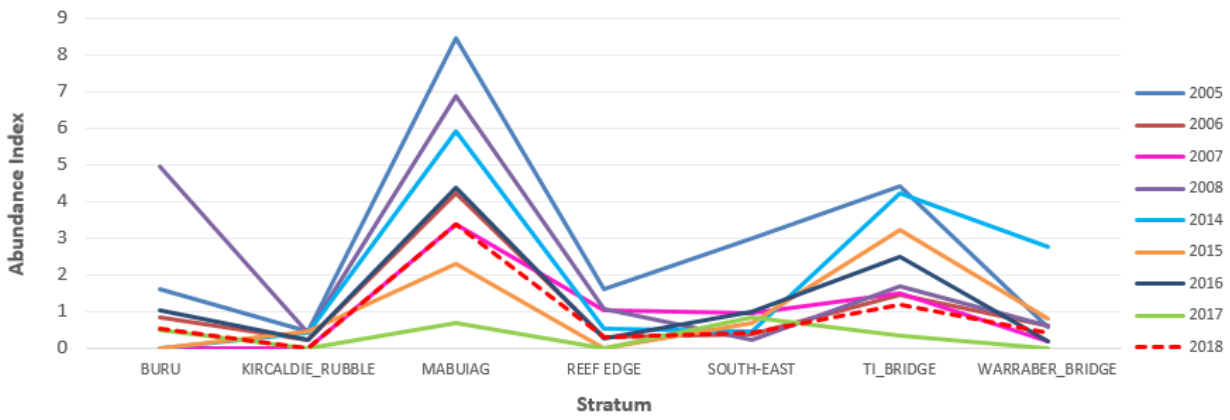


Figure 6-13. Abundance indices of recruiting 0+ ornate rock lobsters (Panulirus ornatus) recorded for each sampling stratum during pre-season surveys in Torres Strait between 2005 and 2018 (Note: pre-season surveys were not conducted during 2009-2013).

Length frequency data

The size distribution of lobsters sampled during the 2018 pre-season survey was like previous surveys as it was comprised mostly of recruiting lobsters. Since 2005 the modal size of recruiting lobsters had been generally decreasing, however the modal size in 2018 increased and was like size data collected in 2005 (Figure 6-14). A greater proportion of legal sized recruiting lobster contributed to the 2018 survey sample in comparison with other pre-season surveys.

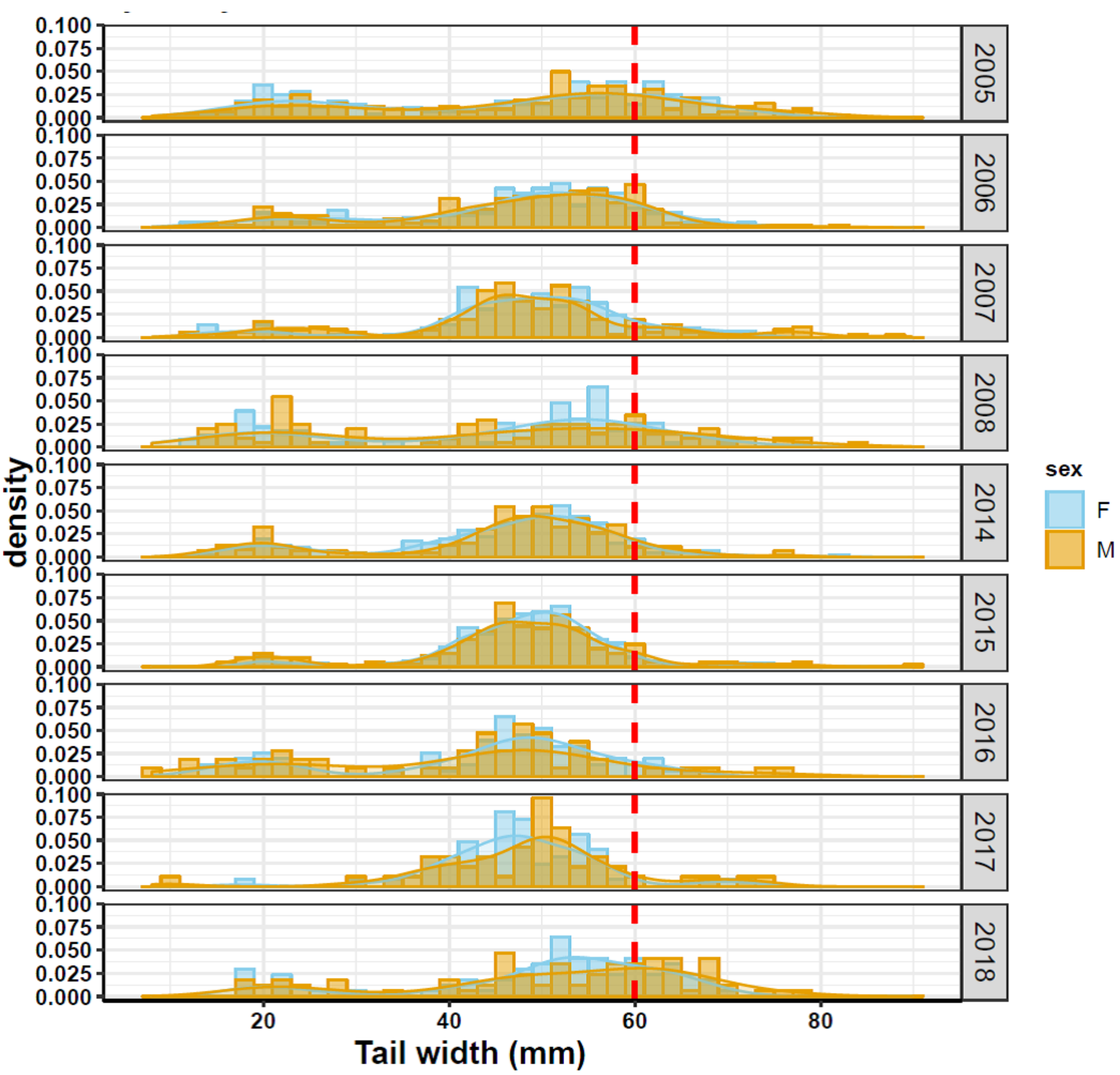


Figure 6-14. Length frequency distributions of all age-class lobster (Panulirus ornatus) sampled during pre-season population surveys in Torres Strait in 2005-2008, 2014-2018. The dotted line represents legal size (90mm CL ≈ 60 mm tail width).

6.4 Long-term Torres Strait Seabed Habitat Monitoring

In conjunction with lobster abundance, seabed habitat data are also collected during TRL surveys. Initially, data were collected during Midyear surveys (1994-2014) and habitat data collection continued at the commencement of pre-season surveys in 2005. Habitat information including percentage cover of substrate types (sand/mud, rubble, hard substrates and coral) and biota (seagrass and algae) are noted and trends explored. A change to the number of pre-season survey sites occurred in 2015. As such, data pre-2015 is representative of ~130 sites, while the 2015-2018 surveys are representative of ~75 sites. In addition, in 2006 and 2007 additional sites were surveyed in Papua New Guinea which have not been repeated in recent surveys. Data recorded during Midyear surveys (1994-2014) have provided the longest time series to identify habitat trends throughout the survey area.

Historical trends in habitat composition

Midyear survey seabed habitat composition (1994-2014)

A comparison of the mean percent cover for various seabed habitat categories through time (Figure 6-15) has identified the following:

- Sand/mud substrates remained relatively consistent (Mean 56%);
- Rubble composition has declined (Mean 13%);
- Hard substrates (including consolidated rubble and limestone pavement has increased (Mean 29%));
- Algal cover has decreased (mean ~20% to ~10%);
- Following a die-back of seagrass circa 2000, seagrass cover had increased between 2000-2010; and
- A coral bleaching event was recorded in 2010.

Pre-season survey seabed habitat composition (2005-2008 and 2014, survey sites ~130)

At the commencement of pre-season surveys in 2005, seabed habitat data continued to be recorded using the same method established for Midyear surveys. A comparison of the mean percentage cover of seabed habitat categories between 2005-2008 and 2014 (Figure 6-16) indicated the following trends:

- Algal cover remained consistent;
- Live coral cover remained consistent between 2005-2008, however dropped to lower levels in 2014;
- Sand cover remained consistent;
- Seagrass cover had been relatively consistent, however lower levels were recorded in 2006 and 2014; and
- No coral bleaching events were recorded.

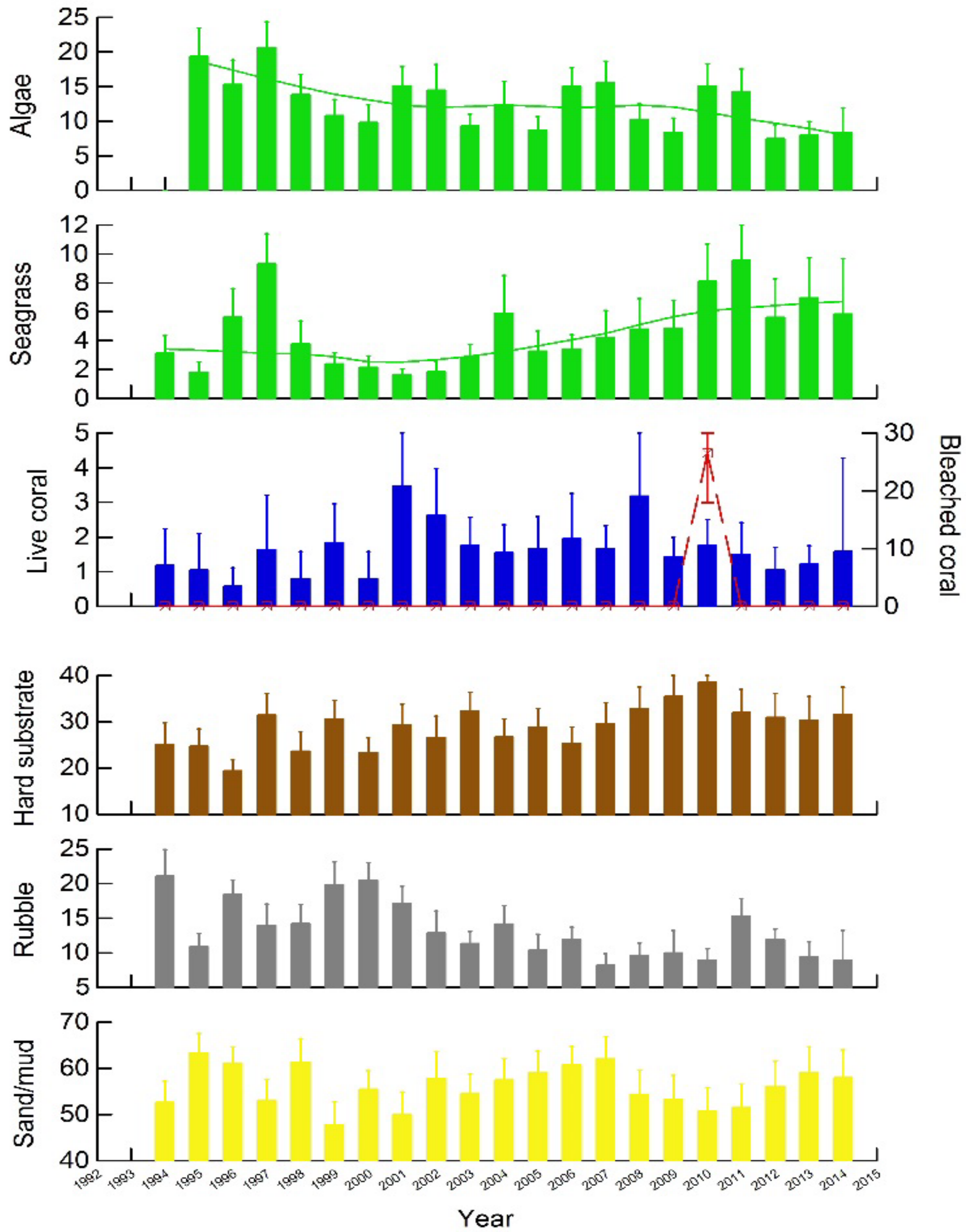


Figure 6-15. Mean percent covers of abiotic and biotic categories recorded during mid-year population surveys in Torres Strait between 1994 to 2014, inclusive. Red dashed line for the live coral plot represents percentage bleached coral. Standard errors are shown.

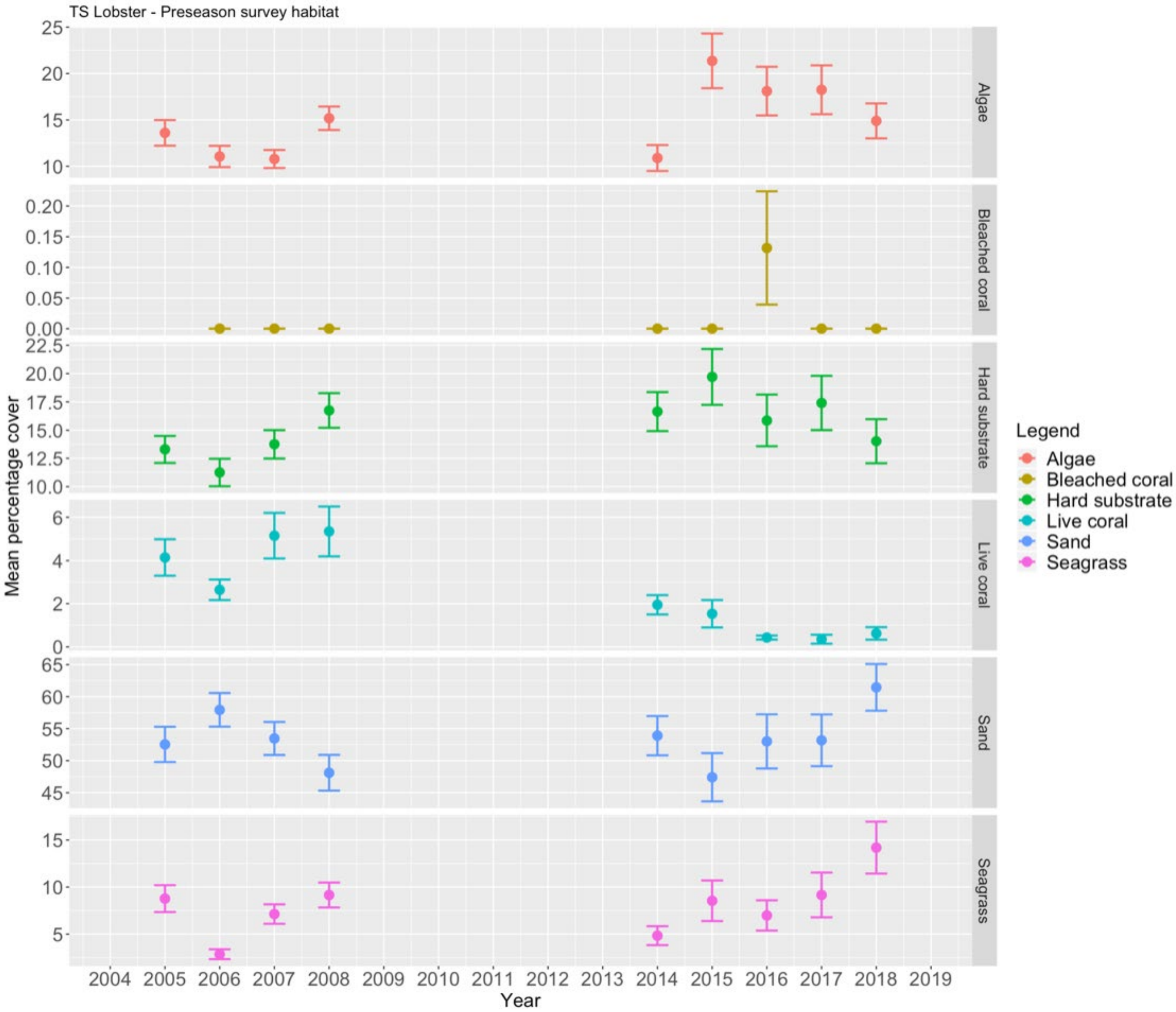


Figure 6-16. Mean percent covers of abiotic and biotic categories recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2018. Standard errors are shown.

Recent trends in habitat composition

Pre-season survey seabed habitat composition (2015-2018, survey sites ~75)

A comparison of the mean percent cover for various seabed habitat categories over the last four-pre-season surveys (Figure 6-16) indicates the following trends:

- Algae cover remains consistent;
- Live coral cover is consistently low; a coral bleaching event was recorded in 2016;
- Sand and seagrass cover were consistent between 2015 and 2017, however in 2018 both recorded an increase; and
- Hard substrate cover (combined consolidated rubble and limestone pavement) remains consistent.

Habitat distribution through time (2005-2018)

Sand

The general distribution of sand within the survey area appears to be relatively consistent through time when accounting for differences in the number of survey sites sampled (Figure 6-17). In 2018, evidence of a slight increase in sand cover between Thursday Island and Moa/Badu was observed, which corresponds with a slight reduction in hard substrates within the same region. In addition, increases in sand cover were also observed in the north-western region between Mabuiag and Turnagain Islands. However, this may be an artefact of the additional five survey sites in these regions in 2018 which generally had high percentages of sand cover (50-80%).

Due to strong tidal flows there have been localised incursions of sand, as reported on transects from previous surveys. Sand incursions (sand that has moved over established habitat) were observed at three sites during the 2018 pre-season survey (N284, N195, 341; identified by red arrows in Figure 6-2). Anecdotal reports of substantial sand incursions by fishers are not always detected in overall survey results because these events con 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 6-16).

Hard substrate (combined consolidated rubble and limestone pavement)

Like the trends identified for sand, the general distribution of hard substrate over the survey area appears to be relatively consistent through time once differences in the number of survey sites has been accounted for (Figure 6-18). In 2018, evidence of a slight reduction of hard substrate between Thursday Island and Moa/Badu has been noted, which corresponds with a slight increase in sand within the same region.

Seagrass

In contrast to sand and hard substrates, the distribution of seagrass through time has been more variable (Figure 6-19). In 2006 and 2014, a reduction in mean percent cover (Figure 6-16) was observed and reflected in the distribution plots (Figure 6-19). Since 2014, the percent cover has been observed to be increasing (recovering). The levels of seagrass at sites in the north-western region (between Mabuiag and Turnagain Islands) have increased significantly. In 2015, majority of sites in this region had a maximum of 10% seagrass cover, while in 2018 similar sites have recorded seagrass cover between 50% to 80%.

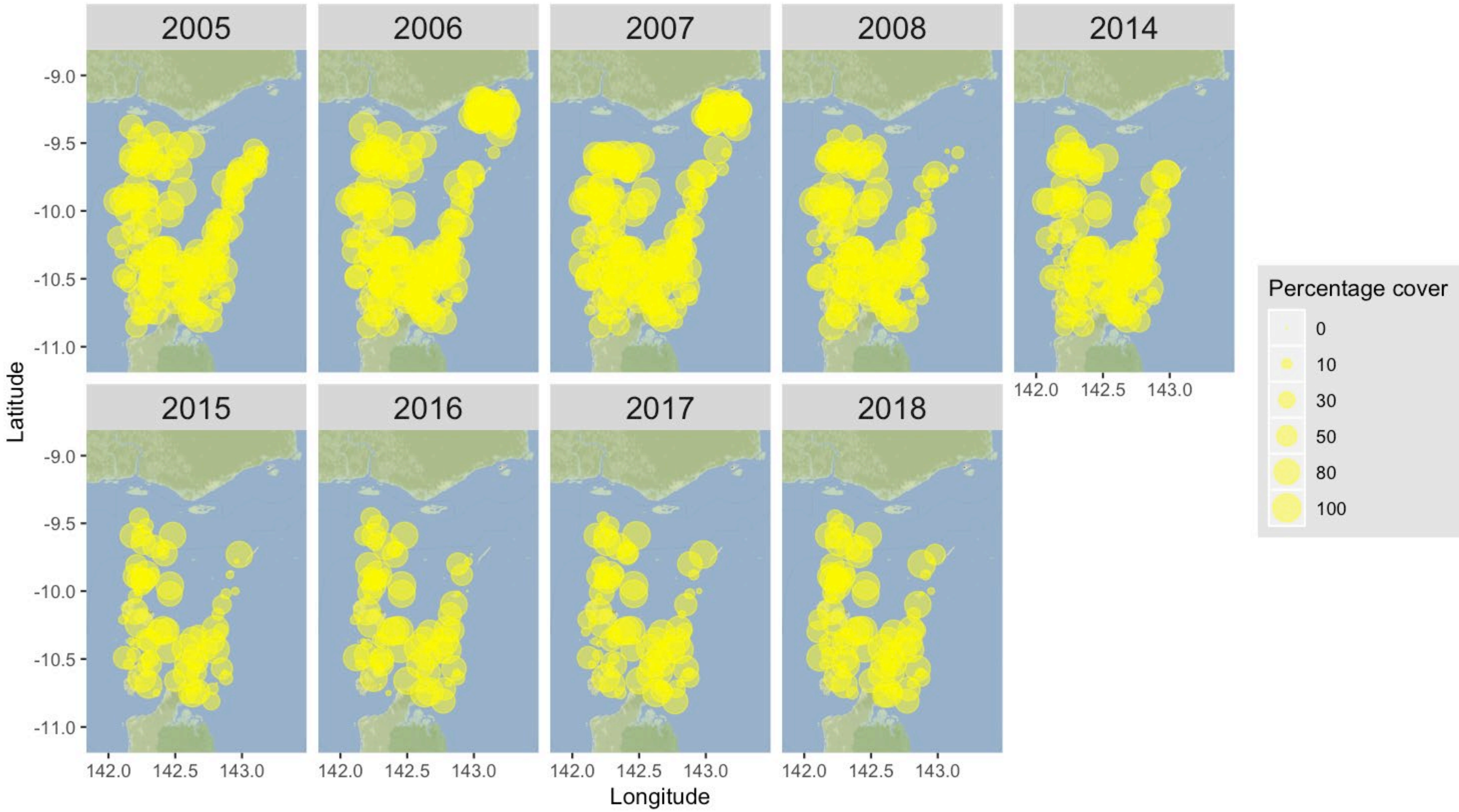


Figure 6-17. Percent cover of sand recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2018. Note: 2005-2014 (~130 sites surveyed); 2015-2018 (~75 sites surveyed).

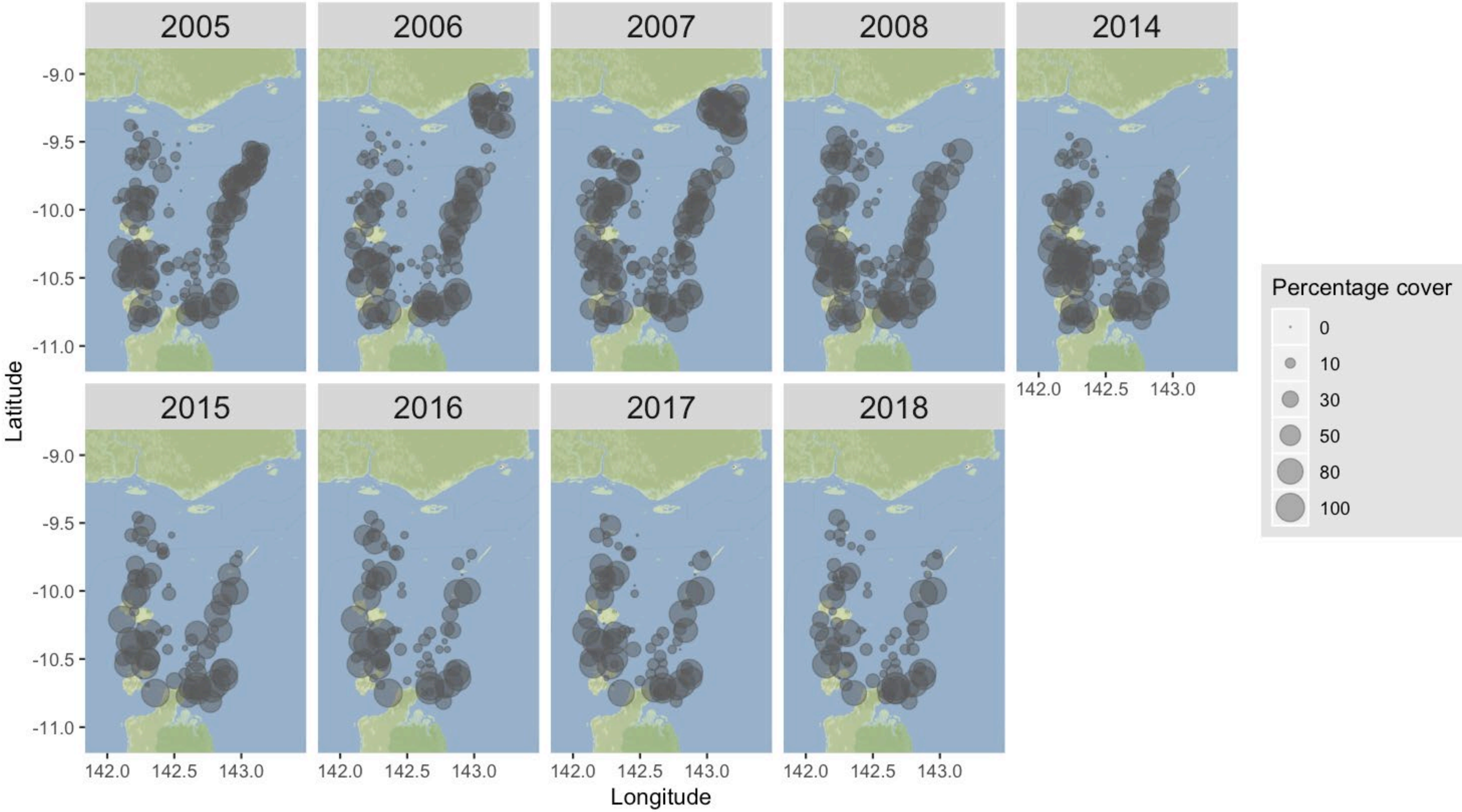


Figure 6-18. Percent cover of hard substrate (consolidated rubble and limestone pavement rock) recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2018. Note: 2005-2014 (~130 sites surveyed); 2015-2018 (~75 sites surveyed).

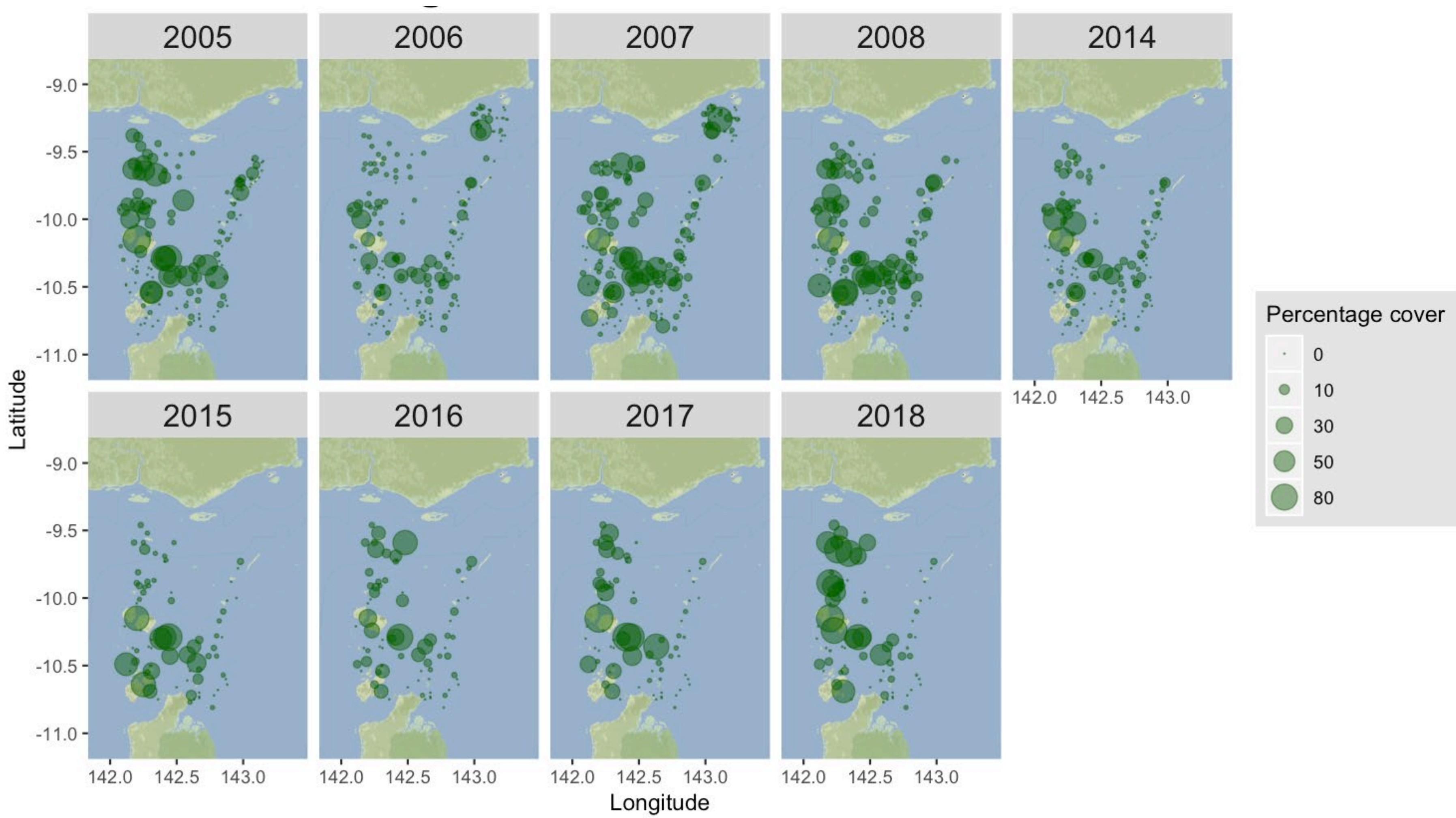


Figure 6-19. Percent cover of seagrass recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2018. Note: 2005-2014 (~130 sites surveyed); 2015-2018 (~75 sites surveyed).

6.5 Discussion

Annual pre-season dive surveys of *Panulirus ornatus* (Ornate or Tropical Rock Lobster (TRL)) within a defined region of the Torres Strait are used to inform the Recommended Biological Catch (RBC) for the prospective fishing season. Between 11th and 23rd November, the 2018 TRL Pre-season Population Survey was conducted at 82 pre-determined sites. The mothership "Wild Blue" (Rob Benn Holdings Pty Ltd) and a 5 metre CSIRO naiad supported CSIRO divers in undertaking the survey. Lobster abundance, size and seabed habitat information was collected for each of the survey sites. The lobster abundance data were used to calculate age-class abundance indices for input to the TRL stock assessment. In 2017, the lowest abundance index yet for recruiting and recently-settled lobster was recorded over all years since 2005 (last 9 surveys). In 2018, the results from the pre-season survey indicated that lobster abundance had improved significantly across the survey region and the outlook for the 2019 fishing season was considerably more optimistic.

In 2017, very low abundance indices were reported for recently-settled (0+) and recruiting lobster (1+) age-classes. It was hypothesised that environmental conditions were likely to have affected the timing and distribution of lobster settlement and recruitment, which may have biased survey results. Historically, recently-settled lobsters are typically found along the western regions of the survey area during November, however in 2017 this trend was not observed. Instead, low abundances of the recently-settled lobster were identified in limited areas of the southern and north-western regions only. Further, there was little to no settlement of lobster observed outside of these regions.

In 2018, recently-settled (0+) lobster abundance and distribution was observed to be more like most pre-season surveys with settlement occurring along most of the western regions of the survey area. This suggests there may have been a return to more typical environmental conditions influencing larval distribution and settlement.

Recruiting (1+) lobster abundance observed during the 2018 pre-season survey was widespread and relatively consistent across most of the survey stratums (regions). Recruitment and abundance indices however were highest in Buru and Mabuiag (north-western region of the survey area). The Northern Region (AFMA catch reporting sector) which includes Buru also produced the greatest lobster catch (kg) for the 2017 fishing season (Chapter 1).

There was an observed increase in the modal size (tail width) of sampled lobster collected during the 2018 pre-season survey compared to previous surveys where the modal size had been generally decreasing since 2005. A possible explanation for this could be an effect of density-dependent interactions between age-classes. Skewes et al. (1997) suggested that temporal differences at size-at-age could be related to density dependent interactions because of the significant inverse relationship between size and abundance. Such relationships have been suggested for other lobster species, such as *Panulirus cygnus* and *P. marginatus*, where higher abundances increase competition for food and shelter therefore potentially slowing growth. In contrast, the low abundance of recruiting (1+) lobster observed in the 2017 pre-season survey may have resulted in reduced competition for resources (habitat and food) for the 2018 recruiting lobster cohort, therefore allowing for faster growth rates.

In conjunction with recording lobster abundance and size/age structure, seabed habitat information is also collected during TRL dive surveys where percent cover is recorded at each site for the various substrate types. Generally, the overall distribution of most seabed habitats has remained reasonably consistent since 2005, particularly for hard substrates and sand cover, although localised variations in habitat composition have been observed. In 2018, there is evidence of a slight increase in sand cover on the western region of the survey area from Thursday Island up to Turnagain Island, with a corresponding slight reduction in hard substrates within the same region. Sand incursions were observed at three survey sites in 2018 and likely represent a temporary loss of habitat or displacement of lobster from these local areas. In 2018, a notable increase in seagrass cover in the north-west region between Mabuiag and Turnagain Island is the most notable regional change in habitat from 2017. This is supported by anecdotal reports from fishers in early 2018, who indicated that the biota (including seagrass and associated fauna such as echinoderms etc.) in this region had recovered significantly and suggested that lobster abundance had increased here because of increased food availability. This trophic relationship was also discussed by Skewes et al. (1997) who suggested that along with increases in seagrass there is generally an increase in the productivity of the epibenthos by providing food and shelter for small molluscs and crustaceans that lobsters eat.

6.6 Conclusion

The 2018 TRL pre-season survey results suggest a considerable increase in stock size for recruiting lobster compared to 2017 which was particularly low. The recruiting lobster abundance index is a key input to the stock assessment model (and the empirical Harvest Control Rule if implemented), and hence the Recommended Biological Catch prediction for the 2019 season is more optimistic than 2018.

Chapter 7 Mid- and Pre-season surveys – Summary of observed and modelled size (tail width) distributions

Judy Upston, Éva Plagányi, Mark Tonks, Tim Skewes, Kinam Salee, Frank Coman, Nicole Murphy, Rob Campbell, Mick Haywood, Roy Deng, Trevor Hutton

7.1 Summary

This chapter comprises a summary of observed and modelled size (tail width) distributions for Torres Strait tropical rock lobsters based on observations from independent research surveys during the Mid-Season (June/ July) and Pre-season (November/ December), with emphasis on 2018 and recent survey years. The paper provides a reference set of summary statistics and plots to support discussion by the TRL Research Advisory Group, as necessary.

A summary of the size distribution of lobsters from commercial catches is presented in Appendix E.

7.2 Methods

The research survey methods are outlined in Chapters 5 and 6 of this report. The data summary in Table 7-1 and plots of TS lobster tail width density distributions were produced using R statistical software R Vers. 3.5.1 (R Development Core Team, 2018).

The mixture model analyses to identify component size distributions (possible cohorts, Figure 7-6, 7-7) were done using the R package 'mixtools' (Young et al. 2017). We assumed a normal distribution (the model was not improved by applying a semiparametric EM algorithm for a univariate symmetric location mixture). Starting values for lambda (initial value of mixing proportions), mu (vector of component means) and sigma (vector of component standard deviations) were specified at the mean values after running a normal mixture model without these values specified (see Young et al. 2017 for assumed distributions where values for lambda, mu, sigma are NULL).

7.3 Results

The number of TS rock lobsters observed and measured each survey and year, by area and location, are reported in Table 7-1.

Figure 7-1 shows density distributions of TS rock lobster tail width, by sex and years (since 2004), sampled in Mid- and Pre-season surveys (plots are shown on the one page to enable comparison across surveys, as appropriate).

Figures 7-2 shows density distributions of TS rock lobster tail width, by sex and years, for Pre-season surveys.

Figures 7-3 and 7-4 show density distributions of TS rock lobster tail width, by sex and years, for Mid-season surveys, for 1989 to 2000 and for years since 2000 respectively.

Figure 7-5 is a ridge plot showing TS rock lobster tail width density distributions for combined sexes, each year surveyed in Mid-season since 1989. As a visual guide to assist with comparison of distributions across years, dashed lines indicating minimum legal size and nominal 40 mm tail width (estimated mean TW for 1+ cohort in Mid-season) are displayed.

Figure 7-6 shows histograms and normal component density distributions of TS rock lobster tail width (cohorts on average across all survey years) for Mid- and Pre-season surveys.

Figures 7-7a and 7-7b show histogram and normal component density distribution of TS rock lobster tail width and mean estimates for recent years, for Mid-season and Pre-season surveys respectively.

Figures 7-8 and 7-9 are for diagnostic purposes only (i.e. used primarily for broad checks of the data) as the survey design does not include a hierarchy based on areas (north, south) or zones (1 to 4). The respective plots shows density distribution of TS rock lobster tail width by sex, areas, years, and by sex, zone.

Further diagnostic plots are shown in Appendix D.

Table 7-1. Number of TS rock lobsters (n_lob) observed and measured each Survey and Year, by area (n_lob_North,…South). The number of locations (sites) at which lobsters were observed and measured (loc_lob_obs) and total locations surveyed (loc_surveyed) are indicated.

Year	Survey	n_lob	Ratio_MF	n_lob_North	n_lob_South	loc_lob_obs	loc_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	0.90	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	0.88	286	213	94	158
2004	Mid	340	0.88	123	217	77	117
2005	Mid	232	0.86	72	160	54	86
2005	Pre	302	1.14	100	202	84	154
2006	Mid	303	1.16	68	235	56	80
2006	Pre	395	1.09	175	220	105	189
2007	Mid	339	0.97	130	209	78	106
2007	Pre	327	1.21	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	290	92	130
2015	Pre	440	0.86	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

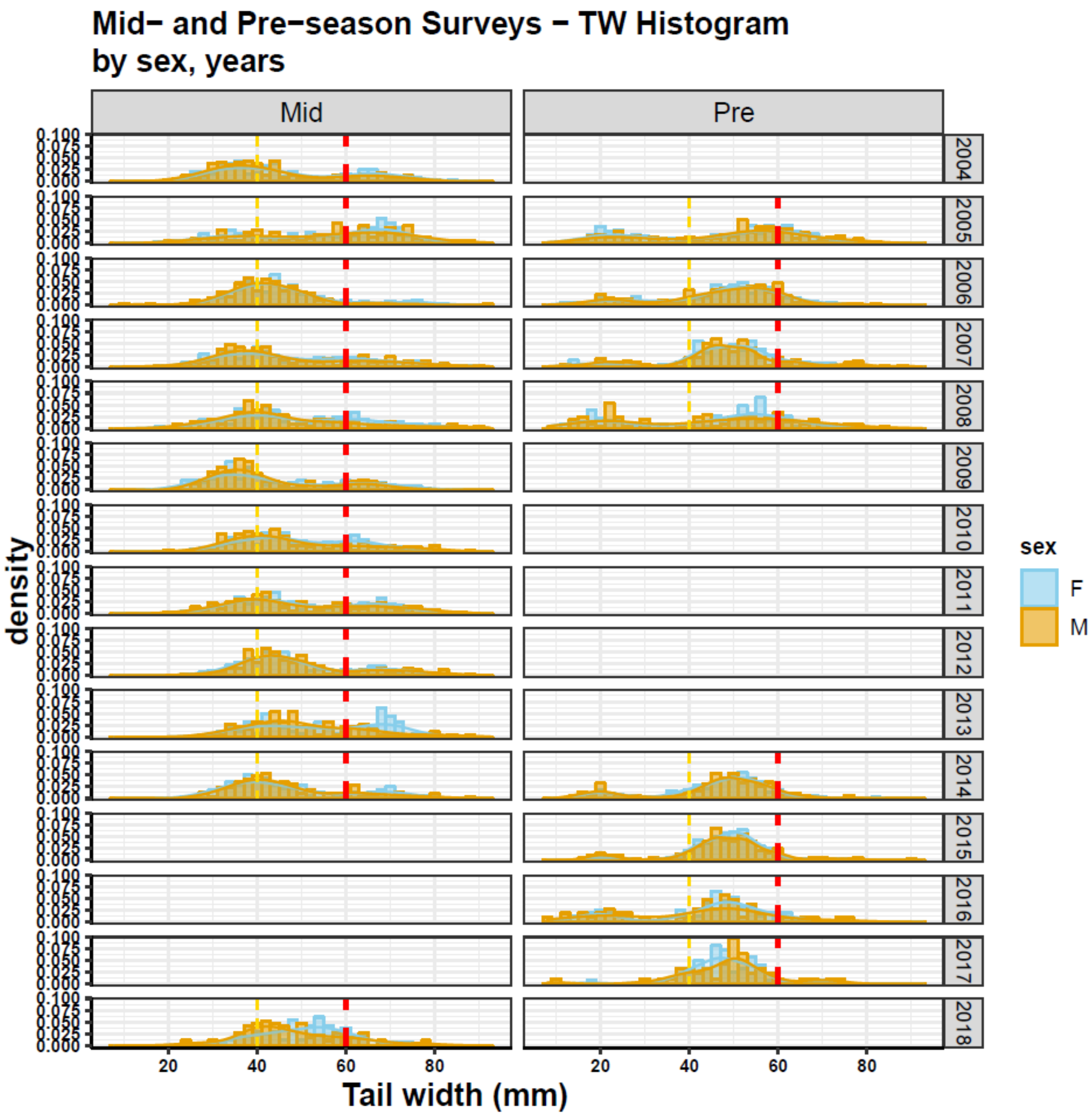


Figure 7-1. Mid- (Jun/ Jul) and Pre-Season (Nov/ Dec) Surveys – Histogram (density distribution) of TS rock lobster tail width (TW) by sex, years (since 2004). Minimum legal size (converted. Males 60 mm TW, combined sexes 62 mm TW) and nominal 40 mm TW (estimated mean TW for 1+ cohort in Mid-season) are indicated (red and yellow dashed lines).

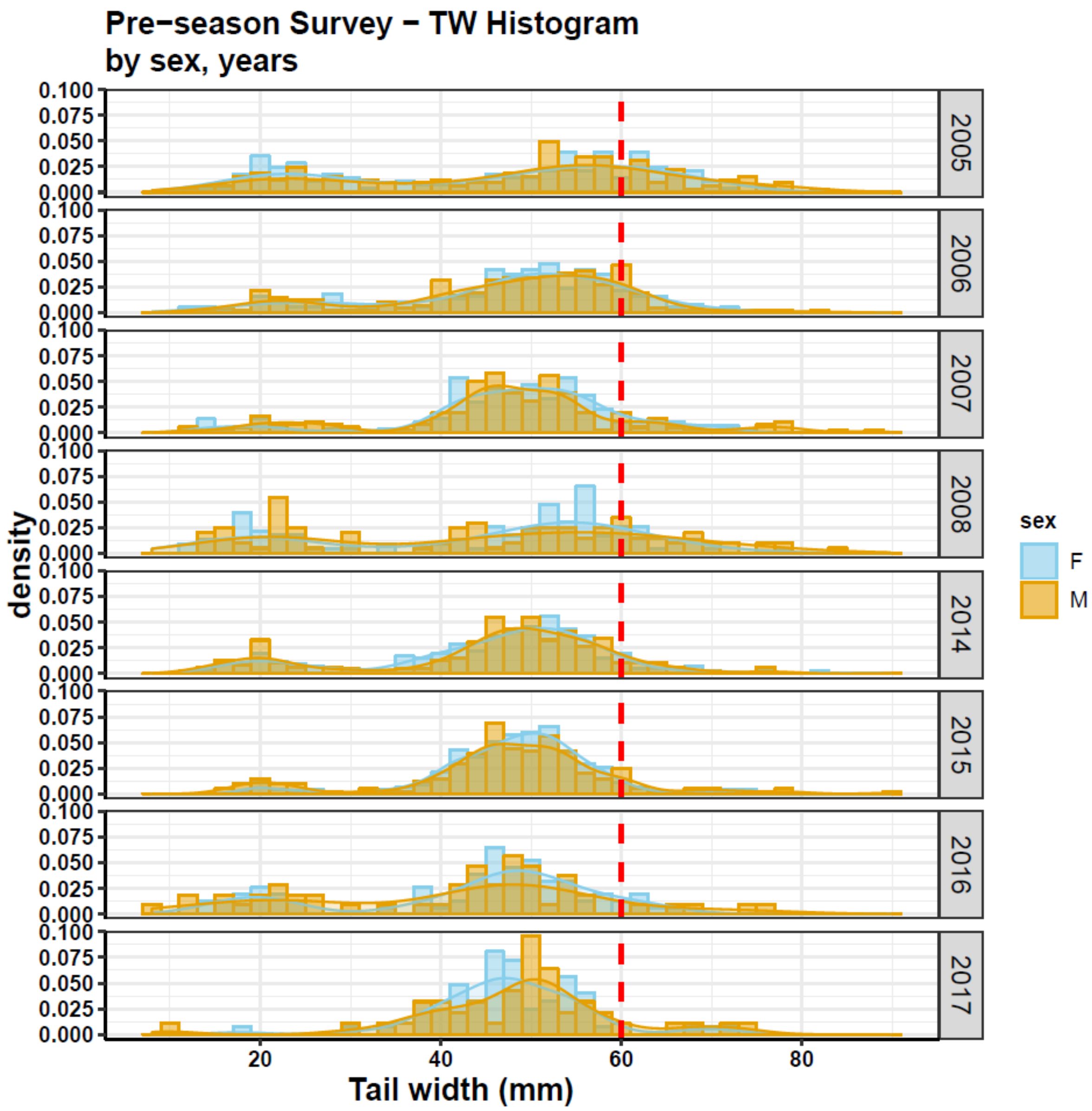


Figure 7-2. Pre-Season Survey – Histogram (density distribution) of TS rock lobster tail width (TW) by sex, years (2005 to 2008, 2014 to 2017). Minimum legal size (converted. Males 60 mm TW, combined sexes 62 mm TW) is indicated (red dashed line).

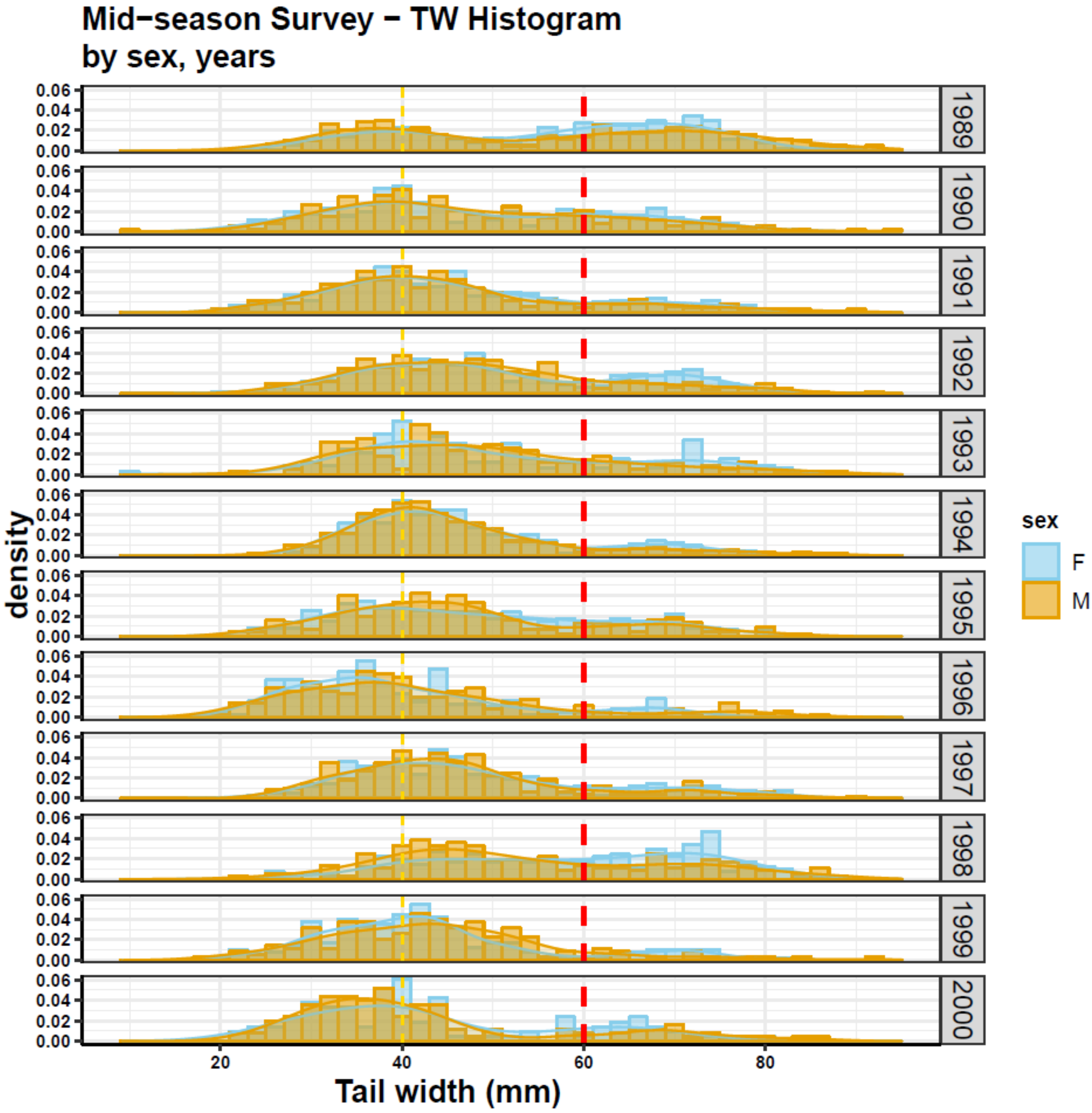


Figure 7-3. Mid-Season Survey - Histogram (density distribution) of TS rock lobster tail width (TW) by sex, years (1989 to 2000). Minimum legal size (converted. Males 60 mm TW, combined sexes 62 mm TW) and nominal 40 mm TW (estimated mean TW for 1+ cohort in Mid-season) are indicated (red and yellow dashed lines).

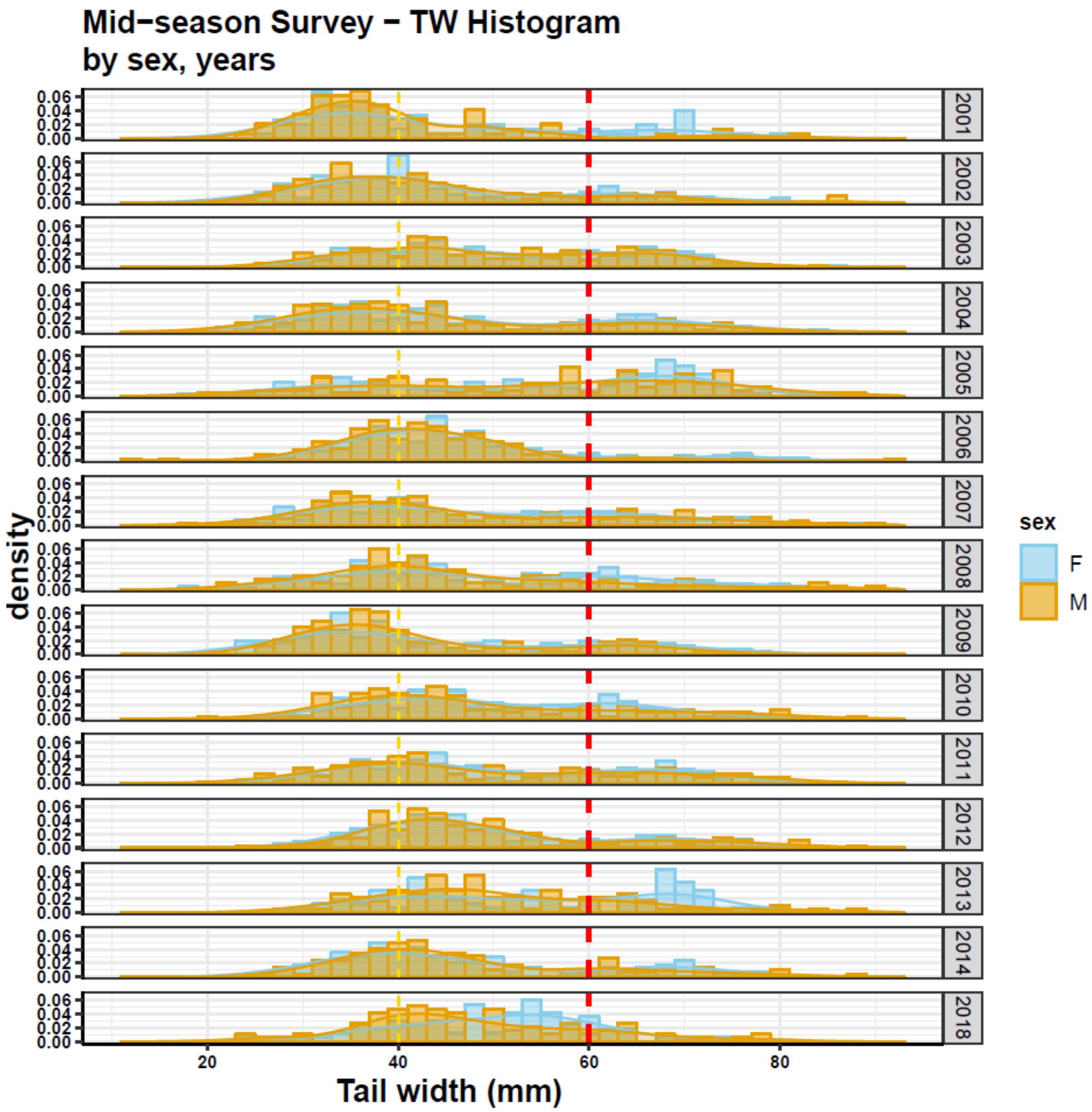


Figure 7-4. Mid-Season Survey - Histogram (density distribution) of TS rock lobster tail width (TW) by sex, years (2000 to 2014, 2018). Minimum legal size (converted. Males 60 mm TW, combined sexes 62 mm TW) and nominal 40 mm TW (estimated mean TW for 1+ cohort in Mid-season) are indicated (red and yellow dashed lines).

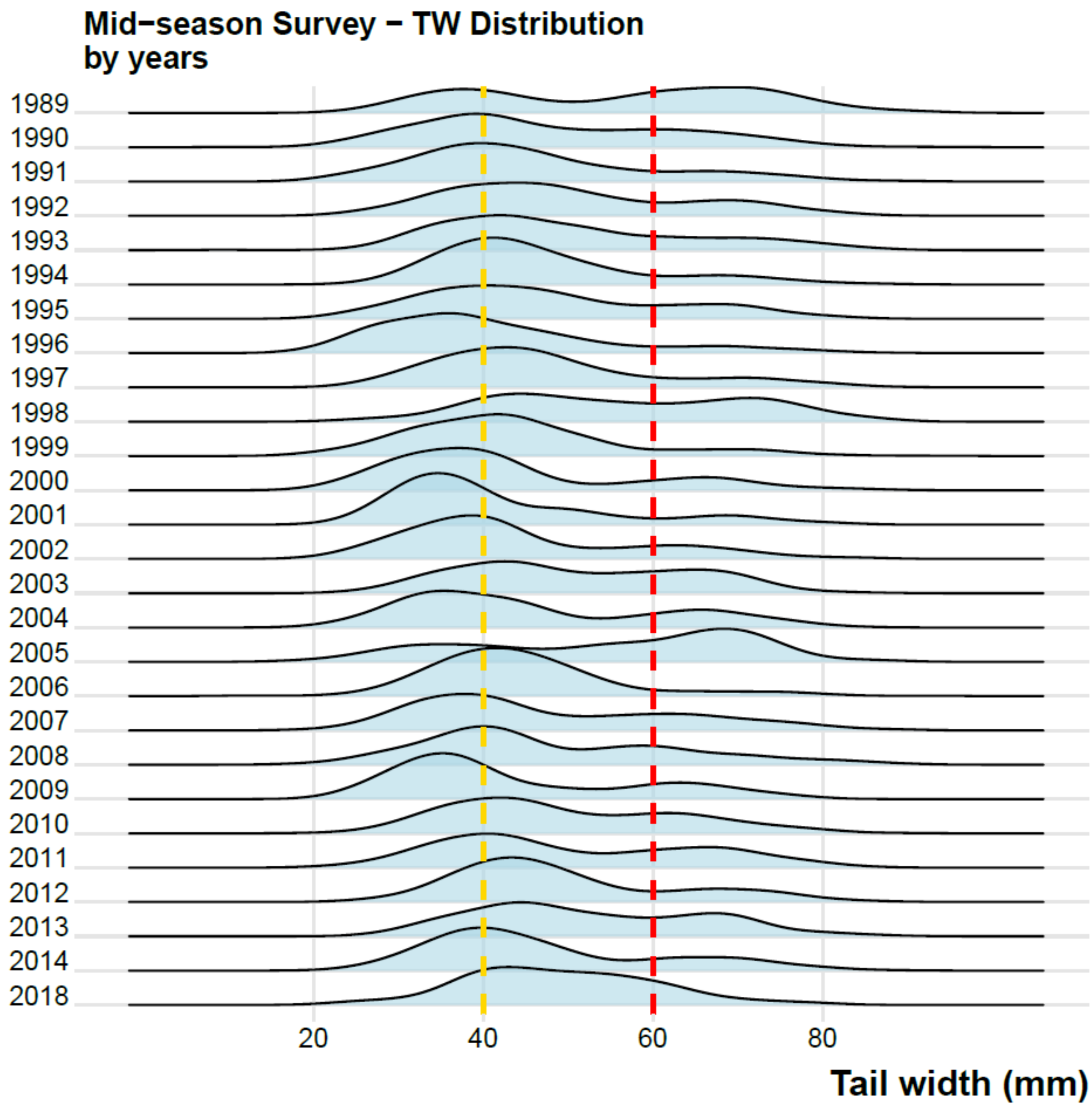
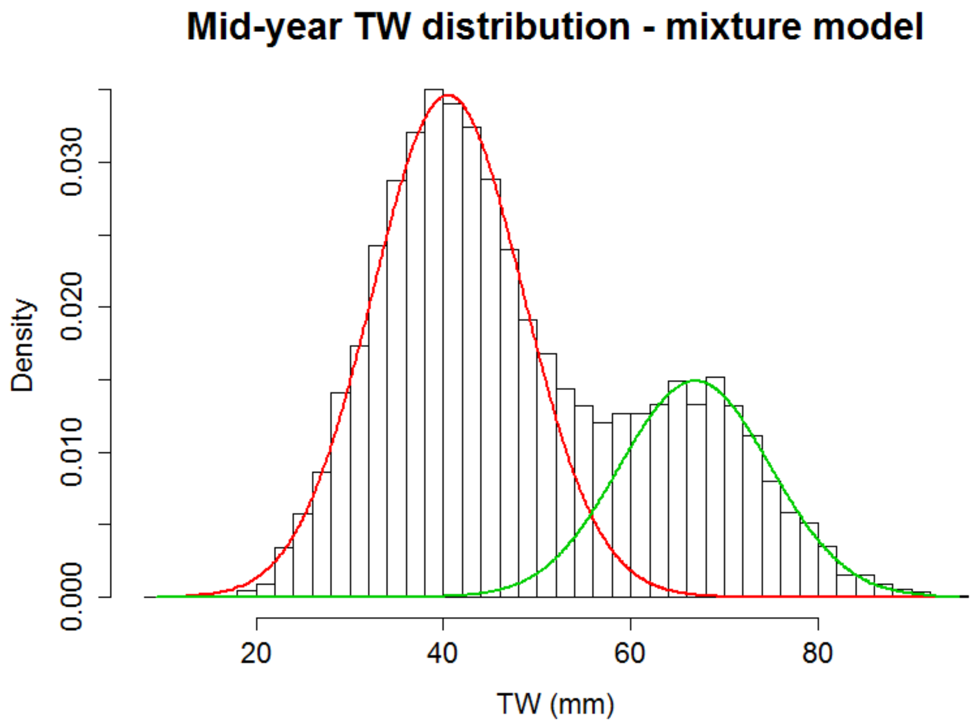


Figure 7-5. Mid-Season Survey – Ridge plot showing TS rock lobster tail width (TW) density distributions for combined sexes, each year surveyed (1989 to 2018). Minimum legal size (converted. Males 60 mm TW, combined sexes 62 mm TW) and nominal 40 mm TW (estimated mean TW for 1+ cohort in Mid-season) are indicated (red and yellow dashed lines).



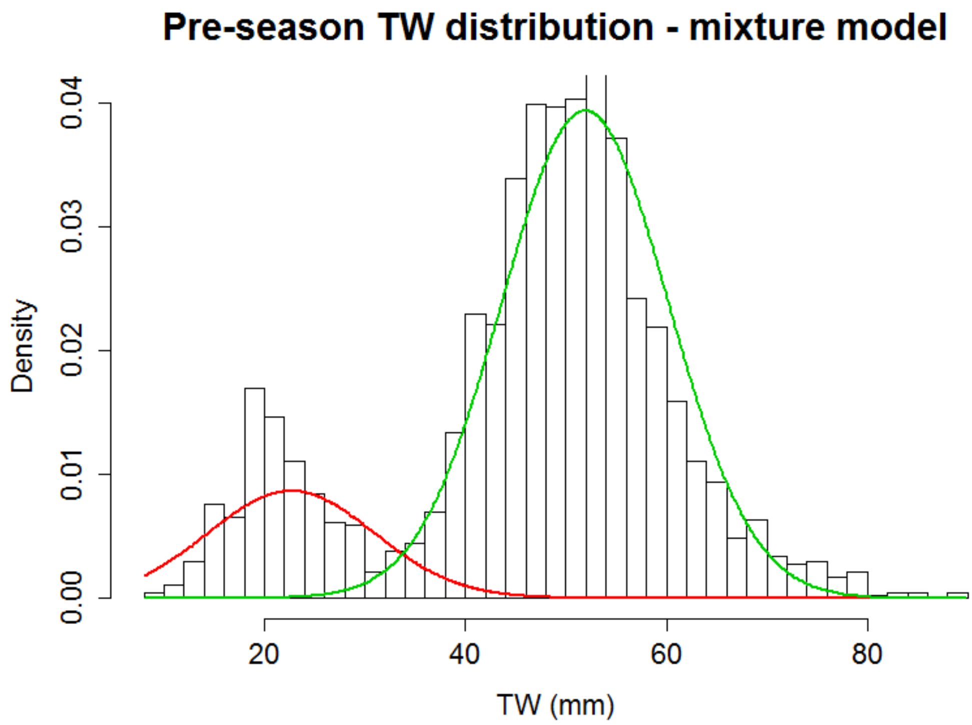


Figure 7-6. Histogram and fitted normal component density distributions of TW (cohorts on average across all survey years) for Mid-Season (Mid-year) Survey (top plot), and Pre-Season Survey (bottom plot).

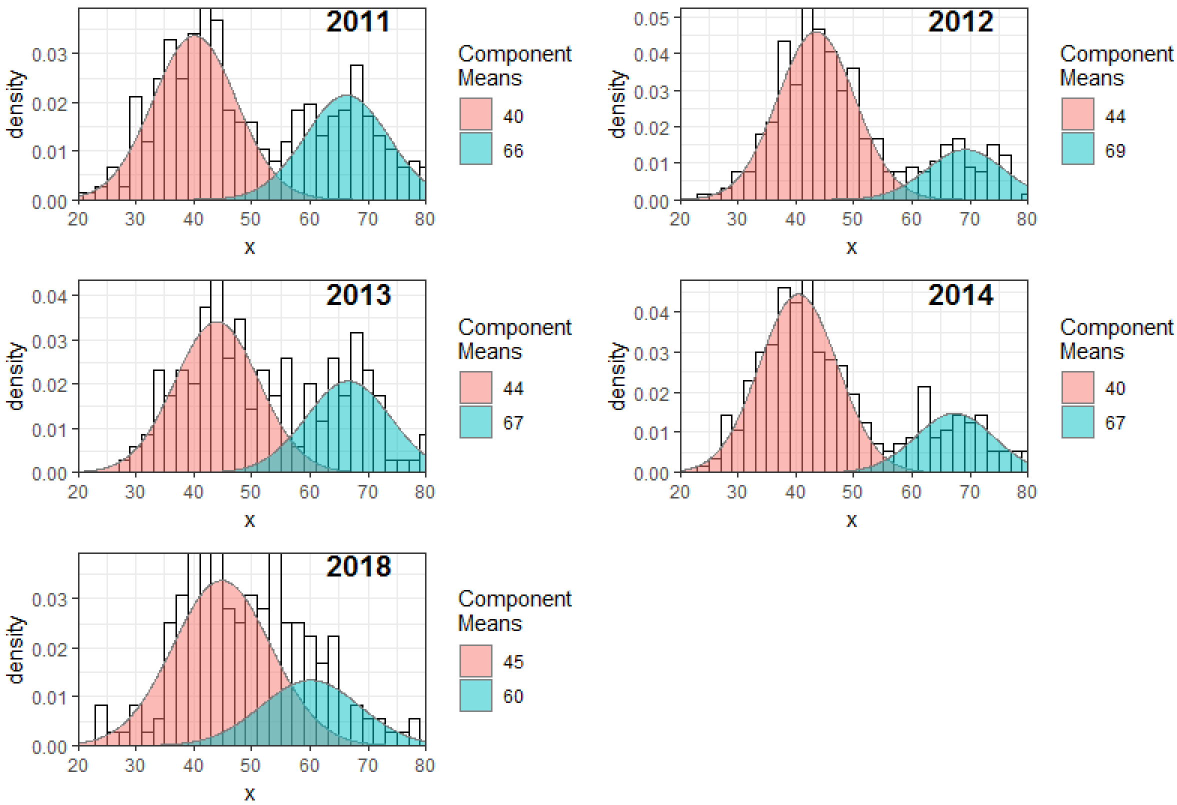


Figure 7-7a. Mid-Season Survey - Histogram and fitted normal component density distributions of TW and mean estimates for recent years. x-axis: tail width (mm).

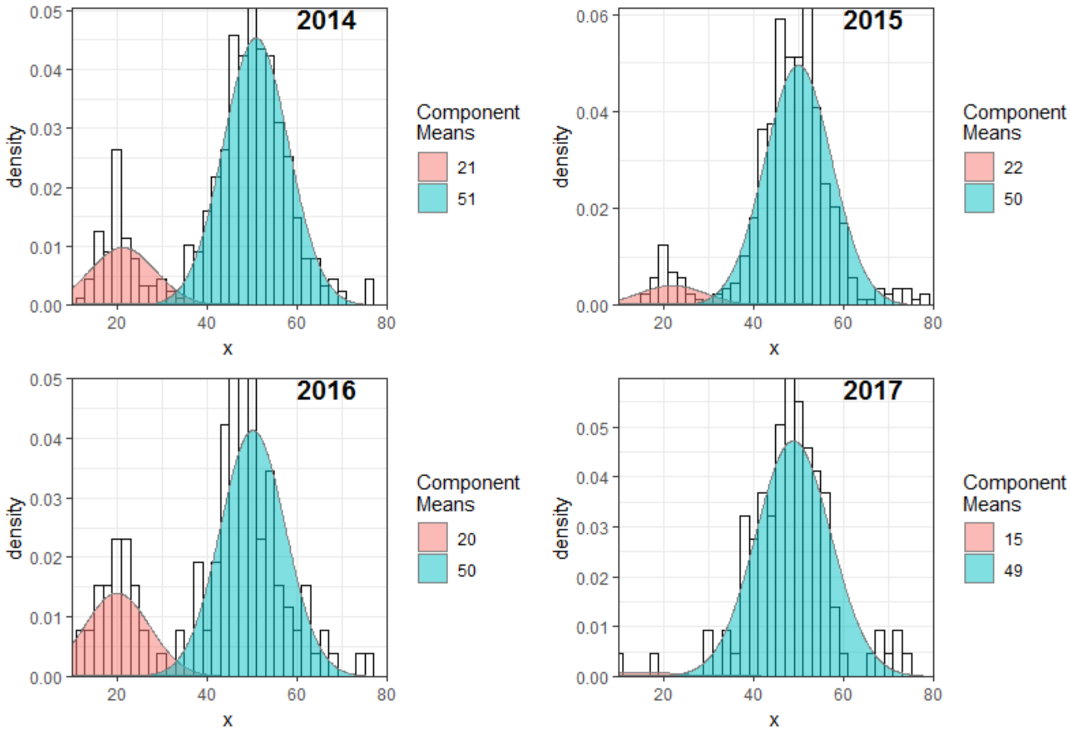


Figure 7-7b. Pre-Season Survey - Histogram and fitted normal component density distributions of TW and mean estimates for recent years. x-axis: tail width (mm).

7.4 Diagnostic plots

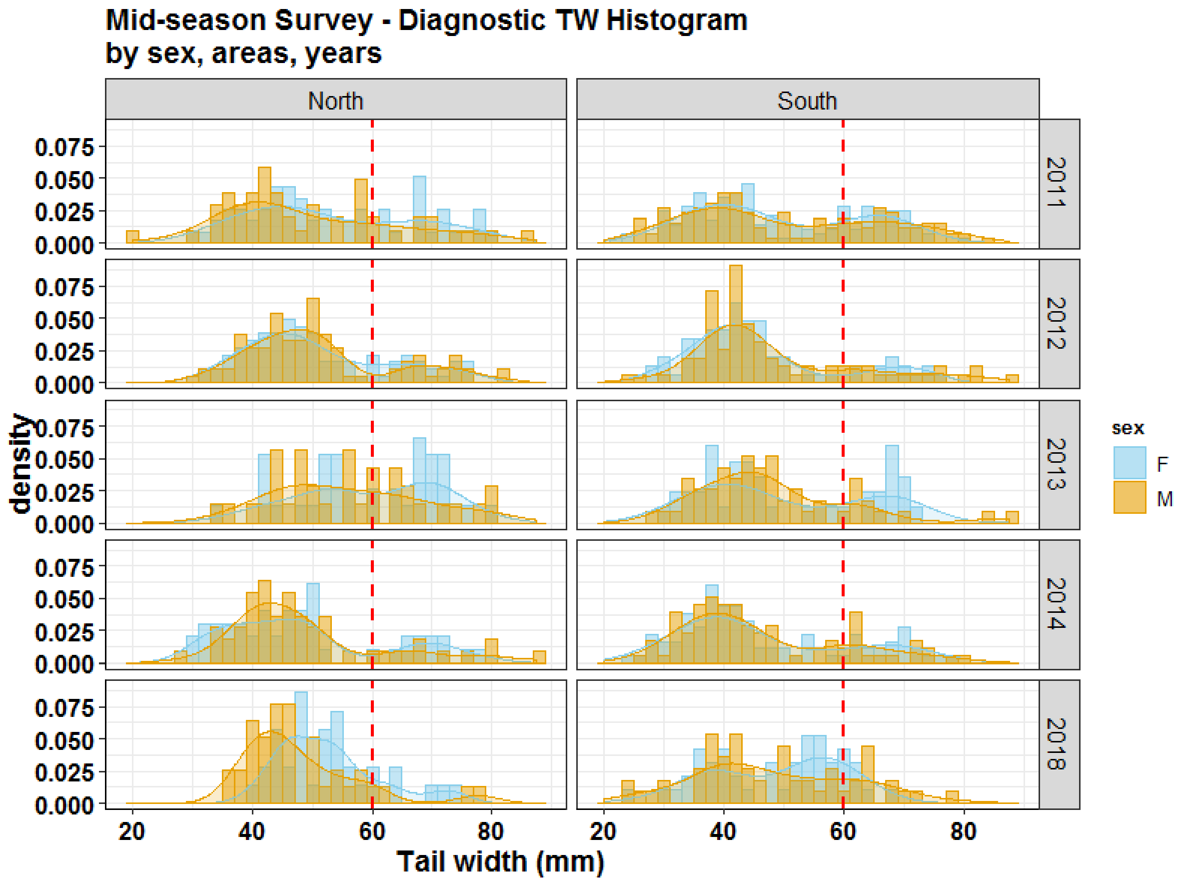


Figure 7-8. Mid-Season Survey - Histogram (density distribution) of TS rock lobster tail width (TW) by sex and areas (North and South), 2018 and recent years surveyed.

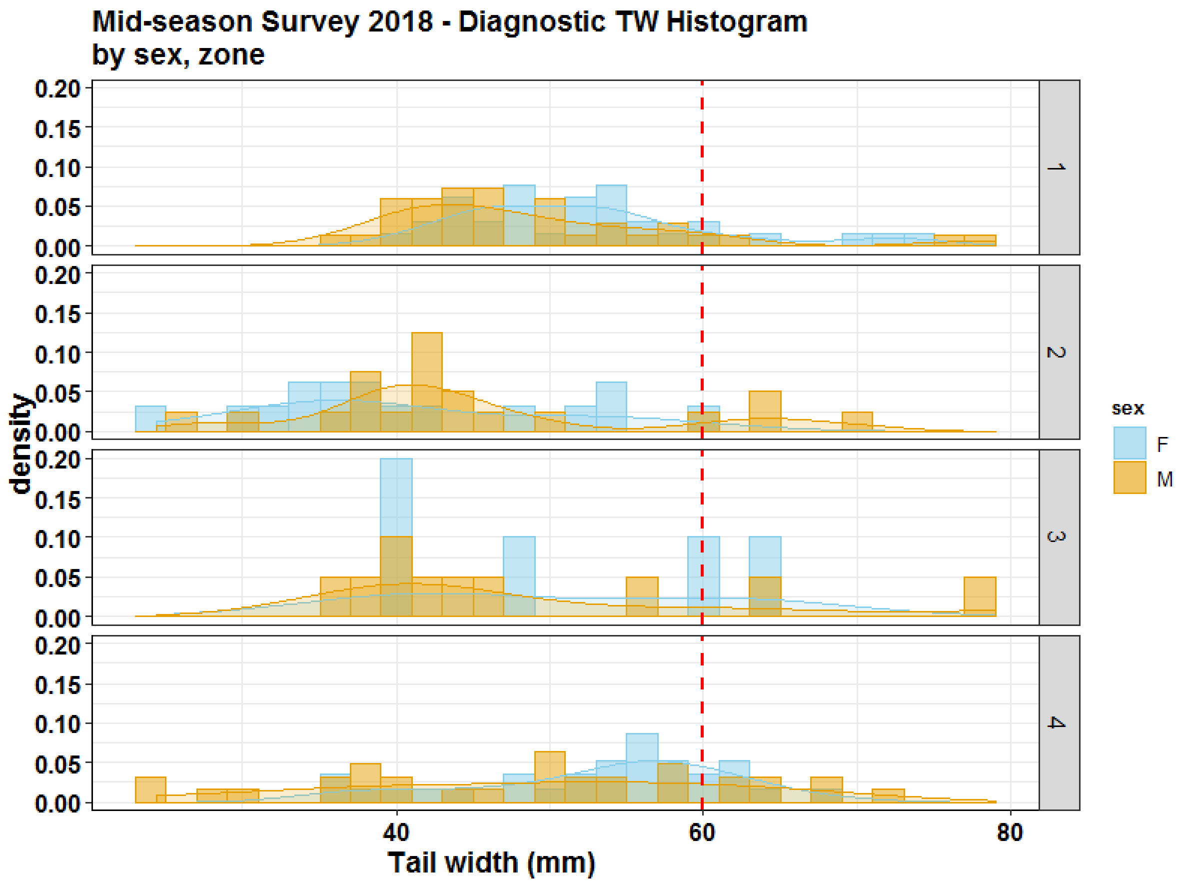


Figure 7-9. Mid-Season Survey 2018 - Histogram (density distribution) of TS rock lobster tail width (TW) by sex and zone). Zones: 1=North West, 2=South West, 3=Central, 4=South East.

Chapter 8 Accounting for Observation and Process Error in the Torres Strait tropical lobster TRL stock 0+ survey index for input to the stock assessment

SUMMARY

The Integrated Stock Assessment Model was updated using results from the 2018 TRL Preseason Survey (conducted between the 11th and 23rd November 2018) as well as the Midyear survey conducted during 28th June - 9th July 2018. The preliminary results were presented at the TRLRAG meeting 11-12 December, Thursday Island, 2018, but no final RBC set as there was a conflict identified between different abundance data sets in the model, and more time was needed to decide how best to handle the data conflict. This report summarises 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) (Figs 8-1; 8-2). Given we are reasonably confident in survey observations of 1+ lobsters (for reasons outlined in Plagányi et al. (2018)), the focus is on the anomalous 0+ observations. The stock assessment model is sensitive to the inclusion or exclusion (or downweighting) of the 2017 0+ index, and hence it is important that the TRLRAG 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 merit investigation:

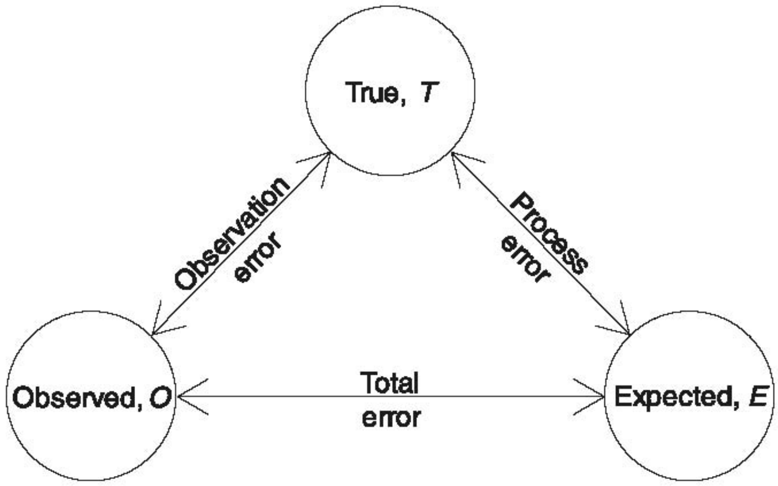
(1) Reviewing the relative weighting assigned to the 2017 0+ index (Upston et al. 2019);
(2) Analysing and standardizing the 0+ index to take into account additional factors that may have influenced it, for example, using a General Linear Model approach (see Campbell et al. 2019);
(3) Quantifying and accounting for environmental influences (see Table 8.1 summary and also (Plagányi et al. 2018a))

(1) Reviewing the relative weighting assigned to the 2017 0+ index

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.

(2) Standardising the 0+ index using a GLM

The methods and results are presented in Campbell et al. (2019). Alternative model results are presented for model version that use the standardized GLM 0+ series rather than the unstandardized series.

(3) Quantifying and accounting for environmental influences

Substantial research has already been conducted to try and explain the large inter-annual variability in TRL recruitment strength but with limited success thus far (Plagányi et al. 2018a). This is by no means unusual as is the case in almost all fisheries globally, despite intensive research since Hjort's (1914)[1] influential work to understand the relationships between spawners, recruits and environmental variability. However ongoing research in this area may improve the ability to quantify the role of environmental factors, and this would in turn reduce process error in the model.

The different analysis approaches considered to resolve the current data conflict are outlined in more detail in an accompanying document (Upston et al. 2019). Similarly, some preliminary results of alternative analyses used to calculate the 0+ index of abundance are detailed in (Campbell et al. 2019). Finally, based on the analyses in these accompanying

[1] In June 2019 ICES are celebrating the 150-year anniversary of Johan Hjort at the Hjort symposium: Challenging the scientific legacy of Johan Hjort: time for a new paradigm in marine research?

documents and the summary as outlined in this document, the stock assessment model was revised and the results are summarised in (Plaganyi et al. 2019).

Finally note that the TRLRAG also agreed that the statistical downweighting of the 0+ survey index as described here was for application to the stock assessment model only, and not the empirical harvest control rule (eHCR). The eHCR is deliberately tuned to reduce inter-annual variation in the TAC, and uses the logarithm of the slope of the past 5 years' survey and CPUE data, with a 10% weighting accorded to the preseason 0+ index (Plagányi et al. 2018b).

Table 8-1. Consideration of alternative hypotheses to explain the low 2017 0+ survey index compared with the 2018 1+ survey index.

	Alternative Hypotheses	**Does it explain low 0+ in Nov 2017?**	**Does it explain 1+ size distribution in June 2018?**	**Notes and evidence**	**PLAUSIBILITY**
1	The 2017 0+ index was negatively biased due to observational error	No (see Appendix 1)	no	There was some concern that as 2017 was the first year without a “gold standard” (GS) diver participating in the survey with considerable experience detecting the small 0+ age class, this may have biased the index negatively. However a statistical comparison of historical performance between GS and Other teams showed that whereas the GS teams generally found slightly more 0+, there was no significant difference between the results, and evidence of rapid learning. Even if the maximum likely bias is applied to the 0+ index, it does not increase it sufficiently to explain the 2018 1+ abundance.	low
2	The 2017 0+ index was low because of the timing of settlement	maybe	maybe	As lobsters spawn over a period of a few months, there is also approximately 3 months variability in terms of when they settle. In addition, the anomalous environmental conditions in 2016 (influencing the spawners producing the 2017 0+ cohort) could easily have influenced the timing of spawning and successful transport and settlement of pueruli. If settlement occurred earlier than usual, then this could explain relatively larger 1+ observed during 2018, but it means the 0+ would have been easier to observe during the 2017 survey. On the other hand, if settlement occurred later, then this explains the reduced numbers during the survey, but not the larger sizes of 1+ during 2018 (but it’s possible that this was a result of a combination of timing of settlement and change in growth rate as below).	medium
3	Faster growth due to higher temperatures in 2017-2018 and/or reduced density dependence	no	yes	TRL growth is known to increase with increasing SST (Skewes et al. 1997) and there is evidence to suggest that the 2016 high temperatures had an influence on the stock, but there is less evidence of high temperatures over December 2017-June 2018 (Fig. 9) potentially influencing growth of the recruiting cohort. Differences in growth due to SST will be more substantial	high

				for younger animals as the von Bertalanffy growth curve predicts that growth converges as animals approach maturity. Density dependence is also thought to influence growth rates (Skewes et al. 1997), and the relatively low average density of 2+ lobsters during 2018 means the 1+ lobsters would have had access to more favourable habitat and food supplies and this may also have influenced growth rate. The broad spread in size distribution of this cohort suggests these dynamics may have been spatially patchy (and hence that density dependence may have played a role rather than just temperature) and the relatively large sizes of some individuals lends further support to this hypothesis.	
4	The 2017 0+ index was low because the distribution of settling recruits changed substantially	yes	yes	The recent anomalous environmental conditions would have had an influence on local Torres Strait currents, as well as sand and habitat distribution and quality which could have influenced the spatial pattern of puerulus settlement. There is some evidence from the 2017 preseason survey 0+ spatial distribution data that the pattern differed to that observed in previous years eg lower than usual density in TI_Bridge stratum. The highest densities of 0+ were in the South-East and Mabuiag strata, so it's possible that relatively more settlement may have occurred to the north-west to the extent that the index wasn't as comparable as in previous years. Previous research (Skewes et al. 1997) showed that there are differences in growth rate between the four zones (NW,SW,Central, SE), with lobsters being larger in the NW, and this may have contributed to the larger average size of this 1+ cohort (see Tonks et al. 2018). Commercial catch data from 2018 PNG commercial catches also suggested there was good recruitment up north which lends further support to this hypothesis.	very high

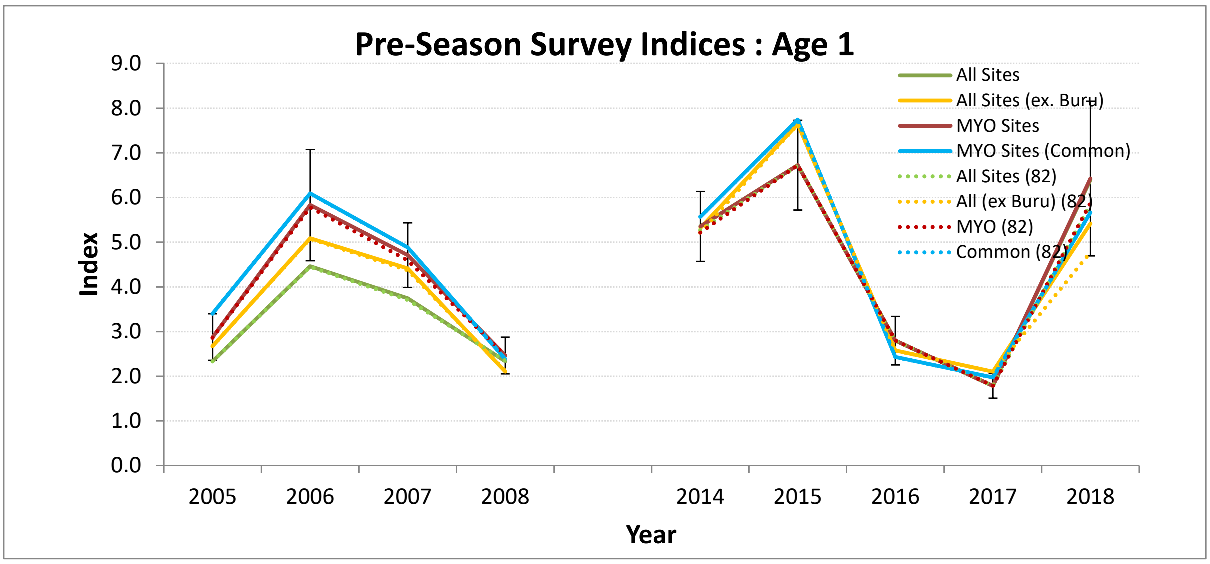


Figure 8-1. Comparative indices of abundance of recruiting (1+) ornate rock lobsters (Panulirus ornatus) recorded during pre-season surveys in Torres Strait between 2005 and 2018 (note surveys were not done during 2009-2013) shown for all sites as well as reduced series including Midyear-Only Sites (MYO). Error bars of MYO indices represent standard errors

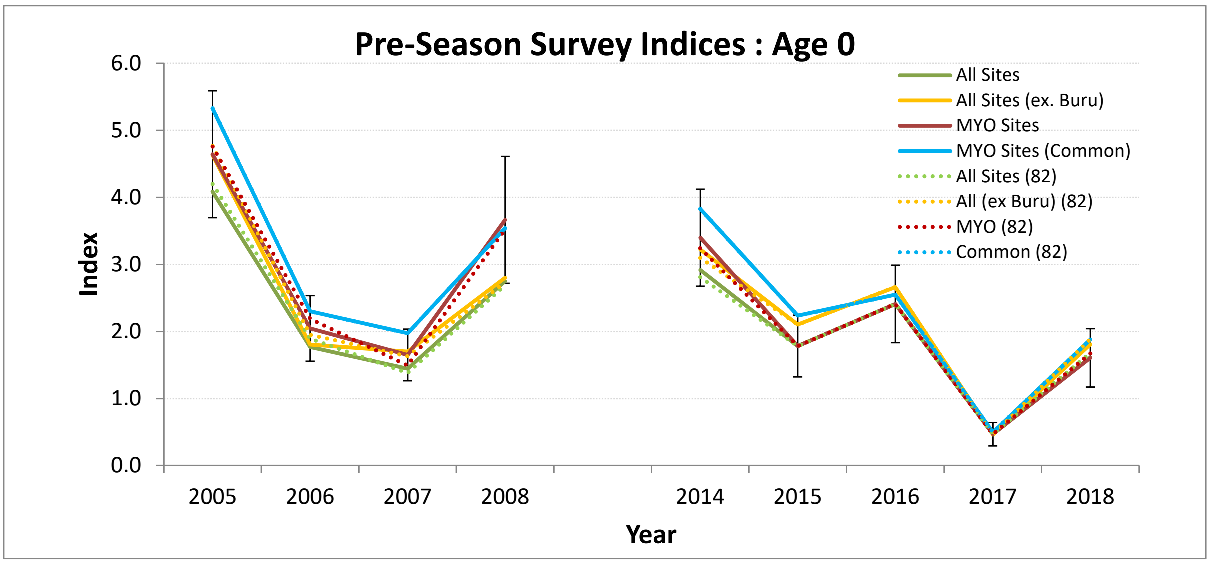


Figure 8-2. Comparative indices of abundance of newly settled (0+) ornate rock lobsters (Panulirus ornatus) recorded during pre-season surveys in Torres Strait between 2005 and 2018 (note surveys were not done during 2009-2013) shown for all sites as well as reduced series including Midyear-Only Sites (MYO). Error bars of MYO indices represent standard errors

Chapter 9 Updated Assessment of the Tropical Rock Lobster (*Panulirus ornatus*) Fishery in Torres Straits following November 2018 Preseason survey

9.1 Summary

This document summarises the post-Nov 2018 preseason survey update of the integrated stock assessment model presented at the December 2018 TRLRAG, with subsequent updated conducted for the February 2019 TRLRAG. The TRLRAG agreed that if the fishery transitions to using an empirical Harvest Control Rule (eHCR) to inform the Recommended Biological Catch (RBC), then the stock assessment would only need to be conducted every three years. However until such time as this is formally adopted, the stock assessment model is being used to inform the RBC for the tropical rock lobster *Panulirus ornatus*.

The data updates include the latest (Nov 2018) pre-season survey results, the catch total for 2018 including revisions which became available since the December 2018 RAG meeting and revisions and updates to the commercial CPUE (TVH & TIB) data series. The full details of the stock assessment model are provided in this report.

The model predictions for 2019 are much more optimistic than the previous season because they are based mostly on the preseason survey 1+ index, which is appreciably higher than the previous year when it was the lowest of the series to date. Note that the model results presented here are fitted to the preseason survey index based on midyear sites only. A number of alternative sensitivity tests were presented at the December 2018 RAG meeting and are not repeated here.

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. 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 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 accompanying papers. 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 and these analyses are also described in accompanying papers. Based on the updated analyses, the stock assessment model was updated and this report summarises the updated results as a basis for informing management.

The model reasonably fits the recent CPUE series for both sectors, although the observed 2018 CPUE for both sector is slightly higher than the expected values, even after accounting for hyperstability. This is not surprising given the detailed analyses as described in papers discussed by the TRLRAG in 2018 (when fishing was capped for the first time at a low TAC amount of 299t) and the TRLRAG has recommended that a data meeting be held to further assess any changes in the

fishing patterns and technological methods (fishing power) used. Results presented at the December 2018 RAG also suggested the model fit could be improved by estimating rather than fixing the CPUE hyperstability parameters in the model. As before, the model is unable to satisfactorily fit the 2015 CPUE data for TIB and TVH sectors. The potential reasons for this are discussed in more detail in Plagányi et al. (2015a,b). It is highly plausible that anomalous environmental changes have caused a change in catchability in 2015, but there is also likely to have been an impact of changes in lobster habitat on their survival and productivity, but there are no data available to assist in separating the effect of changes in catchability and survival on the overall catches for 2015 (noting that the total catch was higher than initially expected due to trawling catches). The model assumes constant annual natural mortality, and hence cannot straightforwardly model the change in catchability and/or survival without additional information, and hence the Reference Case model has not included any *ad hoc* adjustments, but these have been further investigated via sensitivity analyses (not presented in detail in this document).

The Reference case model presented here is fitted to the TVH CPUE Main Effects Int1 option and the standardised Seller CPUE TIB series. There isn't much difference between the alternative CPUE standardisations except for recent differences between the Main and Seller series for TIB.

The December 2018 RAG advice was " to apply a statistically calculated down-weighting to the 2017 0+ index, the RAG noted that the final RBC would likely lie somewhere between 533 and 637 tonnes. A final RBC value will not be available until the February 2019 TRL RAG meeting" and a revised Reference case to be developed "using an appropriate statistical methodology" (TRLRAG25 Meeting Minutes). This document has therefore selected a revised Reference Case that includes estimation of Additional Variance for all 0+ survey observations. This document presents full results for this illustrative case as well as summary results for other variants, with the final choice of model version to be used to inform the RBC to be finalised at the forthcoming TRLRAG meeting, and hence note that the final RBC may differ from the revised reference case value presented here.

The revised reference case model suggests a RBC (2019) of 641t [90% CI 426-857t]. Using the revised reference case, the stock is currently estimated to be at 46% of the pristine (1973) spawning biomass level (K). Previous analyses forewarned that the 2018 spawning biomass may be lower than average and provides support for the management decisions taken in 2018 to limit catches so that sufficient lobsters would remain for spawning purposes and subsequent recruitment to the fishery in 3 years' time. Fortunately, the good 1+ numbers observed in the most recent survey means that the model spawning biomass projection for the following year is once again much more positive. The very large inter-annual variability in the stock has long been recognised. Hence it is entirely plausible that the current lobster stock have been boosted by good recruitment, however we suggest ongoing monitoring of 2019 catch and the next survey observations will be prudent.

9.2 Introduction

A new stock assessment model (termed the "Integrated Model") (Plagányi *et al.* 2009) 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 a 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, 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 each year, 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 2018 model assessment using the 2018 pre-season survey data.

The revised Reference Case includes the following specifications (see Plagányi et al. 2010):

- 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 2018 recruitment residual;
- the use of historic 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 pristine stock size.

At the December 2018 TRLRAG meeting, there was agreement 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 and same series as in November 2017 without the additional 5 sites added
e) CPUE TVH – Int-1 standardised series (and Int-3)
f) CPUE TIB – Seller standardised series

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. 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 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 accompanying papers. 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 and these analyses are also described in accompanying papers. Based on the updated analyses, the stock assessment model was updated and this report summarises the updated results as a basis for informing management.

9.3 Objectives

This document describes an update of the TRL stock assessment model using the results of the preseason survey conducted in November 2018 and applying an objective statistically-justifiable approach for resolving the conflict between the 2017 0+ and 2018 1+ survey observations.

9.4 Methods

The model details are given in Appendix A of this document. A summary of the input catch data is shown in Table 9-1. Lobster catches (tonnes whole weight) landed in different jurisdictions from 1973 to 2018. 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. The historical mid-year survey data are shown in Table 9-2. The latest November 2018 Pre-season survey (Fig. 1-3) is included in the model. The commercial catch-at-age data have been updated and the revised series is shown in Table 9-4.

The model uses the latest revised historical catch estimates. As 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 9-1). If recent trawling catches continue, then the model will need to similarly account for these separately to the total catch.

The TVH CPUE data input series have been revised and updated for the period 1989-2018 and TIB for 2004-2018 (Campbell *et al.* 2018a,b).

The model is fitted to additional historical information as described in Plagányi et al. (2010). 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 a 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. (2010) 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 (Pascoe et al. 2013, Plagányi et al. 2012, 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.

Table 9-1. Lobster catches (tonnes whole weight) landed in different jurisdictions from 1973 to 2018. 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.

SEASON	TIB	TVH	AUS_DIVERS	AUS_TRAWL	AUS-TOTAL	PNG_DIVERS	YULE_DIVERS	PNG-DIVERS TOTAL	PNG_TRAWL	PNG-TOTAL	TS_TOTAL
1973			0	0	0	54	19	73	562.2	635.2	635.2
1974			0	0	0	75	83	158	107.1	265.1	265.1
1975			0	0	0	62	13	75	214.2	289.2	289.2
1976			0	0	0	48	0	48	262.3	310.3	310.3
1977			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	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			444.100	0	444.100	168.0	0	168.0	0.0	168.0	612.1
1992			423.200	0	423.200	134.0	0	134.0	0.0	134.0	557.2
1993			505.700	0	505.700	166.0	0	166.0	0.0	166.0	671.7
1994		120.061	577.800	0	577.800	247.0	0	247.0	0.0	247.0	824.8
1995		87.022	556.900	0	556.900	257.0	0	257.0	0.0	257.0	813.9
1996		210.872	584.100	0	584.100	228.0	0	228.0	0.0	228.0	812.1
1997		271.449	653.100	0	653.100	241.0	0	241.0	0.0	241.0	894.1
1998		351.396	661.400	0	661.400	201.0	0	201.0	0.0	201.0	862.4
1999		93.563	409.600	0	409.600	163.0	0	163.0	0.0	163.0	572.6
2000		132.374	418.000	0	418.000	235.0	0	235.0	0.0	235.0	653.0
2001	52.000	79.968	131.968	0	131.968	173.0	0	173.0	5.4	178.4	310.4
2002	68.000	147.178	215.178	0	215.178	327.0	0	327.0	42.8	369.8	585.0
2003	123.000	358.799	481.799	0	481.799	211.0	0	211.0	5.4	216.4	698.2
2004	210.381	481.082	691.463	0	691.463	182.0	0	182.0	0.0	182.0	873.5
2005	367.615	549.935	917.550	0	917.550	228.0	0	228.0	0.0	228.0	1145.6
2006	140.451	135.473	275.924	0	275.924	142.0	0	142.0	0.0	142.0	417.9
2007	268.688	268.596	537.284	0	537.284	228.0	0	228.0	0.0	228.0	765.3
2008	185.666	100.437	286.103	0	286.103	221.0	0	221.0	0.0	221.0	507.1
2009	147.813	91.060	238.873	0	238.873	161.4	0	161.4	0.0	161.4	400.3
2010	140.039	282.614	422.653	0	422.653	292.8	0	292.8	0.0	292.8	715.5
2011	199.060	503.534	702.594	0	702.594	165.0	0	165.0	0.0	165.0	867.6
2012	142.380	370.483	512.863	0	512.863	173.7	0	173.7	0.0	173.7	686.6
2013	138.439	361.661	500.100	0	500.100	108.3	0	108.3	0.0	108.3	608.4
2014	196.827	273.214	470.041	0	470.041	151.4	0	151.4	109.8	261.2	731.2
2015	204.659	152.710	357.369	0	357.369	235.7	0	235.7	0.0	235.7	593.1
2016	264.725	243.010	507.735	0	507.735	248.0	0	248.0	0.0	248.0	755.8
2017	117.891	149.738	267.629	0	267.629	113.0	0	113.0	0.0	113.0	380.7
2018	127.010	134.100	261.110	0	261.110	66.6	0	66.6	0.0	66.6	327.7

Table 9-2. Mid-year survey data summary for the period 1989-2014 and 2018. Indices reflect abundance.

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 9-3. Pre-season survey index (Midyear-Only (MYO) Sites – see Campbell et al. 2018) for the period 2005-2008 and 2014-2018. Indices reflect relative abundance.

Annual	Region	N-Stratum	Area	Fraction	Transects	Age0	All-82 Age0	SE0	Age1	All-82 Age1	SE1	Age2	All-82 Age2	SE2
2005	Total	7	5571500	1.000	71	4.644	4.758	0.946	2.877	2.863	0.519	0.263	0.260	0.097
2006	Total	7	5571500	1.000	74	2.045	2.188	0.49	5.831	5.783	1.243	0.031	0.031	0.024
2007	Total	7	5571500	1.000	75	1.65	1.495	0.384	4.711	4.592	0.723	0.182	0.178	0.095
2008	Total	7	5571500	1.000	76	3.666	3.527	0.947	2.463	2.473	0.409	0.034	0.034	0.020
2014	Total	7	5571500	1.000	75	3.399	3.243	0.725	5.354	5.215	0.782	0.090	0.090	0.031
2015	Total	7	5571500	1.000	73	1.783	1.783	0.46	6.724	6.724	1.005	0.242	0.242	0.092
2016	Total	7	5571500	1.000	73	2.411	2.411	0.579	2.798	2.798	0.542	0.194	0.194	0.072
2017	Total	7	5571500	1.000	74	0.468	0.468	0.174	1.784	1.784	0.277	0.049	0.049	0.028
2018	Total	7	5571500	1.000	76	1.607	1.675	0.437	6.425	5.884	1.729	0.070	0.098	0.038
					Mean	2.408	2.394	0.571	4.330	4.235	0.803	0.128	0.131	0.055

Table 9-4. Summary of commercial catch at age information from 1989 to 2018.

Year	Percentage 1+	Percentage of 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	23.92	76.08
1996	26.47	73.53
1997	28.63	71.37
1998	16.15	83.85
1999	31.25	68.75
2000	10.79	89.21
2001	1.21	98.79
2002	2.93	97.07
2003	3.13	96.87
2004	2.54	97.46
2005	1.19	98.81
2006	6.79	93.21
2007	1.48	98.52
2008	5.37	94.63
2009	0.71	99.29
2010	6.75	93.25
2011	0.90	99.10
2012	7.20	92.80
2013	5.88	94.12
2014	1.96	98.04
2015	1.72	98.28
2016	1.53	98.47
2017	1.41	98.59
2018	1.25	98.75

9.5 Results

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

Initial model runs were problematic as very low additional variance was estimated for some years but not others, and this also resulted in large associated C.V.s due to the small parameter estimates. A lower bound of 0.05 was set for estimation of the additional variance to improve model estimation. The model estimated 8 additional variance parameters resulting in an 8.44 improvement in the log likelihood, which is statistically significant ($p<0.05$) using log-likelihood ratio test for which the corresponding critical chi-square value is 7.75 (Table 9-5).

The model additional variance parameters could not be reliably estimated for 2005, 2008 and 2016, and the estimates for years 2006 – 2015 hit the lower bound so were not well estimated either (Table 9-5). However the model estimated a large additional variance (0.43) for the 2017 survey 0+ observation with very high precision (C.V. = 0.005). This is consistent with the a priori expectation that the 2017 0+ survey would have the greatest amount of process error (see Table 1 in Plaganyi et al. 2018). For similar reasons, it was also hypothesized that the 2016 0+ survey would have large associated process error.

The 2017 additional variance estimate was considerably larger than the survey variance of 0.08. These results were very similar to the additional variance estimates obtained using the model version with the GLM-standardized 0+ series and associated standard errors instead (Table 9-5). It is not surprising that the 2008 0+ estimate has a high associated C.V. because there was no preseason survey conducted in 2009, and hence no directly comparable 1+ preseason index, but the model is also fitted to a 2009 midyear survey 1+ observation.

Table 9-5. Summary of model-estimated additional variance parameters.

	(b) Model version with AV but not GLM0						(d) Model with AV and GLM0				
	parameter	S.E.	C.V.	90% CI			parameter	S.E.	C.V.	90% CI	
2005	0.112	2.283	20.344	0.000	0.534		0.105	0.220	2.098	0.000	0.468
2006	0.050	0.025	0.503	0.048	0.052		0.050	0.000	0.003	0.050	0.050
2007	0.050	0.004	0.076	0.050	0.050		0.050	0.000	0.007	0.049	0.051
2008	0.051	0.621	12.285	0.000	0.102		0.050	0.000	0.006	0.050	0.050
2014	0.050	0.050	0.999	0.046	0.054		0.050	0.001	0.011	0.049	0.051
2015	0.050	0.016	0.313	0.049	0.051		0.050	0.000	0.004	0.050	0.050
2016	0.256	1.779	6.958	0.000	1.004		0.123	0.272	2.205	0.000	0.571
2017	0.430	0.002	0.005	0.429	0.431		0.430	0.002	0.004	0.427	0.433

Previously the model fit to the 0+ survey index was not satisfactory and estimation of additional variance parameters significantly improved the fit to both the 0+ and 1+ preseason survey indices. This resulted in a much more satisfactory fit to 1+ 2018 observation which was considered important as it is the key predictor of the following year's fished biomass.

Given the problems in trying to estimate all 8 additional variance (A.V.) parameters, two illustrative models runs are also shown in Table 9-6 with first scenario (scenario e in Table 9-7b) a single common 0+ survey additional variance parameter estimated for all years (except 2018) and second (scenario f in Table 9-7b) an additional variance parameter only estimated for 2017. The former scenario is not recommended as an approach though because there are a priori reasons provided as to why process error can be expected to vary inter-annually. The second scenario is also not ideal as it singles out a single year rather than applying an approach consistently, but is useful for comparison purposes. Neither of these two scenarios were preferred compared with the Model version 1 when using the AIC model selection criterion.

Table 9-6. Summary of model-estimated additional variance parameter when estimating a single value only.

	parameter	S.E.	C.V.	90% C.I	
Single common A.V.	0.357	0.250	0.698	-0.053	0.768
A.V. for 2017 only	3.444	5.011	1.455	-4.799	11.686

Given the issues with the estimated A.V. parameters hitting the lower bound, the lower bound was decreased to a very small number and the model refitted as shown in Table 9-7b scenario (g). Using the AIC model; selection criterion, scenario (g) is the preferred model. The A.V. parameter estimates and associated C.V.s are shown in Table 9-7. Once again the largest process error is estimated for the 2017 0+ observation with a very small associated standard error. The model fit to both the 0+ and 1+ index is highly significantly better than the base model version 1 (Table 9-8).

Table 9-7. Summary of model-estimated additional variance parameters for final model versions, including Revised Reference Case and version with GLM0.

Base model with Add Var estimated with no bounds					
	parameter	S.E.	C.V.	90% C.I	
2005	0.118	0.250	2.124	-0.326	0.584
2006	0.001	0.003	3.227	0.000	0.000
2007	0.001	0.001	0.982	0.000	0.000
2008	0.020	0.157	8.003	-0.257	0.316
2014	0.001	0.008	5.807	-0.001	0.001
2015	0.001	0.001	0.641	0.000	0.000
2016	0.258	0.432	1.672	-0.628	1.237
2017	0.450	0.009	0.019	-4.119	10.190
GLM0 with Add Var estimated with no bounds					
	parameter	S.E.	C.V.	90% C.I	
2005	0.11	0.217	1.913	-0.243	0.470
2006	0.00	0.000	0.279	0.001	0.001
2007	0.00	0.000	0.284	0.001	0.001
2008	0.00	0.000	0.286	0.001	0.001
2014	0.00	0.000	0.060	0.001	0.001
2015	0.00	0.000	0.038	0.001	0.001
2016	0.13	0.265	2.042	-0.306	0.565
2017	0.45	0.001	0.002	0.448	0.452

The Final set of runs used the GLM standardized 0+ index as described in Campbell et al. (2019). The analysis of Campbell et al. (2019) accounts for a range of factors which may influence the survey index, and as some of these factors are environmental variables, the standardized series implicitly accounts for part of the process error. For this reason, the base GLM0 scenario (scenario (c) in Table 9-7a) does not also include estimation of additional variance. Although this scenario is not directly comparable using AIC to the Model version 1 scenario because they use different data inputs, the use of the GLM0 series is seen to substantially improve the fit to the 0+ and 1+ preseason survey indices. This is partly because the GLM0 series estimates a substantially larger C.V. associated with the 2017 0+ observation. When the GLM0 scenario was run in conjunction with estimation of 8 additional variance parameters, these scenarios (d and h) were not preferred (using AIC) relative to the base GLM0 scenario. The base GLM0 (c) is therefore the preferred model using the GLM0 index. Overall the results are fairly similar to the non-GLM with A.V. estimated preferred scenario (g) which provides further confidence in terms of using model (g) as the basis for developing management advice.

Model fits

The fits of the Model to all available data sources are shown in Figure 9-1 to Figure 9-9. The results are shown primarily for the TRLRAG Revised Reference Case, with additional results presented at the previous TRLRAG and to be presented at the forthcoming TRLRAG. The starting number of lobsters is estimated and Figure 9-1 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 9-2.). 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 Fig. 1-3.

The model fits to the catch at age data are adequate (Figure 9-4). 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 nine data points available from the Pre-season survey for the TRLRAG Revised Reference Case, and the model was fitted to data on both 0+ and 1+ abundance, with a close fit evident for the 1+ (Figure 9-5). 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. The model doesn't fit the 2017 0+ index as the variability associated with this value is high and the model likelihood contribution is weighted by the inverse of the variance (see Appendix A). The Revised Reference Case incorporates a large additional variance associated with the 2017 0+ observation which allows the model to fit the 2018 1+ index reasonably.

Comparisons between CPUE data from the TVH sector (in kg per tender-day from 1994 to 2018) and corresponding model-predicted estimates are shown in Figure 9-6a (when fixing the lower bound of sigma at 0.15). Similarly, Figure 9-6b shows the fit to the standardised CPUE TIB data as described in Chapter 4. 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 historic data and model estimates of the proportions of 1+ and 2+ lobsters in the catch is shown in Figure 9-7. 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 9-8, and the stock-recruit residuals are shown in Figure 9-9., from which it is clear that recruitment has been high over the recent period but has declined substantially during the past two years. There is considerable variation about the stock-recruit curve (as is expected), but nonetheless there is some support for an underlying stock-recruit relationship.

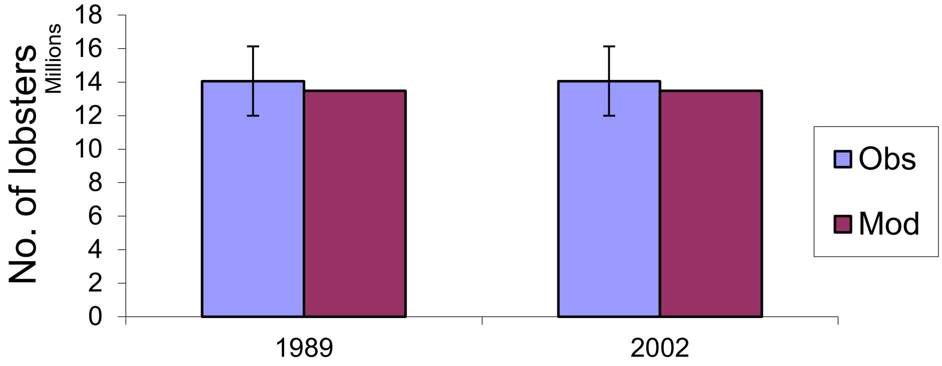
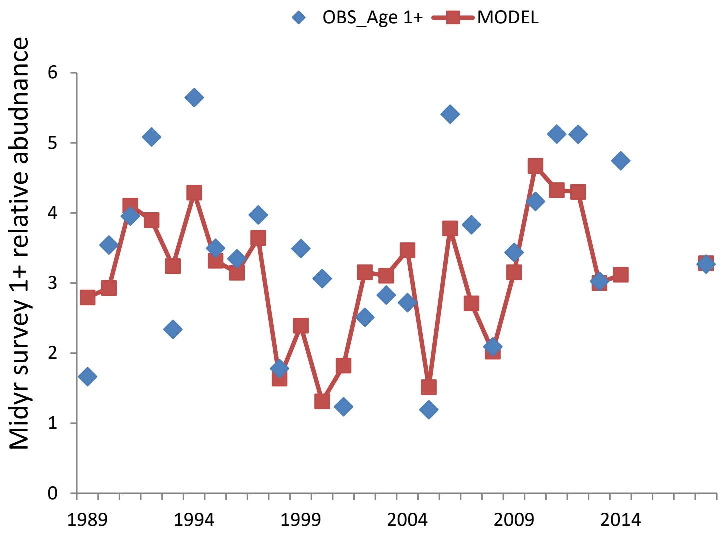
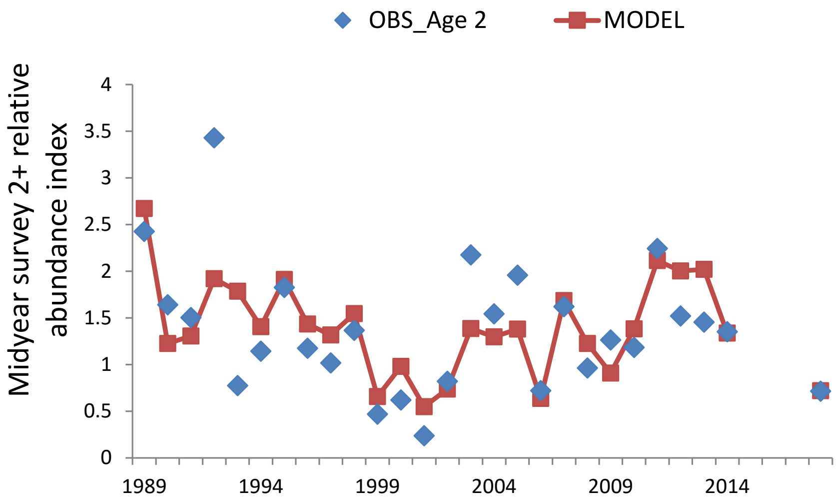


Figure 9-1. Comparison of benchmark survey observed lobster total abundance (with standard errors) and corresponding Revised Reference Case model-estimates of abundance.





Fit shown when combining total numbers from survey

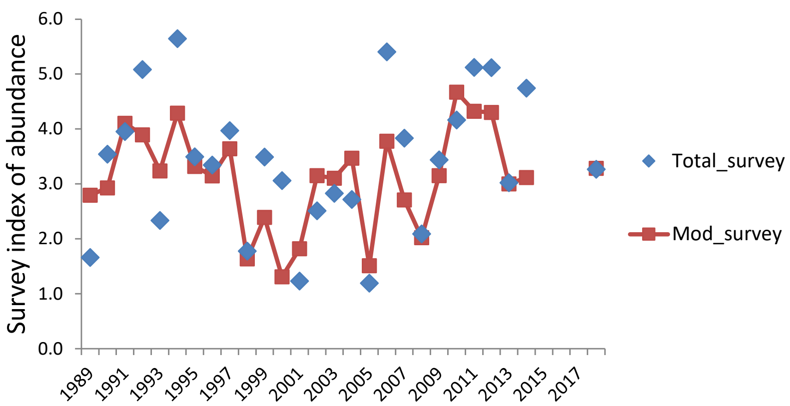
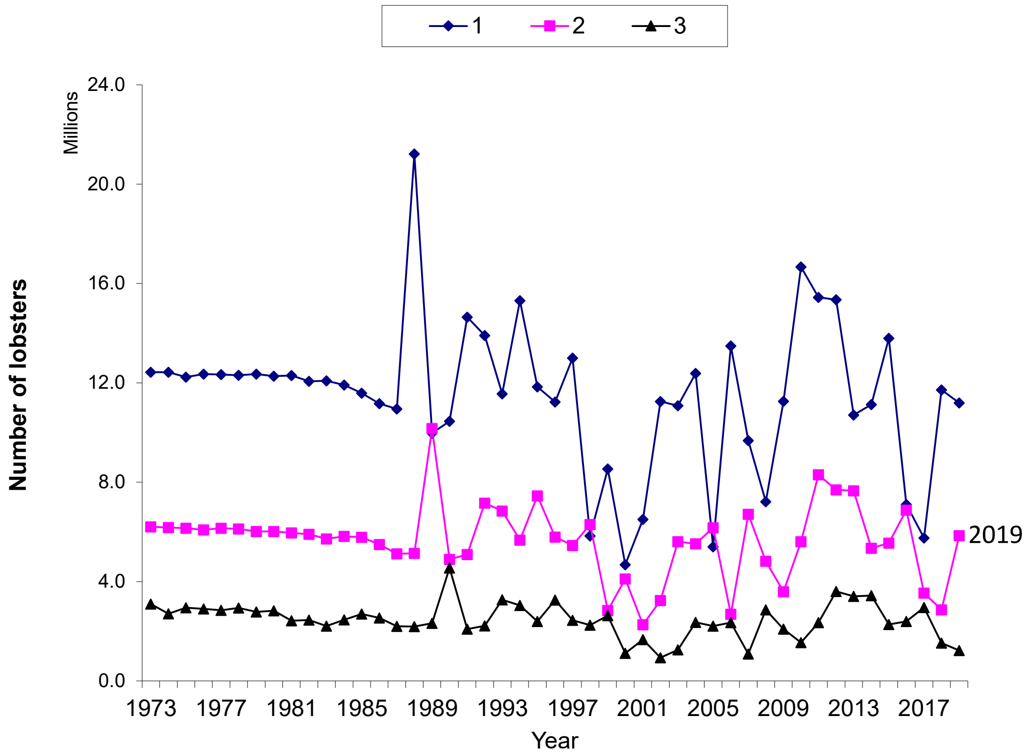
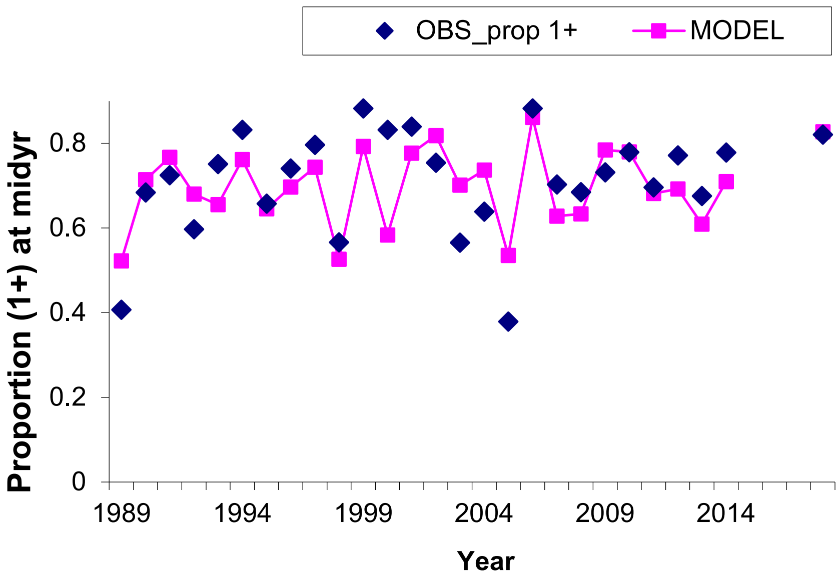


Figure 9-2. Comparison between survey midyear index of abundance (in terms of total numbers of 1+ and 2+ lobsters) compared with the corresponding model-estimated values for TRLRAG Revised Reference Case.



1
2
3
Millions
Number of lobsters
24.0
20.0
16.0
12.0
8.0
4.0
0.0
2019
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
2013
2017
Year



OBS_prop 1+
MODEL
Proportion (1+) at midyr
0.8
0.6
0.4
0.2
0
1989
1994
1999
2004
2009
2014
Year

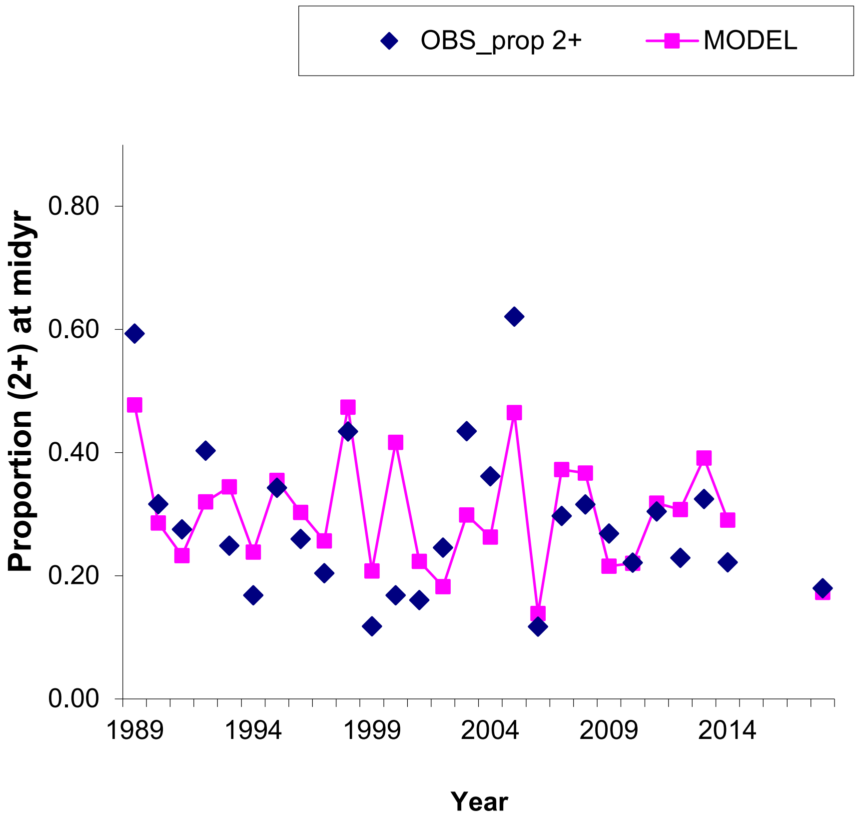
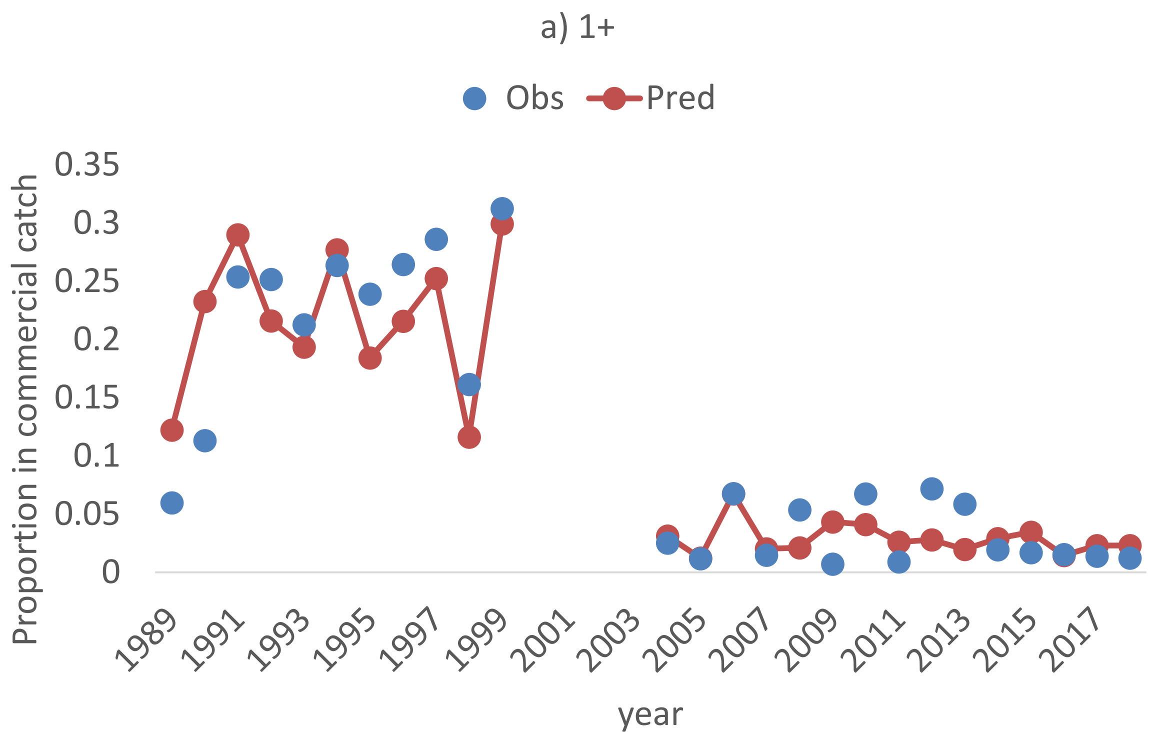


Figure 9-3. Comparison between observed and model-predicted proportions of 1+ and 2+ lobsters in the midyear survey



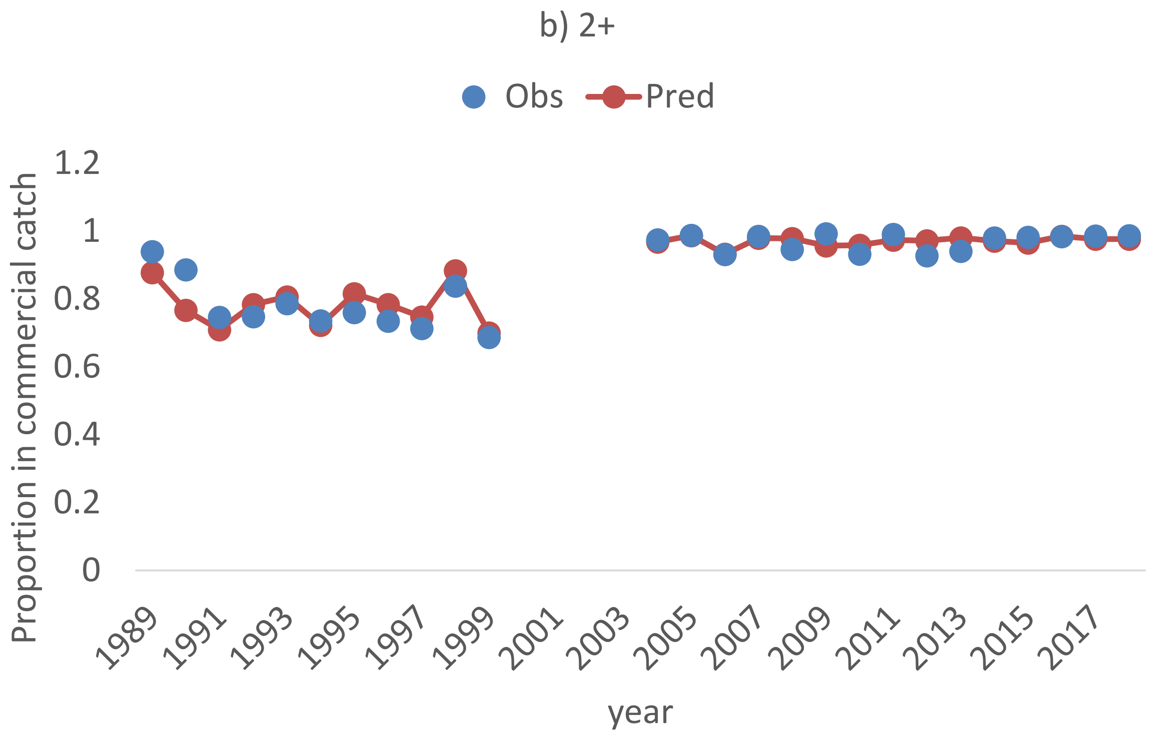
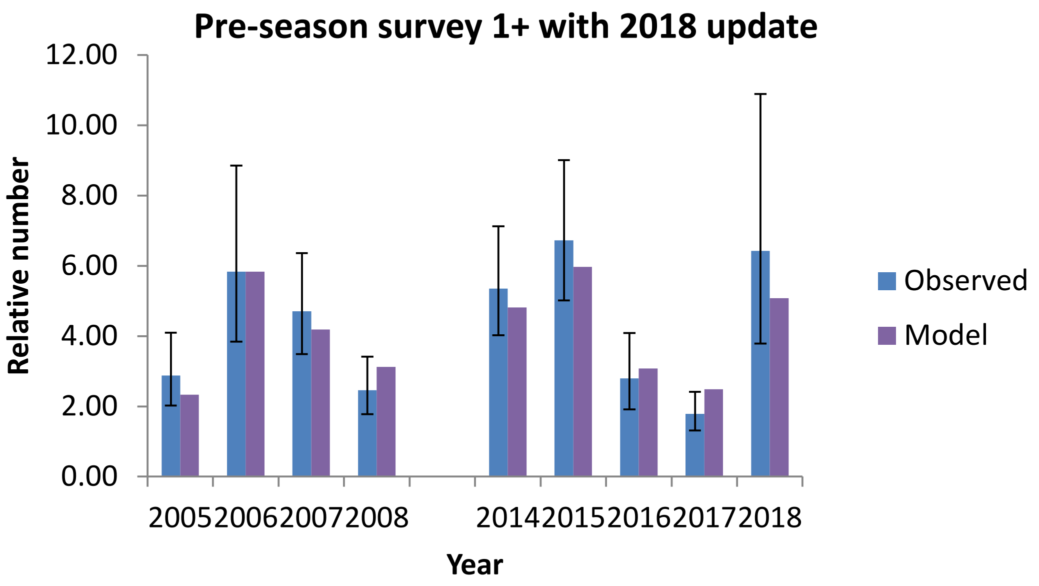


Figure 9-4. Comparison between available commercial catch-at-age data and corresponding model-predicted estimates.

(A)



(B)

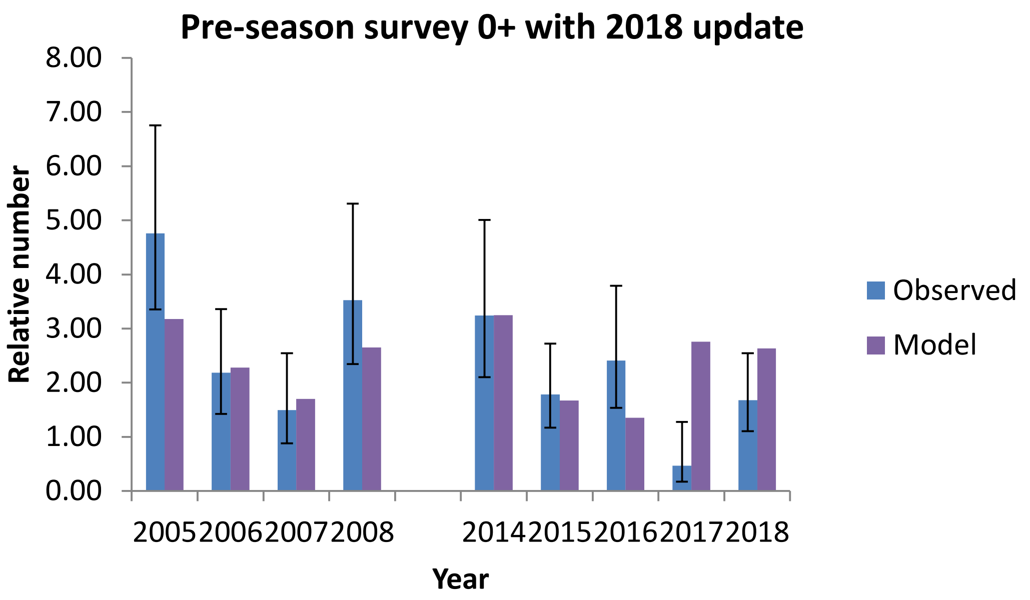
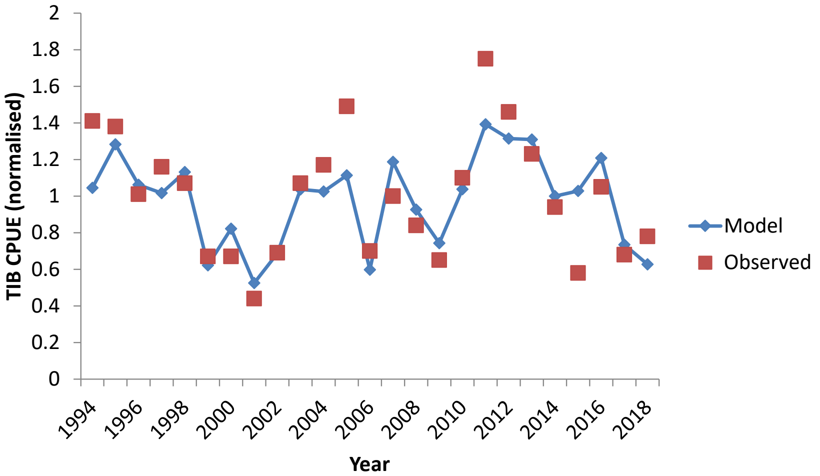


Figure 9-5. Comparison between observed Pre-season survey data (expressed in terms of number * 104) and corresponding (A) 1+ and (B) 0+ model-predicted estimates for TRLRAG Revised Reference Case which incorporates estimation of Additional Variance associated with each of the 0+ observations.

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



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

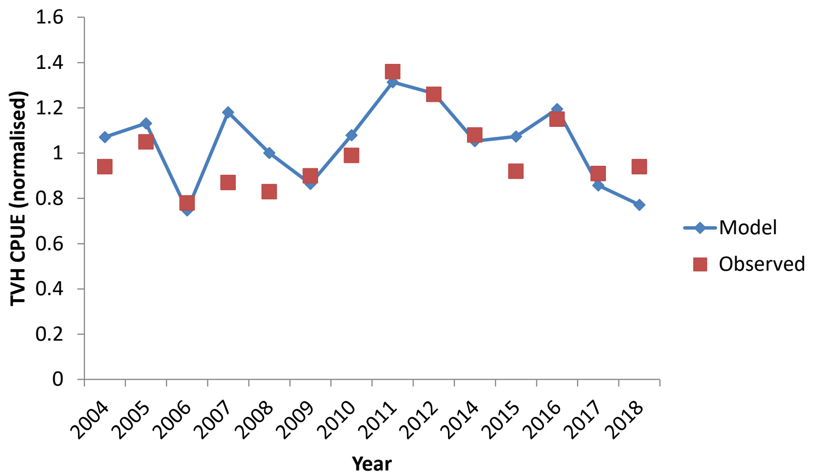


Figure 9-6. Comparison between CPUE data and corresponding model-predicted estimates. The plots are respectively a) Revised reference-Case fit to CPUE standardised estimates from the TVH sector with lower bound for sigma set at 0.15, b) fit to TIB CPUE standardized estimates available from 2004-2018. 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.

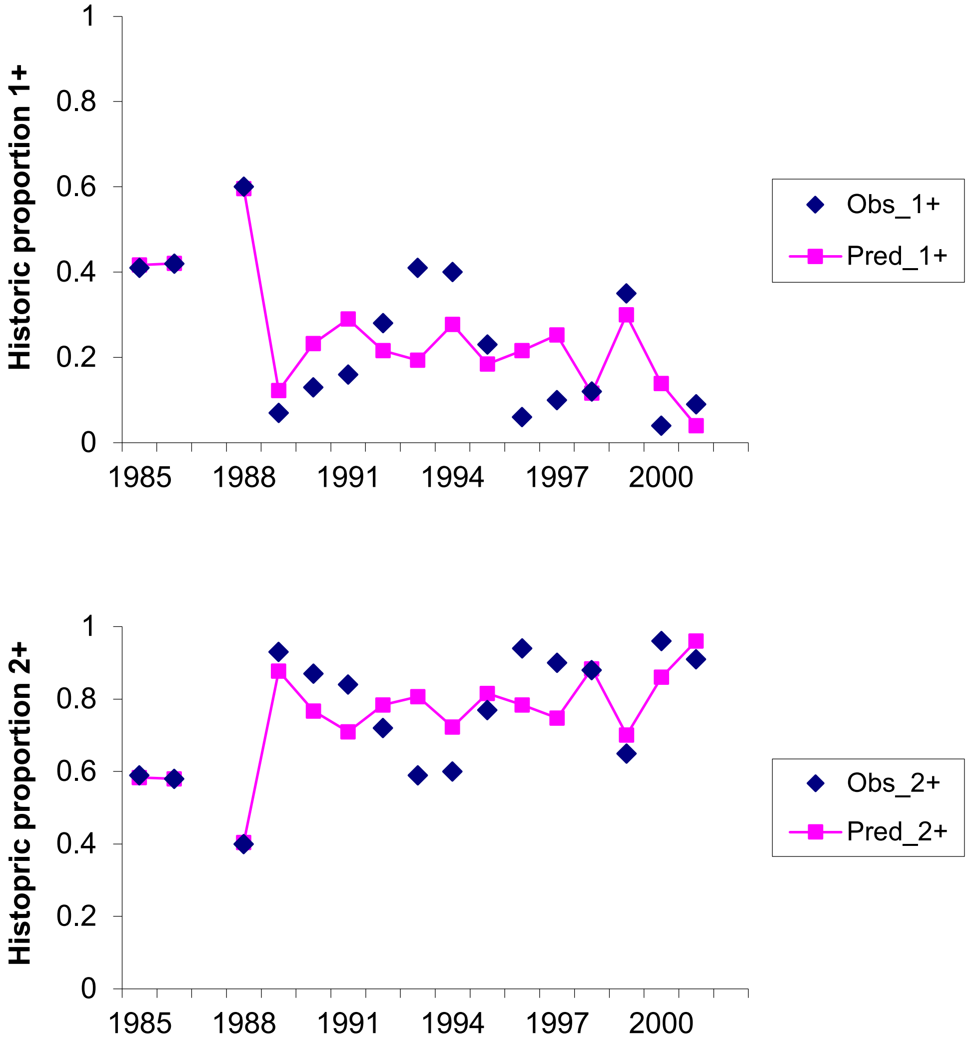


Figure 9-7. Comparison between historic data and model estimates of the proportions of 1+ and 2+ lobsters in the catch.

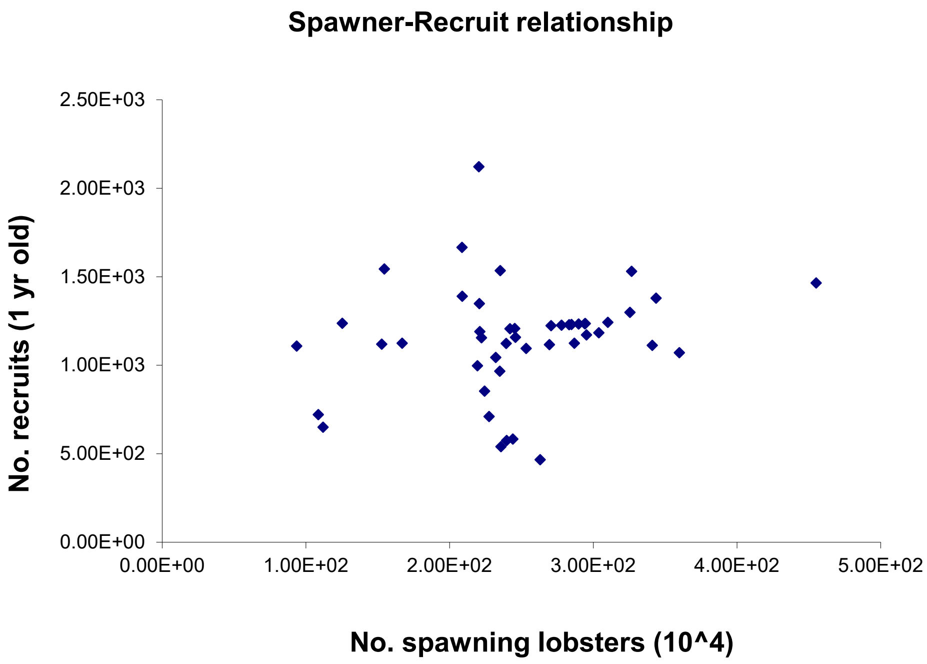


Figure 9-8. Integrated model stock recruitment relationship showing relative number of recruits R as a function of the spawning biomass Bsp for Revised Reference Case.

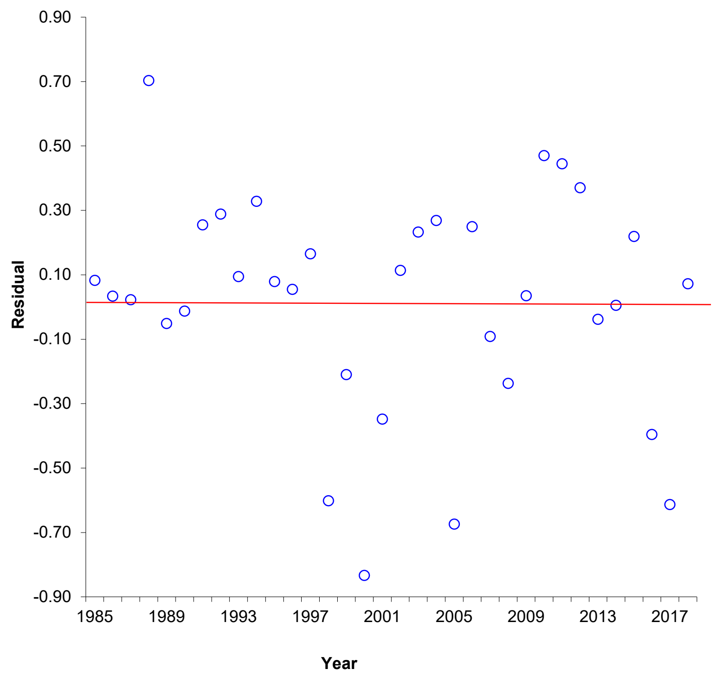


Figure 9-9. Plot of stock-recruit residuals, where recruits are defined as 1+ lobsters. Note the low 2017 residual compared with the roughly average 2018 residual

Estimates of model parameters

A full set of model parameter estimates, depletion statistics and likelihood contributions for the TRLRAG Revised Reference Case including 2018 Pre-season survey and a range of alternative model versions is shown in Table 9-8. In all cases the 90% Hessian-based Confidence Intervals (CI) are given alongside. The Revised Reference model estimates a total of 47 parameters, namely the starting biomass $B(1973)^{sp}$, natural mortality *M*, 1+ selectivity for the 1973-1988, 1989-2001 and post-2002 periods, 34 stock-recruit residuals and 8 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. 1995). However sensitivities to this are also tested given previous assessments suggesting *h* may be lower. The natural mortality estimate of 0.69 [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 the Torres Straits. 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 9-10.), with a decreasing trend evident following the implementation of the new management measures in 2002. The fishing mortality rate for age 2+ lobsters ranged from 0.09 year^{-1} to 0.27 year^{-1} (Figure 9-10.), with a historic average (from 1989) of 0.15 year^{-1}. The target fishing mortality rate is 0.15 year^{-1}. The 2018 catch of 299t was assessed to have been at the target fishing mortality rate (0.15) which suggests that the management decision to limit catches at this low level in 2018 was appropriate.

The fishing mortality estimates above refer to the combined estimate when lumping all TRL catches in the Torres Straits, 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 9-11., with small catches taken during the period (2001-2003) and zero values for all other years, except for some recent reports that are under discussion by the TRLRAG.

A summary of previous RBC and TACs is shown in Table 9-10.

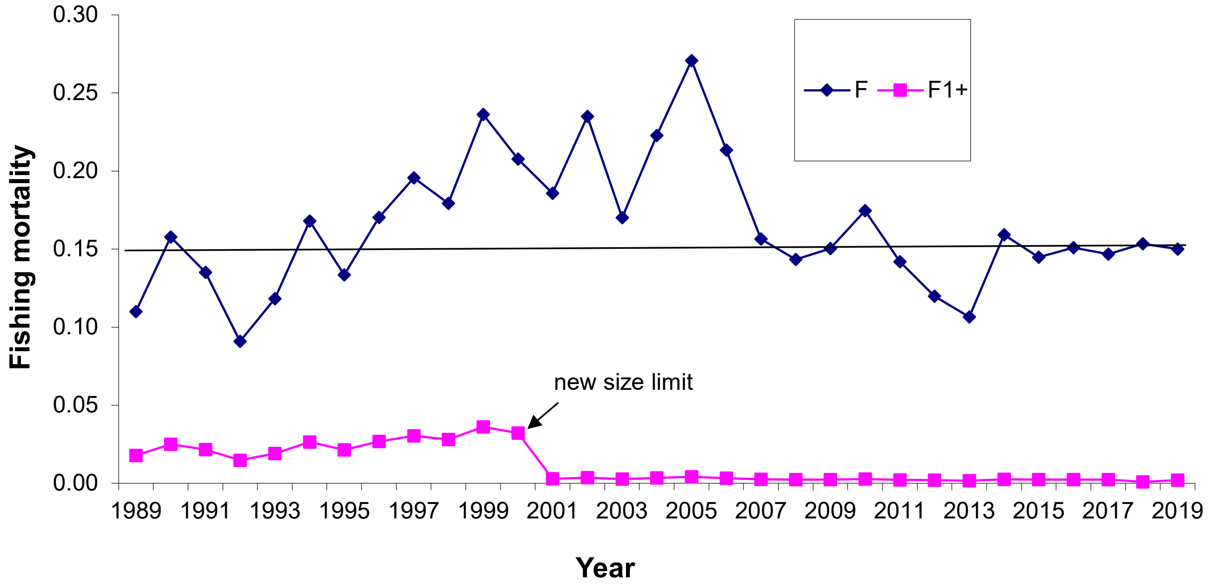


Figure 9-10. Model-estimated fishing mortality trends for 1+ (F 1+star) and 2+ (F 2+ star) lobsters. The 2002 change in size limit is highlighted and the 2019 fishing mortality set equal to the target value of 0.15.

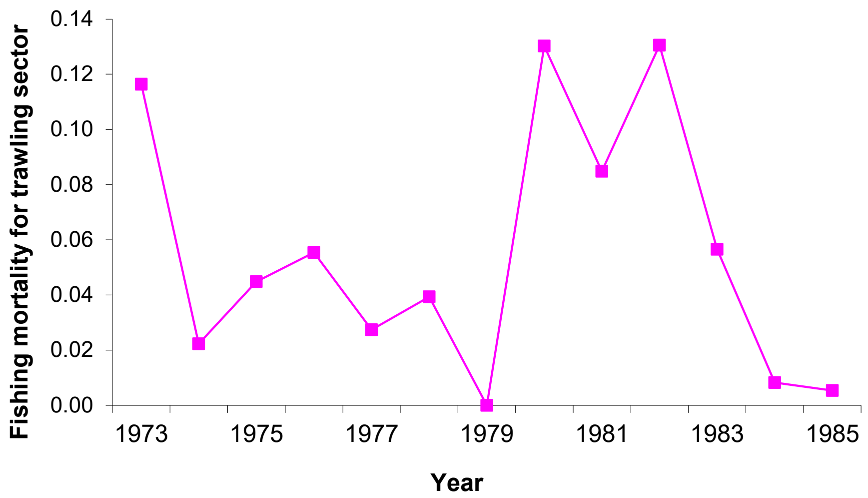


Figure 9-11. Model-estimated trawling sector fishing mortality trends for the early period of the fishery from 1973 - 1985.

Table 9-8. Summary of model parameter estimates for the Revised Reference Case and model variants as described in the text. The likelihood contributions from fitting to the preseason survey data are highlighted to facilitate comparison across model versions.

	(a) Model version 1			(2) Model not fitting Preseason 0+ index			(b) Additonal Variance (AV) Pars estimated			(c) Model with GLM0		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
B(1973) ^{sp} *(tons)*	4326	3095	5556	4551	3243	5859	4459	3182	5735	4332	3108	5557
M	0.69	0.57	0.82	0.69	0.57	0.82	0.69	0.57	0.82	0.69	0.57	0.82
h	fixed 0.7			fixed 0.7			fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.42	0.23	0.60	0.42	0.23	0.61	0.42	0.23	0.61	0.42	0.23	0.60
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19
Sel (age 1+) post2002	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03
Recruitment residuals (1985-2018)		34 parameters			34 parameters			34 parameters			34 parameters	
Model estimates and depletion statistics												
B(2018) ^{sp} *(tons)*	2204	1451	2958	1953	1251	2654	1994	1275	2713	2140	1408	2873
RBC(2019) model	533	359	708	691	457	925	645	429	862	601	402	801
RBCforecast(2020) model	600	435	765	625	451	799	614	444	785	600	436	764
Current Depletion (Nov)												
B(2018) ^{sp} */ B(1973)sp*	0.52	0.38	0.66	0.44	0.31	0.56	0.46	0.32	0.59	0.51	1407.71	2872.69
Bexp(2018) (tons)	2518	1782	3255	2295	1604	2986	2329	1623	3035	2465	1747	3182
No. parameters estimated	39			39			47			39		
'-lnL:overall	**-182.113**			-187.39			-190.550			-189.807		
AIC	**-286.226**			-296.780			-287.100			-301.614		
Likelihood contributions		**Sigma**	**q**		Sigma	q		Sigma	q		Sigma	q
'-lnL:CAA	-65.87	0.05		-65.93	0.05		-65.92	0.05		-65.90	0.05	
'-lnL:CAAsurv	-20.35	input from data		-20.64	input from data		-20.53	input from data		-20.33	input from data	
-lnL:CAA historic	-21.99	0.13		-21.97	0.13		-21.97	0.13		-21.97	0.13	
-lnL:Survey Index 1+	-19.56	input from data	3.937E-07	-19.13	input from data	3.931E-07	-19.53	input from data	3.940E-07	-19.85	input from data	3.928E-07
-lnL:Survey Index 2+	-15.38	input from data	4.089E-07	-15.66	input from data	4.125E-07	-15.57	input from data	4.126E-07	-15.58	input from data	4.101E-07
-lnL:Survey benchmark	-3.13	input from data		-3.13	input from data		-3.13	input from data		-3.13	input from data	
'-lnL:PRESEASON	-7.97	input from data	8.033E-07	-10.54	input from data	8.101E-07	-10.14	input from data	8.113E-07	-8.43	input from data	8.121E-07
-lnL:PRESEASON 0+	2.68	input from data	2.214E-07	1.62	input from data	2.036E-07	-3.37	input from data	2.221E-07	-3.86	input from data	9.896E-08
-lnL:CPUE (TVH)	-21.48	0.26	0.0019	-21.12	0.27	0.0019	-21.22	0.26	0.0019	-21.61	0.26	0.0019
-lnL:CPUE (TIB)	-16.71	0.18	0.0162	-16.92	0.18	0.0163	-16.78	0.18	0.0163	-16.79	0.18	0.0162
'-lnL:RecRes	7.63	0.50	(input sigma 0.5)	7.64	0.50	input sigma 0.5	7.61	0.50	input sigma 0.5	7.64	0.50	(input sigma 0.5

Table 9-8 (b) continued

	(a) Model version 1			(d) Model with Add Var estimated & GLM0			(e) Single Preseas0 AV estimate			(f) Single Preseas0 AV for 2017 only		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
B(1973)^{sp} (tons)	4326	3095	5556	4482	3200	5763	4687	3332	6043	4558	3243	5872
M	0.69	0.57	0.82	0.69	0.57	0.82	0.69	0.57	0.81	0.69	0.56	0.82
h	fixed 0.7			fixed 0.7			fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.42	0.23	0.60	0.42	0.23	0.61	0.43	0.24	0.62	0.42	0.23	0.62
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19
Sel (age 1+) post2002	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03
Recruitment residuals (1985-2018)		34 parameters			34 parameters			34 parameters			34 parameters	
Model estimates and depletion statistics												
B(2018)^{sp} (tons)	2204	1451	2958	2016	1287	2746	1815	1087	2542	2066	1284	2848
RBC(2019) model	533	359	708	656	436	876	676	443	908	712	469	956
RBCforecast(2020) model	600	435	765	618	447	789	628	448	808	610	437	782
Current Depletion (Nov)												
B(2018)^{sp} / B(1973)sp	0.52	0.38	0.66	0.46	0.32	0.59	0.39	0.26	0.52	0.46	0.32	0.60
Bexp(2018) (tons)	2518	1782	3255	2352	1636	3068	2165	1448	2882	2411	1642	3180
No. parameters estimated	39			47			40			40		
'-lnL:overall	**-182.113**			-191.912			-179.980			-183.491		
AIC	**-286.226**			-289.824			-279.960			-286.982		
Likelihood contributions		**Sigma**	**q**		Sigma	q		Sigma	q		Sigma	q
'-lnL:CAA	-65.87	0.05		-65.93	0.05		-66.00	0.04		-65.93	0.05	
'-lnL:CAAsurv	-20.35	input from data		-20.54	input from data		-20.55	input from data		-20.23	nput from data	
-lnL:CAA historic	-21.99	0.13		-21.98	0.13		-21.74	0.13		-21.73	0.13	
-lnL:Survey Index 1+	-19.56	input from data	3.937E-07	-19.35	input from data	3.936E-07	-25.78	input from data	3.789E-07	-25.91	nput from dat	3.785E-07
-lnL:Survey Index 2+	-15.38	input from data	4.089E-07	-15.66	input from data	4.122E-07	-13.94	input from data	3.971E-07	-13.90	nput from dat	3.961E-07
-lnL:Survey benchmark	-3.13	input from data		-3.13	input from data		-3.14	input from data		-3.14	nput from data	
'-lnL:PRESEASON	-7.97	input from data	8.033E-07	-9.77	input from data	8.137E-07	-11.79	input from data	7.193E-07	-10.85	nput from dat	7.243E-07
-lnL:PRESEASON 0+	2.68	input from data	2.214E-07	-4.72	input from data	9.499E-08	-0.19	input from data	1.645E-07	-4.79	nput from dat	2.225E-07
-lnL:CPUE (TVH)	-21.48	0.26	0.0019	-21.42	0.26	0.0019	-8.40	0.44	0.4116	-8.42	0.44	0.4117
-lnL:CPUE (TIB)	-16.71	0.18	0.0162	-17.00	0.18	0.0163	-16.31	0.19	0.4329	-16.31	0.19	0.4328
'-lnL:RecRes	7.63	0.50	(input sigma 0.5)	7.57	0.50	(input sigma 0	7.84	0.50	(input sigma 0.5)	7.72	0.50	nput sigma 0.5

Table 9-8 (c) continued

	(a) Model version 1			(g) AV Pars estimated no lower bounc			(h) GLM0 & AV estimated no lower bou		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
$B(1973)^{sp}$ (tons)	4326	3095	5556	4439	3168	5710	4472	3194	5750
M	0.69	0.57	0.82	0.69	0.57	0.82	0.69	0.57	0.82
h	fixed 0.7			fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.42	0.23	0.60	0.42	0.24	0.61	0.42	0.23	0.61
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19
Sel (age 1+) post2002	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03
Recruitment residuals (1985-2018)		34 parameters			34 parameters			34 parameters	
Model estimates and depletion statistics									
$B(2018)^{sp}$ (tons)	2204	1451	2958	1969	1260	2678	2013	1286	2740
RBC(2019) model	533	359	708	641	426	857	656	436	876
RBCforecast(2020) model	600	435	765	612	442	781	618	447	788
Current Depletion (Nov)									
$B(2018)^{sp}$ / B(1973)sp	0.52	0.38	0.66	0.45	0.32	0.59	0.46	0.32	0.59
Bexp(2018) (tons)	2518	1782	3255	2304	1607	3000	2349	1635	3062
No. parameters estimated	39			47			47		
'-lnL:overall	**-182.113**			-191.779			-193.558		
AIC	**-286.226**			-289.558			-293.116		
Likelihood contributions		**Sigma**	**q**		Sigma	q		Sigma	q
'-lnL:CAA	-65.87	0.05		-65.79	0.05		-65.91	0.05	
'-lnL:CAAsurv	-20.35	input from data		-20.48	nput from data		-20.48	nput from data	
-lnL:CAA historic	-21.99	0.13		-21.98	0.13		-21.98	0.13	
-lnL:Survey Index 1+	-19.56	input from data	3.937E-07	-19.07	nput from dat	3.964E-07	-19.22	nput from dat	3.936E-07
-lnL:Survey Index 2+	-15.38	input from data	4.089E-07	-15.84	nput from dat	4.153E-07	-15.66	nput from dat	4.120E-07
-lnL:Survey benchmark	-3.13	input from data		-3.12	nput from data		-3.13	nput from data	
'-lnL:PRESEASON	-7.97	input from data	8.033E-07	-10.19	nput from dat	8.200E-07	-9.53	nput from dat	8.190E-07
-lnL:PRESEASON 0+	2.68	input from data	2.214E-07	-4.65	nput from dat	2.223E-07	-6.50	nput from dat	9.579E-08
-lnL:CPUE (TVH)	-21.48	0.26	0.0019	-21.65	0.26	0.0019	-21.62	0.26	0.0019
-lnL:CPUE (TIB)	-16.71	0.18	0.0162	-16.80	0.18	0.0163	-17.11	0.18	0.0163
'-lnL:RecRes	7.63	0.50	(input sigma 0.5)	7.79	0.50	nput sigma 0.5	7.58	0.50	nput sigma 0.

Table 9-9. Summary of model parameter estimates for the Revised Reference Case and additional sensitivities (see text for details).

	(g) AV Pars estimated no lower bound			(i) Estimate hyperstability			(j) Change steepness h		
Parameter	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**	**Parameter**	**Value**	**90% CI**
$B(1973)^{sp}$ *(tons)*	4439	3168	5710	4464	3179	5748	4603	3260	5945
M	0.69	0.57	0.82	0.69	0.57	0.82	0.69	0.57	0.82
h	fixed 0.7			fixed 0.7			**fixed 0.6**		
hyps(TVH)	fixed 0.75			**0.75**	**0.55**	**0.95**	fixed		
hyps(TIB)	fixed 0.5			**0.27**	**0.13**	**0.42**	fixed		
Sel (age 1+) 1973-1988	0.42	0.24	0.61	0.42	0.23	0.61	0.42	0.23	0.60
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19	0.17	0.15	0.19
Sel (age 1+) post2002	0.02	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.03
Recruitment residuals (1985-2018)		**34 parameters**			34 parameters			34 parameters	
<u>Model estimates and depletion statistics</u>									
$B(2018)^{sp}$ *(tons)*	1969	1260	2678	1878	1171	2584	1881	1174	2588
RBC(2019) model	641	426	857	648	430	867	648	430	866
RBCforecast(2020) model	612	442	781	612	441	783	590	423	758
Current Depletion (Nov)									
$B(2018)^{sp}$ */ B(1973)sp*	0.45	1259.81	2678.39	0.43	0.29	0.56	4533.00	3047.48	6018.52
Bexp(2018) (tons)	2304	1607	3000	2215	1521	2909	2218	1524	2912
No. parameters estimated	47			49			47		
'-lnL:overall	-191.779			-194.582			-194.613		
AIC	-289.558			-291.164			-295.226		
<u>Likelihood contributions</u>		<u>Sigma</u>	q		<u>Sigma</u>	q		<u>Sigma</u>	q
'-lnL:CAA	-65.79	0.05		-65.84	0.05		-65.84	0.05	
'-lnL:CAAsurv	-20.48	input from data		-20.44	input from data		-20.43	input from data	
-lnL:CAA historic	-21.98	0.13		-21.92	0.13		-21.91	0.13	
-lnL:Survey Index 1+	-19.07	input from data	3.964E-07	-20.47	input from data	3.919E-07	-20.57	input from data	3.917E-07
-lnL:Survey Index 2+	-15.84	input from data	4.153E-07	-15.62	input from data	4.105E-07	-15.55	input from data	4.099E-07
-lnL:Survey benchmark	-3.12	input from data		-3.13	input from data		-3.13	input from data	
'-lnL:PRESEASON	-10.19	input from data	8.200E-07	-11.07	input from data	8.101E-07	-11.07	input from data	8.100E-07
-lnL:PRESEASON 0+	-4.65	input from data	2.223E-07	-4.72	input from data	2.199E-07	-4.82	input from data	2.210E-07
-lnL:CPUE (TVH)	-21.65	0.26	0.0019	-20.70	0.27	0.0020	-20.65	0.27	0.0019
-lnL:CPUE (TIB)	-16.80	0.18	0.0163	-18.81	0.16	0.1036	-18.79	0.16	0.1045
'-lnL:RecRes	7.79	0.50	(input sigma 0.5)	8.13	0.50	(input sigma 0.5	8.14	0.50	(input sigma 0.

Table 9-10. Summary of TRLRAG Reference Case RBC.

TAC/Catch (t)	2014	2015	2016	2017	2018	2019
Forecast TAC (90% CI)	767 (518-1016)	751 (556-945)	719 (515-923)	677 (489-866)	758 (546-970)	531 (383-678)
Preliminary TAC (90% CI)	616 (294-938)	894 (571-1217) TIB: 328 t TVH: 251 t PNG: 285 t	704 (510-897) Aug 2015 Dec 2015 update	495 (315-676) TIB: 188 t TVH: 144 t PNG: 163 t	299 (196-401) TIB: 136 t TVH: 64 t PNG: 99 t	[533 – 637t] 641t
Final TAC	616	Mar 2015 (revision with preseason survey = 769t)	796	495t	299t	
Catch	682t	562t	572t	368t	328t	

Model trajectories

The model-predicted numbers of 1+ and 2+ lobsters for the entire model period are shown in Figure 9-12. 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 9-13. The stock is currently estimated to be at 46% of the pristine (1973) spawning biomass level but is expected to fluctuate widely about the average target spawning biomass level, and to increase in 2019.

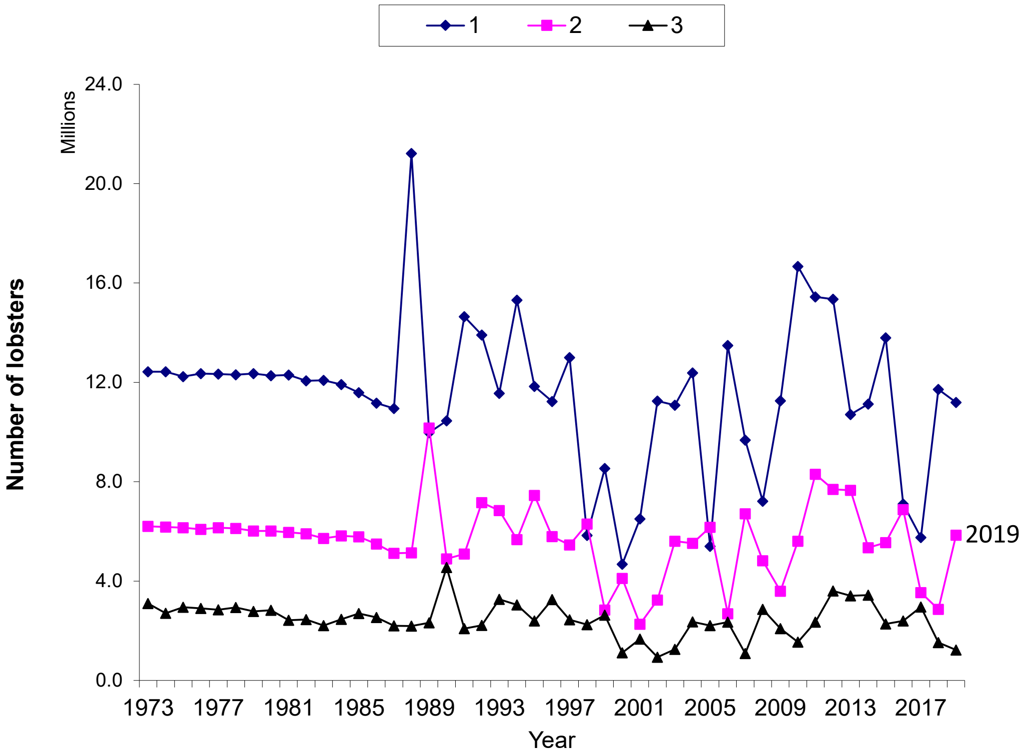


Figure 9-12. Model trajectories of the annual numbers of lobsters in each age class at the start of each of years 1973 to 2016. The increased variability from 1985 onwards is because the model estimates stock recruit residuals for years from 1985 to 2016.

.

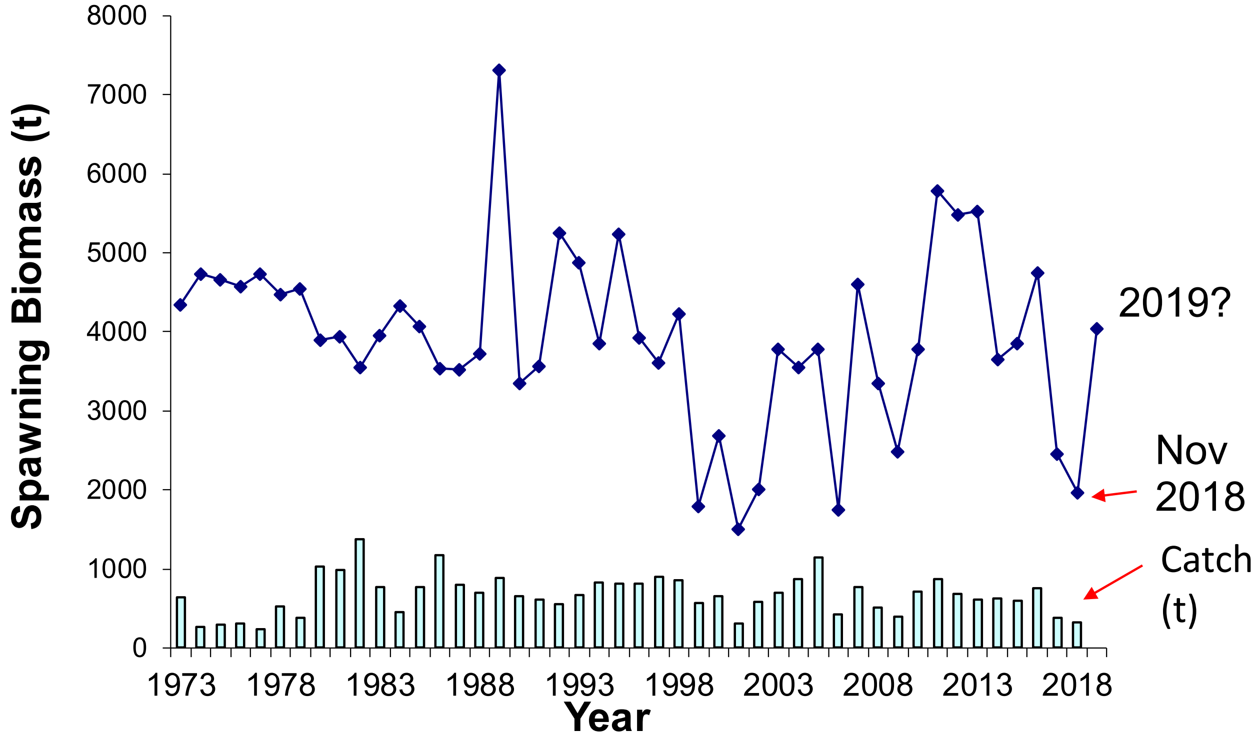


Figure 9-13. Model trajectories of the lobster spawning biomass (t) over the model period shown together with annual catches by the trawling and other sectors combined.

The model-predicted spawning biomass trajectory is shown in Figure 9-14.. The November 2018 spawning biomass for the TRLRAG Revised Reference Case is estimated to be 1969 t [1260; 2678] (Table 9-7). Fig. 1-15 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 2018 estimate is 2304t [1607; 3000], but this is predicted to increase in 2019 (Fig. 1-15).

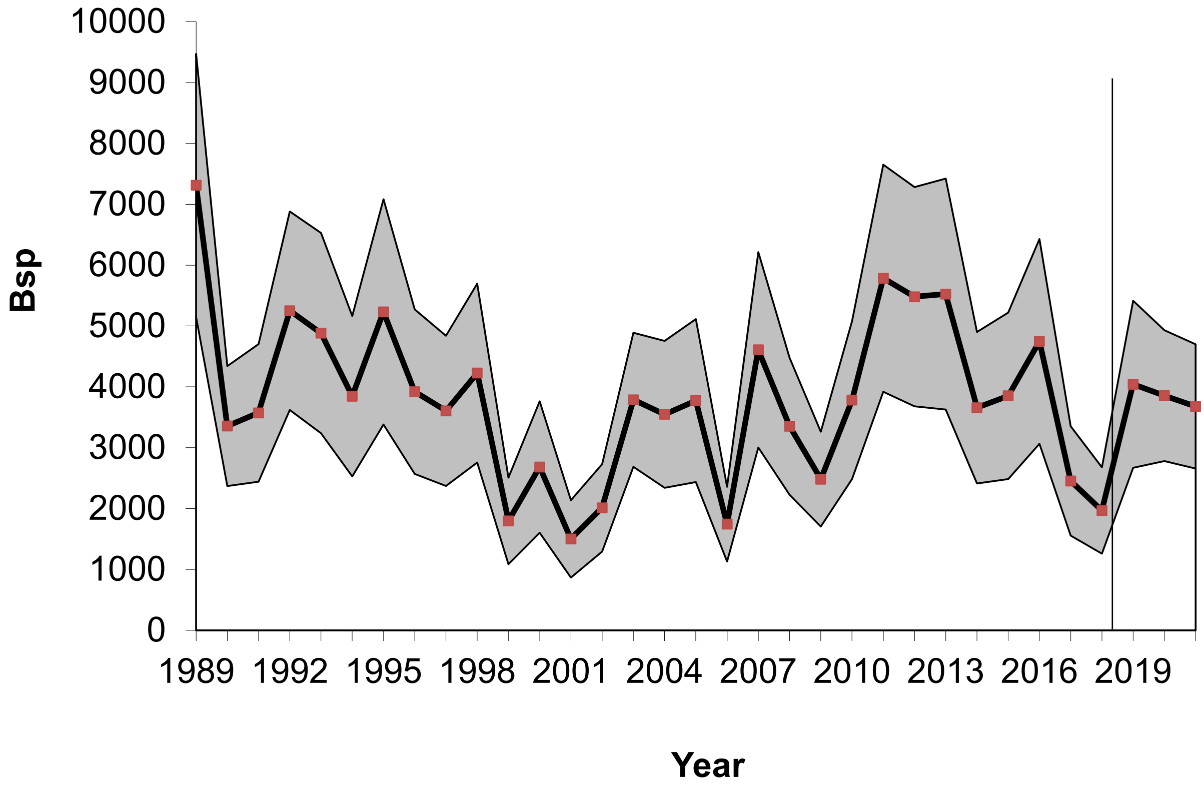


Figure 9-14. Model -predicted lobster November spawning biomass trajectory shown together with Hessian-based 90% confidence intervals for revised Reference Case model. The vertical line indicates the separation between historic and predicted estimates.

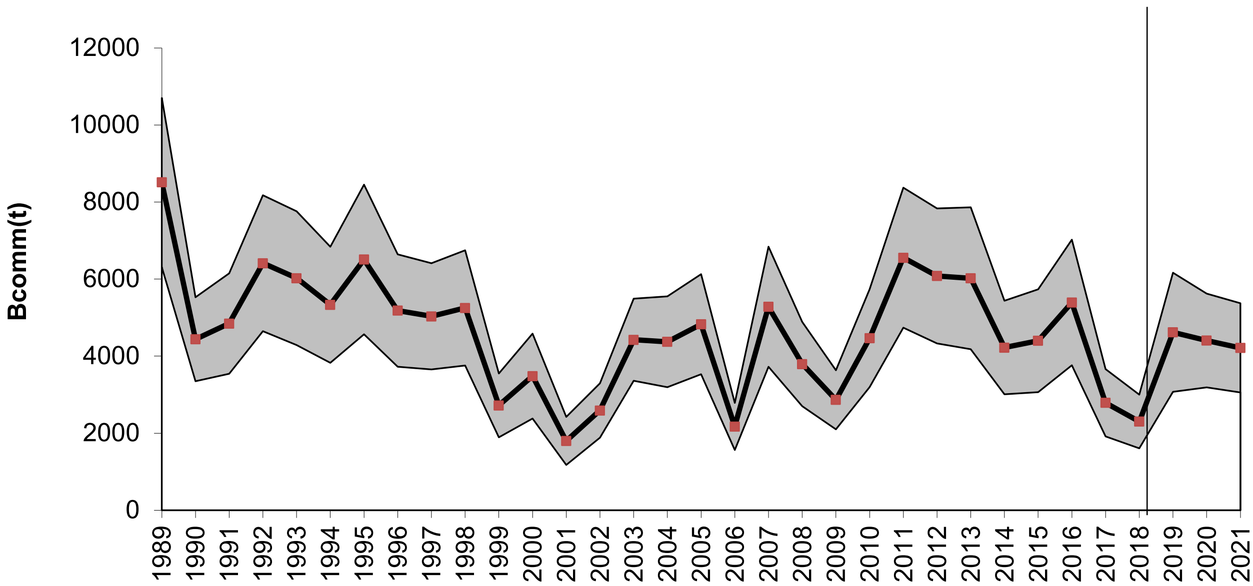


Figure 9-15. Model-predicted commercially available (also termed exploitable) lobster biomass (Bcomm), which is the sum of all 1+ and 2+ lobsters which are “available” to be caught each year. The shaded area shows the Hessian-based 90% confidence intervals. The vertical line indicates the separation between historic and predicted estimates.

Sensitivity Tests

The robustness of model results were tested across a number of important sensitivity tests, including the following which were presented at the TRLRAG December 2018 meeting:

- Fix steepness h=0.6 and try estimate
- Fix hyperstability pars CPUE (TVH 1) (TIB 1); try estimate
- Preseason survey index –
    - use the additional 5 sites added;
    - test other series particularly excluding Buru which gives lower standard error (SE) for 1+ index
    - Downweight Pre0+ (2017)
- CPUE TVH – Int3 standardised series; nominal
- CPUE TIB – Seller&A standardised series ; nominal

This report focuses on alternative methods tested to account for changes to the survey 0+ observation and process error. Full results are presented in Tables 9-8a-c, and illustrative changes in the fit to the survey data are shown below in Fig. 1-16. As previously, revised model runs are compared with a scenario that uses the 0+ preseason survey index without modification (Model 1 - (a) in Table 9-8) as well as a scenario in which these data are excluded (Model 2 Table 9-8) as a means of bounding the range of plausible alternatives. As expected, the latter model fits the preseason 1+ index very well but the fit to the 0+ data is very poor (note the likelihood contribution from comparing with the 0+ series is shown for illustrative purposes, but is not included in calculation of the total likelihood for this scenario).

The change in the model results was fairly consistent when introducing alternative analyses to address the model conflict. Decreasing the lower bound of the estimated additional variance parameters has a negligible impact on the estimate of RBC(2019) - 645 vs 641 for models (b&g) and no change (656) for models (d&h) - and all four results are relatively similar (within 2%). On the other hand the GLM0 only model has an RBC of 601 which is 6% lower than model (g). All are higher than the base model (a) estimate of 533.

Based on the earlier set of sensitivity analyses, a couple of additional sensitivity analyses were run using the revised Reference Case Model. Estimating (instead of fixing) the hyperstability parameters for the TIB and TVH CPUE series had only a small effect on model results (Table 9-9, Fig. 1-17), although the estimated value for the TIB series was lower than currently used. Both parameters were reasonably estimated in the model and the version with these parameters estimated had an improved AIC but the difference was less than 2. This will therefore be investigated further in future work, and before changes are made it is recommended that the data subgroup first review any recommendations for changing the input CPUE series.

Decreasing the stock-recruitment steepness parameter *h* from 0.7 to 0.6 resulted in a small improvement in the likelihood and AIC values (Table 9-9), and there was some support for a lower steepness value, which is being investigated further in ongoing work.

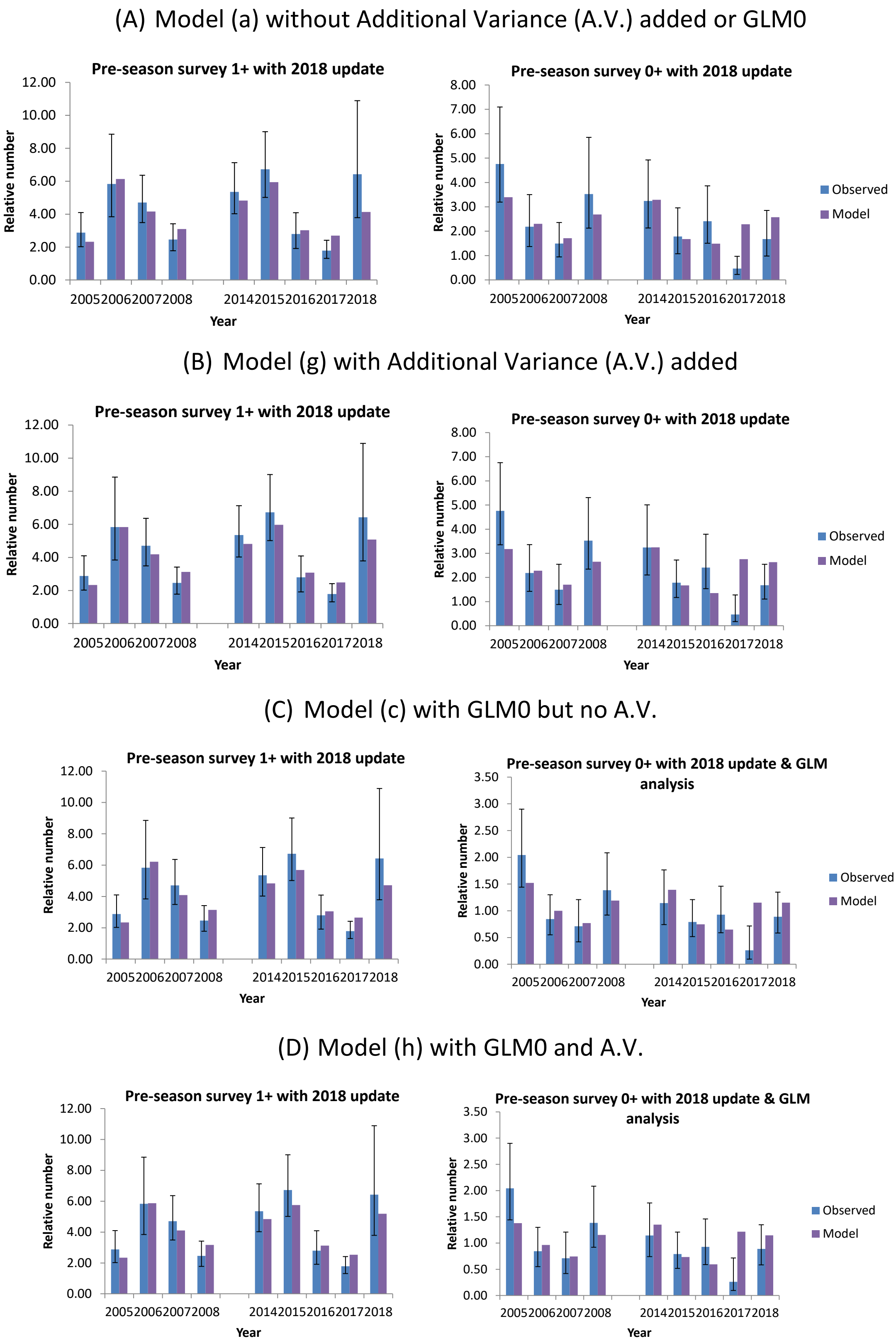
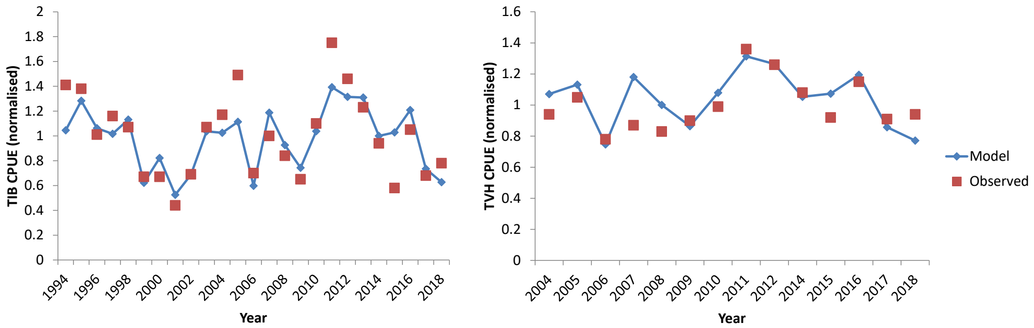


Figure 9-16. Comparison of model fits to preseason survey 0+ and 1+ index using (A) Model version 1 with no Additional Variance (A.V.) estimated versus (B) Revised Reference Case model (g) with A.V. estimated, as well as alternative (C) GLM-standardised 0+ index used and (D) GLM0 and A.V. estimated.

(A) Revised Reference Case (model (g) FIT TO TVH CPUE and TIB CPUE data with fixed hyperstability parameters



(B) Sensitivity analysis when estimating hyperstability parameters

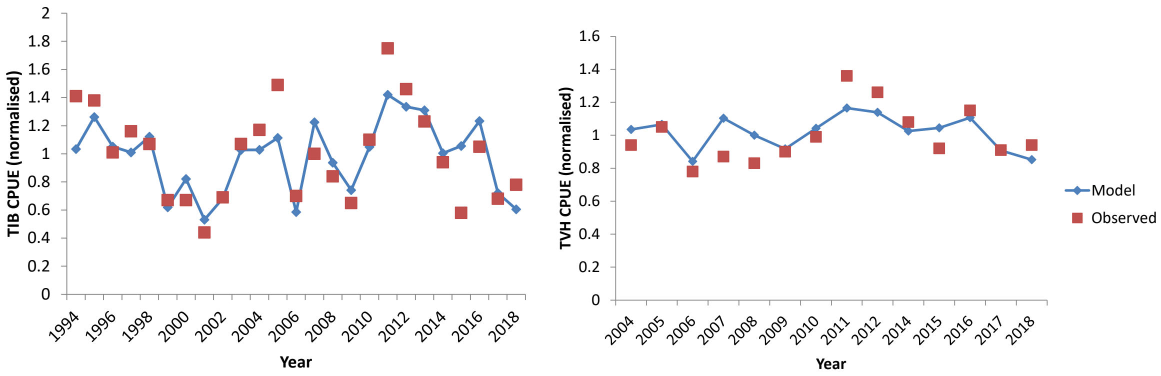


Figure 9-17. Comparison of model fits to CPUE standardised series using (A) Revised Reference Case model (g) and (b) model with hyperstability parameters estimated

9.6 Discussion

The revised and updated model adequately fits the available data and integrates all available information to output a RBC value as required for management. The use of a single model facilitates understanding of the way in which data inputs translate into an assessment of the status and productivity of the resource and hence an associated RBC estimate. Moreover, parameter estimates and resource trajectories are presented together with confidence intervals to illustrate the extent of uncertainty associated with model predictions.

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 during a related MSE project as well as in ongoing work.

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. As more and better surveys are added, it becomes possible to set less conservative TACs.

The TRLRAG is currently considering adopting a pre-tested harvest control rule that 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 (Plaganyi et al. 2018). The advantage of the latter approach is that it can be 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.

Following the advice from the December 2018 RAG to apply a statistically calculated down-weighting to the 2017 0+ index, this document has therefore selected a revised Reference Case that includes estimation of Additional Variance for all 0+ survey observations. This document presents full results for this illustrative case as well as summary results for other variants, with the final choice of model version to be used to inform the RBC to be finalised at the forthcoming TRLRAG meeting, and hence note that the final RBC may differ from the revised reference case value presented here.

The revised reference case model suggests a RBC (2019) of 641t [90% CI 426-857t]. Using the revised reference case, the stock is currently estimated to be at 46% of the pristine (1973) spawning biomass level (K). Previous analyses forewarned that the 2018 spawning biomass may be lower than average and provides support for the management decisions taken in 2018 to limit catches so that sufficient lobsters would remain for spawning purposes and subsequent recruitment to the fishery in 3 years' time. Fortunately the good 1+ numbers observed in the most recent survey means that the model spawning biomass projection for the following year is once again much more positive. The very large inter-annual variability in the stock has long been recognised. Hence it is entirely plausible that the current lobster stock have been boosted by good recruitment, however we suggest ongoing monitoring of 2019 catch and the next survey observations will be prudent.

Chapter 10 Biological and scientific considerations regarding change to fishing season dates for TRL Fishery

SUMMARY

- The current cycle of opening the fishery (hookah ban in Dec-Jan) in December fits well with the biology of the stock and hence data and analysis requirements for informing catch limits. However, as the pre-season survey is conducted in November each year (and there are several reasons why this date shouldn't be changed), this leaves very little time for review and bilateral discussions regarding the Recommended Biological Catch (RBC). Hence a later fishing season opening date (e.g. 1 February or 1 March) as proposed by AFMA might be more practical from a management perspective.
- The key information required to support recommendations for the following fishing season are:
    - November pre-season survey index of recruitment strength (this measures the abundance of the incoming 1+ cohort that will comprise the majority of the 2+ cohort that is fished the following calendar year)
    - Total Annual Catch from previous season – this catch needs to include all 2+ lobsters caught up until the end of September, by which time most have migrated north-east out of Torres Strait towards breeding grounds. Hence the fishery is closed in October-November. The total catch thus needs to be summed over the period December to October the following year. The PNG catch total is also required.
    - Catch-Per-Unit-Effort (CPUE) from TIB and TVH sectors. These data provide an index of the 2+ cohort abundance and hence an indication of the spawning biomass. It isn't essential to include data from Dec-Jan in an analysis as most of the lobsters caught during that time are residual non-migratory large males that do not contribute to spawning (as shown in previous CSIRO analyses). Although some larger faster-growing animals from the new cohort will be included in the December-January catch, this is a relatively small proportion and the new 2+ cohort currently starts entering the fishery from February-March. Hence it is important to use a CPUE index from the period February-September, when most 2+ lobsters have recruited, as an index of relative abundance to inform management recommendations for the next season. The CPUE data are standardised (see e.g Campbell *et al.* 2017) before being input to the stock assessment model or empirical Harvest Control Rule (eHCR). At the moment the TVH analyses included a month-effect and use the months February-September while the TIB analyses include a quarter-effect and use data from all quarters (and hence all months, with diving method recorded as another variable i.e. data for the hookah closure periods are standardised accordingly). There is always a concern that fishing practices may change with a change of the start of a season, but hopefully the information on methods, and so forth is enough to account of any such changes. Also, it would be

possible to just standardise both the TVH and TIB over the February-September period as suggested above to best capture the spawning 2+ abundance. If this change is done, then a change in the season start from 1-December to 1-February should not be a concern.

- Other considerations include:
    - There is a high market demand for lobsters early in the year (Jan-Feb) due to Chinese New Year. The recent dates for Chinese New Year were 19 February (2015), 8 Feb (2016), 28 January (2017), 16 February (2018) and 5 February 2019 and these dates likely influence the pattern of fishing as shown in Figure 10-1 and Figure 10-2.
    - There is an increased cultural and economic demand from the TIB sector for catching lobsters during the Christmas period
    - Based on recent total catch statistics, when compared to the TAC (Total Allowable Catch), it can be assumed that the TAC is likely to be caught in most years, and hence consideration needs to be given to reducing the risk that the TAC will be caught and the fishery closed before one of the high demand periods as outlined above. In addition, to be consistent with the previous history of the fishery and the methods used to date in the analysis and assessment, the TAC that is set includes an assumption that a component of the catch is comprised of residual males, and hence the TAC as currently specified should not be filled solely on the basis of the new 2+ cohort, i.e. if the season opens in February and the entire TAC is caught by end of September, this effectively means an overharvest of 2+ lobsters because it doesn't include the residual males (which play a less important biological role as they don't contribute to spawning). A portion of the TAC therefore needs to be set aside to be comprised of the residual males if the period Dec-Jan occurs at the end, rather than start, of the season (noting the economic incentives to otherwise catch the TAC earlier in the year).
- Based on the above biological and scientific considerations, we suggest that it would be feasible to change the Torres Strait TRL season date to a start date of 1 February (but anything later than this date becomes problematic – see for example Fig. 2 showing the much higher proportion of the catch that is caught in February). However, the TAC for the Australian sector would need to be partitioned into two components, for example, with a fixed proportion reserved for the fishing period Dec-Jan each year. Based on the available data, the average over the seasons from 2005-18 are 13.1% for TIB, 0.21% for TVH and 5.84% (STD 3%) for total catch (Fig. 1). The percentage taken in the Dec-Jan period is quite variable, but is clearly an important component of the TIB catch given an average of 13% with standard deviation (STD) 4.3% and range 5-22% (Figure 10-1). Figure 10-1 suggests that in the 2018 season the percent taken early in the season jumped substantially (this may be suggestive of a race to fish given the low quota, but also reflects that fact that a higher proportion of the total would be taken in each month fished in the 2018 season given that there was no catch in Aug-Oct). So identifying a proportion of the TAC to be set aside for the Dec-Jan period may be difficult and lead to either TAC being wasted or not enough TAC remaining (especially if market demand is high - which would also possibly lead to an economic loss given prices are also high when demand is high). One method could be to set a fixed proportion based on the above (e.g. 6%) of the total catch as reserved each year

for December-January. A fixed catch could also be selected based on socio-economic considerations. An alternative that could be discussed by the TRLRAG and WG would be to increase the size limit during the Dec-Jan fishing period.

The points above will be discussed in more detail at the TRLRAG, and background documentation can be provided on request.

A summary of the proposed change in timeline is provided below:

Date – current	Date - proposed	Activity
1 December	1 February	TS TRL season opens
Oct-Nov	Oct-Nov	Commercial fishing closure
October-November	October-November	Analyse Catch and CPUE data from Feb-Sept, assuming Dec-Jan catch is 5% of Aus TAC (for 1 Feb opening) and excluding Dec-Jan CPUE data
November	November	Preseason Survey conducted
Early December	End November	RBC computed and TAC set (if using eHCR); preliminary stock assessment could be available early December, and final stock assessment when required in March following year
December - January	December-January	Seasonal closure – hookah gear
October?	December-January	Bilateral discussions?

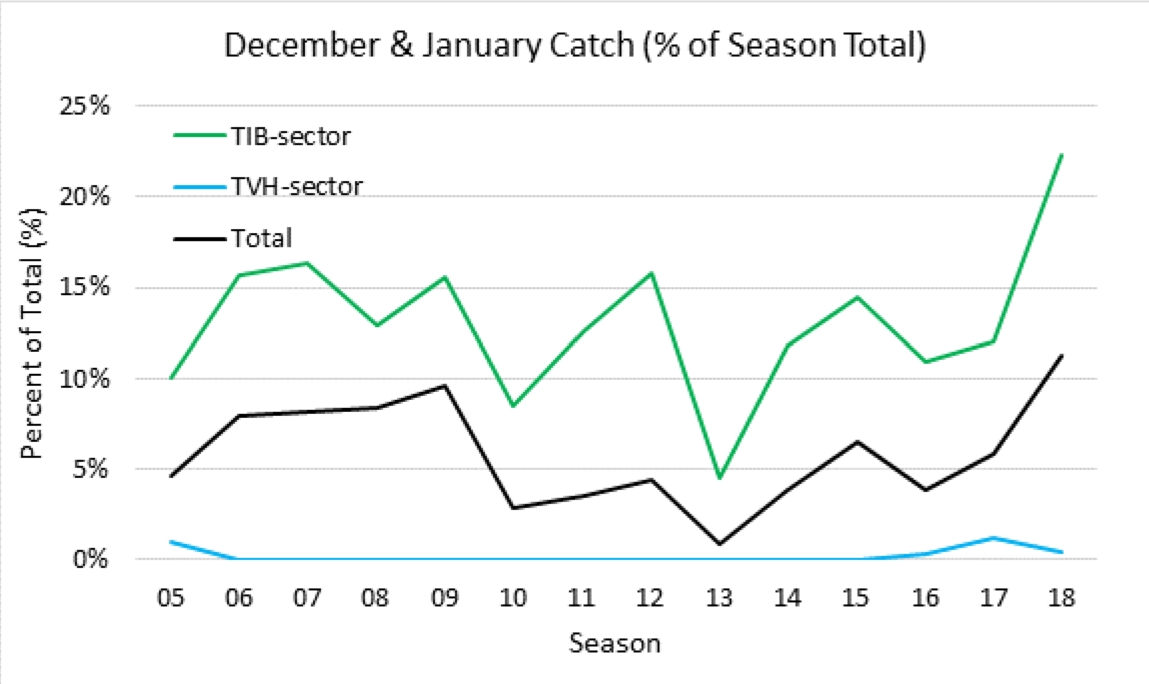


Figure 10-1. Plot showing the percent of the total seasonal catch for each sector caught in December and January. Averages over the seasons from 2005-18 are 13.1% for TIB, 0.21% for TVH and 5.84% for total catch.

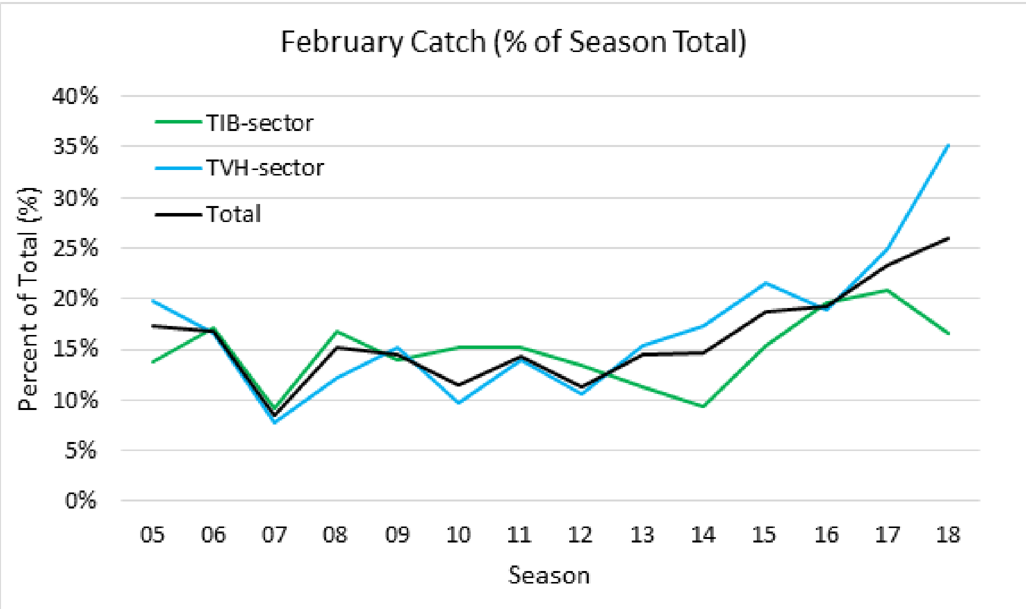


Figure 10-2. Plot showing the percent of the total seasonal catch for each sector caught in February. Note the trend seems to have been increasing over the past 6-7 seasons.

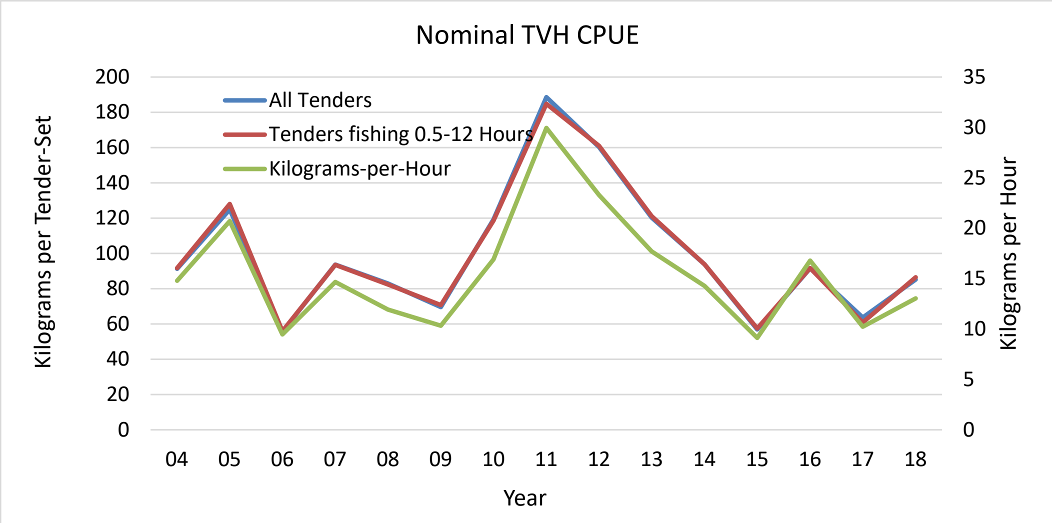
Appendix A Annual Catch-Per-Unit-Effort

A.1 TVH Sector

Effort in the TVH-sector is recorded as hours fished by a tender during each set. As indicated in Table 2-2 the hours fished for the majority of tender sets (93.1%) are between 0.5 and 12 hours, while the hours fished is not recorded for 6.9% of tender sets. The effort recorded for the remainder of tender sets (<0.5 or >12 hours) is considered not reliable. The seasonal total number of tender sets, associated catch and corresponding catch-per-unit-effort (CPUE) for (a) all tender-sets and (b) those where effort is between 0.5 and 12 hours is listed in Table A1 while the CPUE for each of the data sets is displayed in Figure A1.

Apx Table A-1. (a) Seasonal total number of tender-sets, associated catch (kilograms) and corresponding CPUE (kilograms per tender-set) for all TVH tender sets, and (b) seasonal total number of tender-sets, associated hours fished and catch (kilograms) and corresponding CPUE (kilograms per tender-set) and kilograms per hour fished for TVH tender sets where effort is between 0.5 and 12 hours.

	(a) All Sets			(b) Sets fishing 0.5-12 Hours				
Season	N-sets	Catch	CPUE	N-sets	Hours	Catch	CPUE	Kg/hour
04	5,270	481,082	91.3	5,005	31,068	459,227	91.8	14.8
05	4,404	549,936	124.9	3,718	23,001	476,171	128.1	20.7
06	2,432	135,474	55.7	2,333	13,792	130,558	56.0	9.5
07	2,869	268,596	93.6	2,731	17,403	255,468	93.5	14.7
08	1,211	100,438	82.9	1,159	7,996	95,452	82.4	11.9
09	1,308	91,061	69.6	1,240	8,484	87,696	70.7	10.3
10	2,368	282,614	119.3	1,933	13,547	229,162	118.6	16.9
11	2,670	503,533	188.6	2,465	15,216	455,579	184.8	29.9
12	2,311	370,482	160.3	2,131	14,721	342,986	161.0	23.3
13	3,008	361,661	120.2	2,920	19,994	353,786	121.2	17.7
14	2,910	273,186	93.9	2,781	18,296	261,091	93.9	14.3
15	2,683	152,709	56.9	2,615	16,464	150,147	57.4	9.1
16	2,654	243,010	91.6	2,621	14,314	240,229	91.7	16.8
17	2,352	149,738	63.7	2,058	12,235	125,144	60.8	10.2
18	1,506	128,323	85.2	1,473	9,774	127,373	86.5	13.0



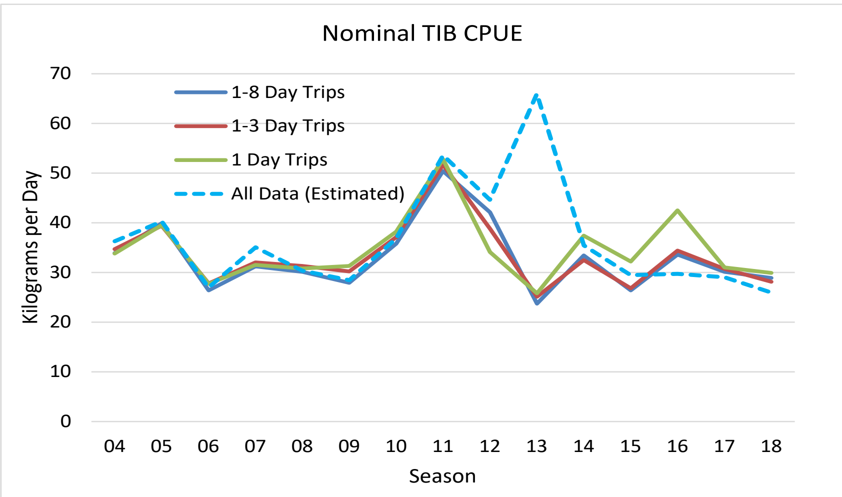
Apx Figure A-1. Seasonal CPUE (kilograms per tender-set and kilograms per hour) for (a) all TVH tender sets and (b) tender sets where effort is between 0.5 and 12 hours.

A.2 TIB Sector

Effort in the TIB-sector is recorded as the length of each fishing trip in days fished. As indicated in Table 2-4 fishing trips of up to 20 days have been recorded in the TIB docket-book, though the majority of trips (73.8%) are recorded as having a length of only one day. Whether or not the effort for trips having a long duration is recorded correctly remains unknown. The seasonal total number of days fished, associated catch and corresponding catch-per-unit-effort (CPUE) for trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only is listed in Table A2 while the CPUE (kilograms per day) for each of the data sets is displayed in Figure A2. For comparison, the CPUE associated with the Total Catch and estimated Total Days-Adj2 calculated for all TIB records in Table 2-4b is also displayed. Note, due to the low number of effort records for 2013 the high CPUE estimate for this season is considered highly unreliable.

Apx Table A-2. Seasonal total number of days fished, associated catch (kilograms) and corresponding catch-per-unit-effort (kilograms per day) for TIB trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only. The CPUE in the column All Data relates to that associated with the Total Catch and estimated Total Days-Adj2 calculated for all TIB records in Table 2-4b.

	Trips 1 to 8 days			Trips 1 to 3 days			Trips 1 day only			All Data
Season	Days	Catch	CPUE	Days	Catch	CPUE	Days	Catch	CPUE	CPUE
2004	4,584	155,271	33.9	3,744	129,980	34.7	2,737	92,517	33.8	36.3
2005	8,448	337,233	39.9	7,012	276,162	39.4	5,556	219,622	39.5	40.3
2006	4,644	122,434	26.4	3,961	109,958	27.8	3,010	83,462	27.7	27.0
2007	6,982	218,131	31.2	6,302	201,513	32.0	5,049	159,195	31.5	35.1
2008	5,630	169,638	30.1	5,136	160,656	31.3	4,133	127,222	30.8	30.3
2009	4,600	128,481	27.9	3,844	116,116	30.2	2,914	91,252	31.3	28.4
2010	3,609	129,282	35.8	3,329	123,636	37.1	2,702	103,260	38.2	36.8
2011	3,325	167,415	50.4	2,711	140,084	51.7	2,378	125,665	52.8	53.6
2012	2,020	85,060	42.1	1,319	51,204	38.8	881	30,068	34.1	44.6
2013	105	2,487	23.7	92	2,312	25.1	75	1,935	25.8	65.9
2014	2,848	95,207	33.4	2,044	66,514	32.5	1,266	47,380	37.4	35.4
2015	3,102	81,878	26.4	2,379	63,678	26.8	1,484	47,845	32.2	29.5
2016	2727	91493	33.6	2308	79433	34.4	1611	68389	42.5	29.7
2017	3080	92558	30.1	2884	88463	30.7	2659	82503	31	29.0
2018	3311	95632	28.9	2823	79217	28.1	1675	50012	29.9	25.9



Apx Figure A-2. Seasonal CPUE (kilograms per day) for TIB trips having a duration of (a) 1-8 days, (b) 1-3 days and (c) 1 day only, together with the estimated CPUE for All Data records.

Appendix B Summary of Data fitted to GLM

The following three spatial-temporal effects were included in the GLM used to standardise the CPUE for lobsters caught in the Torres Strait:

1) Year (all 25 years between 1994 and 2018)
2) Month (all 8 months between February and September)
3) MSE-Area (10 areas)

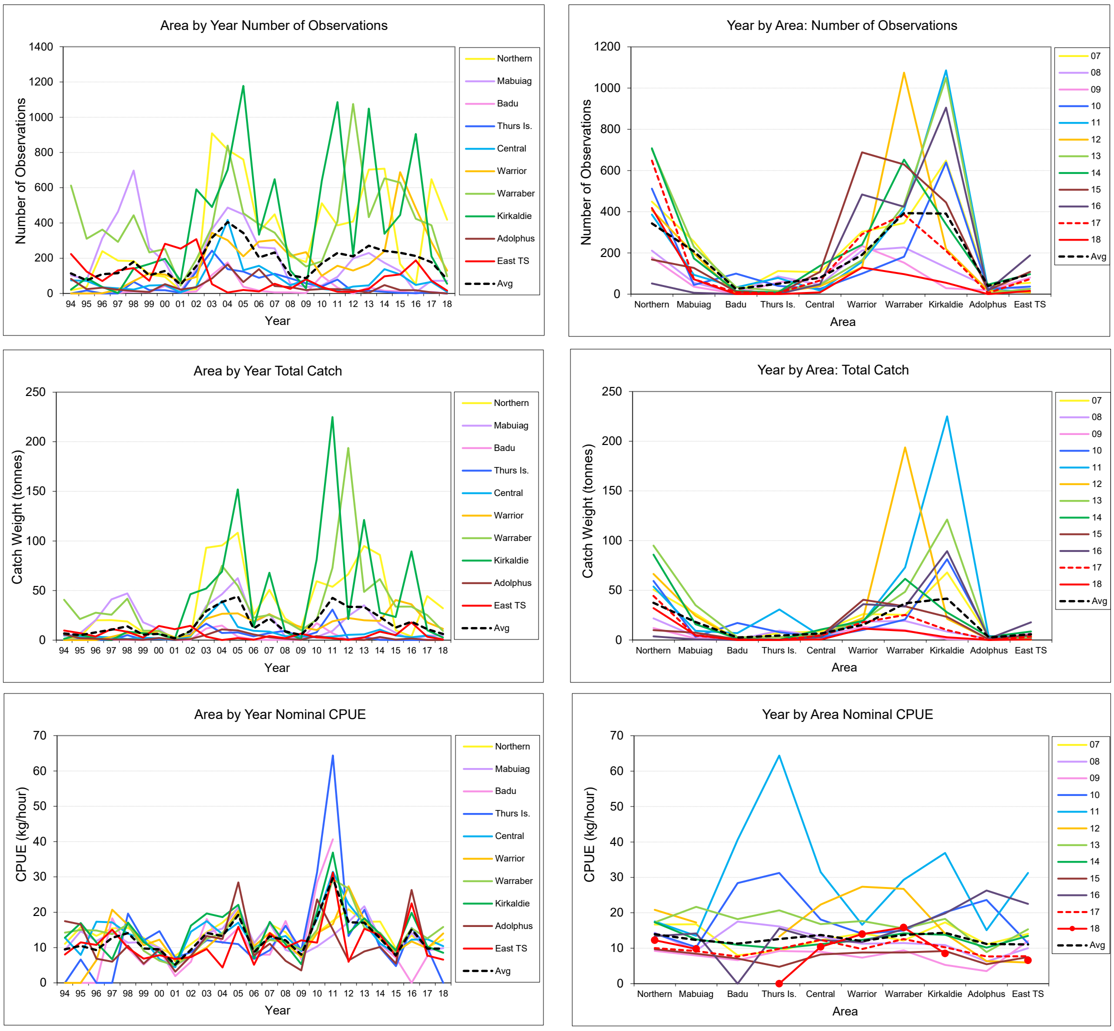
For each 2-way combination of these effects, the following figures provide:

1) Number of data observations
2) Total catch (kilograms of lobsters)
3) Nominal CPUE (kilograms per hour fished)

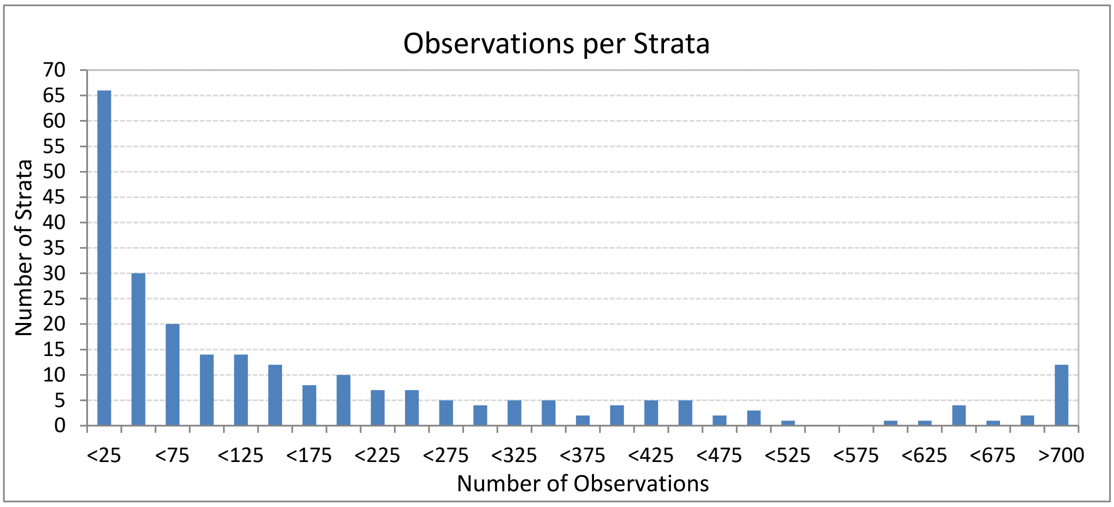
The data is limited to those records fitted to the GLMs and includes 45,427 records.

A histogram of the number of observations within each stratum is also shown for each of the above 2-way combination of these effects.

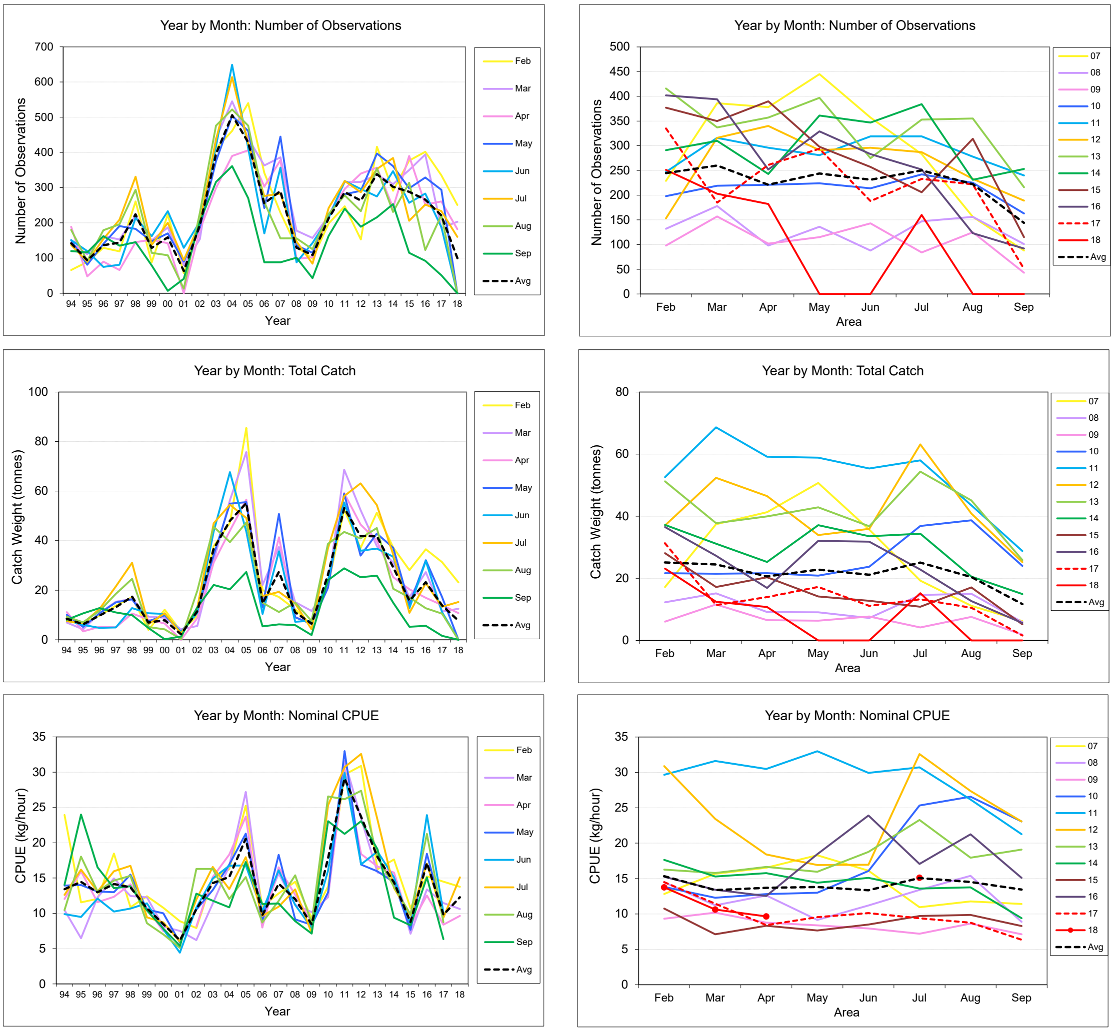
(a) Year*Area



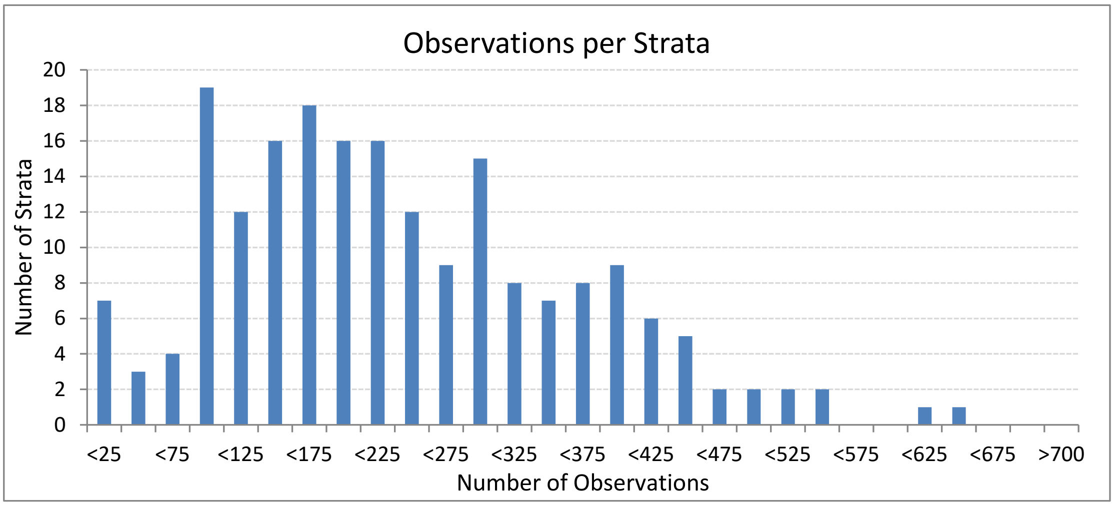
Of the 250 Year*Area strata (25 years x 10 areas) the number of observations is zero for 13 strata: There are a further 8 strata where the number of observations was between 1 and 4 and 15 strata where the number of observations was between 5 and 9. The number of observations for all other strata was between 10 and 1,178.



(b) Year*Month

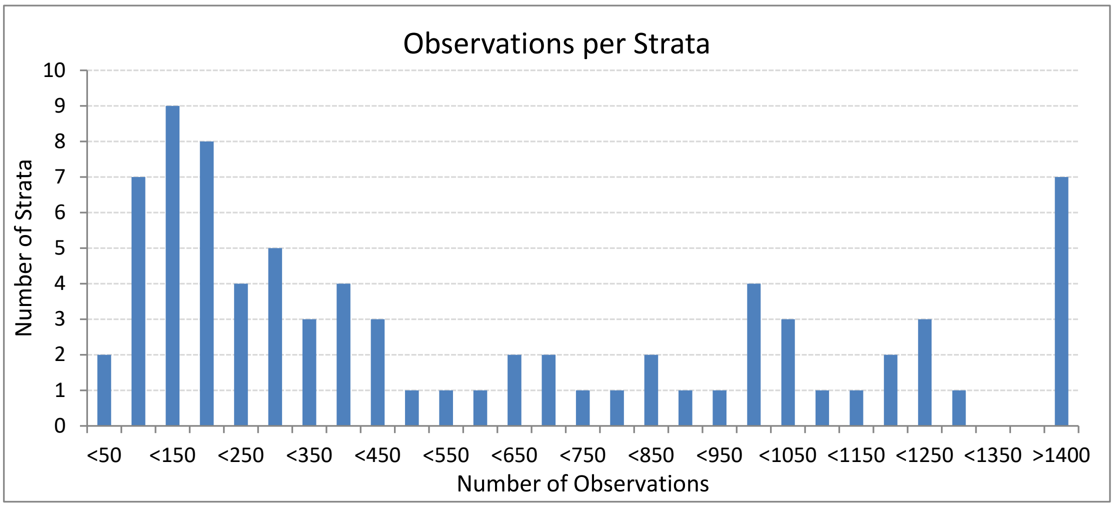


Of the 200 Year*Month strata (25 years x 8 months) the number of observations is zero for 5 strata (Apr-01 and May-Jun-18 & Aug-Sep-18). There was one strata (Sep-00) with only 7 observations. For the remaining 194 strata the number of observations was between 10 and 649.



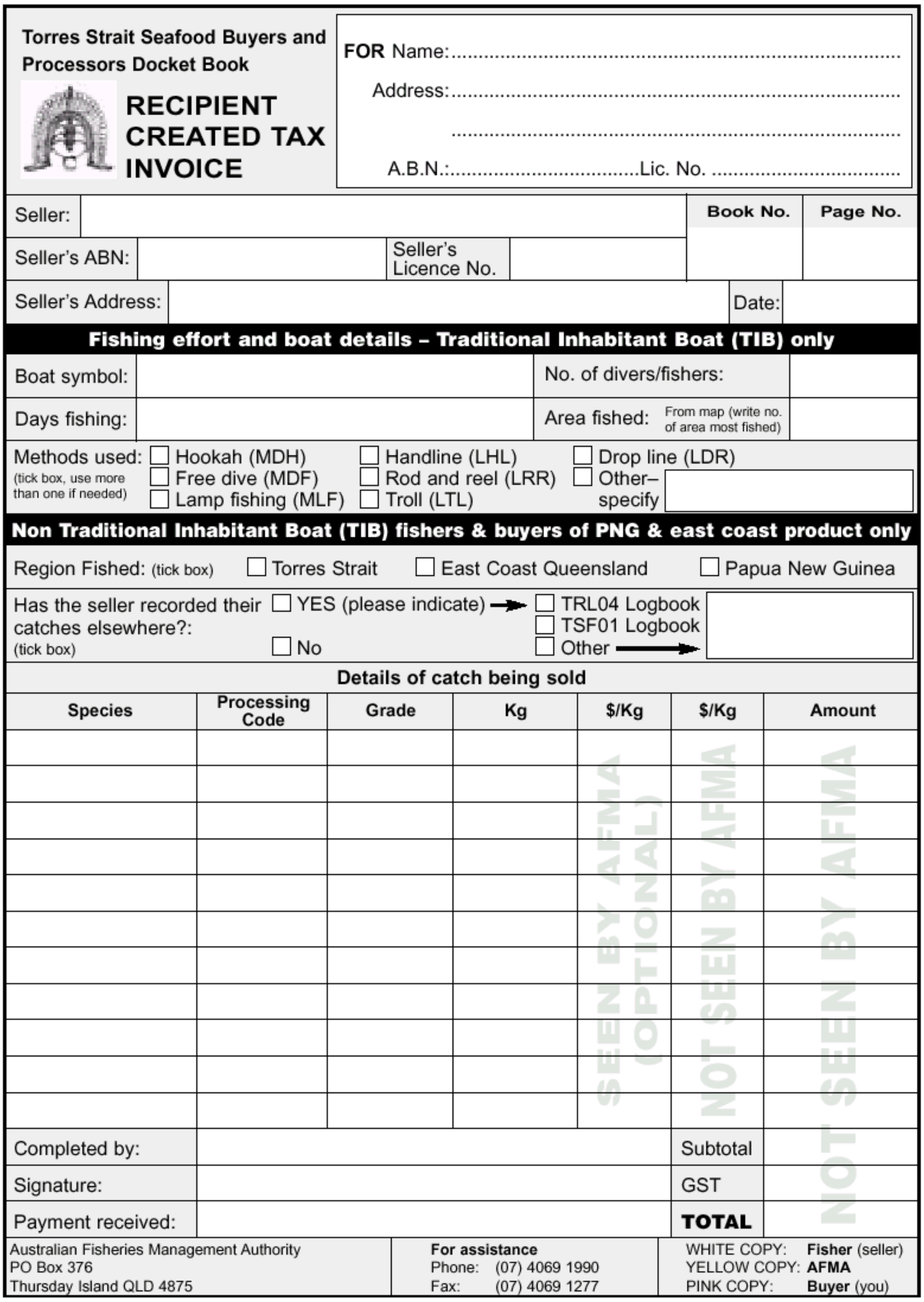
(c) Month*Area

Of the 80 Month*Area strata (8 months x 10 areas) the number of observations for all strata was between 37 and 1,685.



Appendix C Docket-Book Copy

C.1 The old Buyers and Processors Docket Book (TDB01) used in the TIB sector of the Torres Strait rock lobster fishery.



Torres Strait Seafood Buyers and Processors Docket Book

RECIPIENT CREATED TAX INVOICE

FOR Name:

Address:

A.B.N.: Lic. No.

Seller:		Book No.	Page No.
Seller's ABN:	Seller's Licence No.		
Seller's Address:	Date:		

Fishing effort and boat details – Traditional Inhabitant Boat (TIB) only

Boat symbol:		No. of divers/fishers:	
Days fishing:		Area fished: From map (write no. of area most fished)	

Methods used: (tick box, use more than one if needed)
- ☐ Hookah (MDH)
- ☐ Free dive (MDF)
- ☐ Lamp fishing (MLF)
- ☐ Handline (LHL)
- ☐ Rod and reel (LRR)
- ☐ Troll (LTL)
- ☐ Drop line (LDR)
- ☐ Other– specify

Non Traditional Inhabitant Boat (TIB) fishers & buyers of PNG & east coast product only

Region Fished: (tick box) ☐ Torres Strait ☐ East Coast Queensland ☐ Papua New Guinea

Has the seller recorded their catches elsewhere?: (tick box) ☐ YES (please indicate) → ☐ TRL04 Logbook ☐ TSF01 Logbook ☐ Other → ☐ No

Details of catch being sold

Species	Processing Code	Grade	Kg	$/Kg	$/Kg	Amount
				SEEN BY AFMA (OPTIONAL)	NOT SEEN BY AFMA	NOT SEEN BY AFMA

Completed by:		Subtotal	
Signature:		GST	
Payment received:		**TOTAL**	

Australian Fisheries Management Authority
PO Box 376
Thursday Island QLD 4875

For assistance
Phone: (07) 4069 1990
Fax: (07) 4069 1277

WHITE COPY: **Fisher** (seller)
YELLOW COPY: **AFMA**
PINK COPY: **Buyer** (you)

C.2. The new Torres Strait Catch Disposal Record (TDB02) to be used in the TIB sector of the Torres Strait rock lobster fishery.

Australian Fisheries Management Authority
Box 7051
Canberra Mail Centre ACT 2610

CDR No.	40	Page No.	34

Torres Strait Catch Disposal Record TDB02

PART A - MANDATORY

Receiver Details					
Fish Receiver Name		Fish Receiver Licence No.		Date	
Fish Receiver Address					

Fisher Details			
Fisher Name		Fishing Licence Number	
Fisher Type (Circle One)	TIB TVH Sunset	Boat Symbol	

Logbook Number and Page Numbers this catch relates to		Logbook Number	&	Page Number(s)	

Details of Catch					
Part or Whole of Catch? (Circle One)			Part	Whole	
Species	Processing Code	Grade	Weight	$/kg	$ Total
				Not Entered In Database	Not Entered In Database
TOTAL (Optional)					

Signature of Receiver		Received by (Name)	

PART B - VOLUNTARY/OPTIONAL

Fishing Effort and Area (Voluntary)			
Number of Fishers		Number of Days	
Area Fished		Start and End Dates	

Fishing Method (Voluntary)					
Hookah (MDH)		Handline (LHL)		Drop Line (LDL)	
Free Dive (MDF)		Rod and Reel (LRR)		Other	
Lamp Fishing (MLF)		Troll (LTL)		(Specify)	

Tax Receipt Details (Optional)			
Fisher ABN		Fisher Address	
Receiver ABN		Receiver Address	
Invoice Total ($)		GST ($)	
Signature of Fisher		Date	

White Copy Must go to AFMA within 3 days of unload
Pink Copy Fisher to Retain
Green Copy Remains in this logbook (Receiver copy)

For assistance please contact AFMA Direct 1300 723 621

Appendix C (i). Number of GLM data records, total number of days fished, total catch weight, and associated CPUE in each Season*Area strata. Note, strata with less than 10 records are shaded (dark shading where number is zero) and nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.

(a) Number of TIB RECORDS

		Season														
Area	Area	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Northern	6	36	40	60	54	12	7	4	14	7		53	24	1	6	3	321
Mabuiag	7	502	1107	430	482	272	102	15	409	141		799	252	24	9	85	4629
Badu	8	342	1063	583	703	429	26	49	356	174		246	370	218	191	218	4968
Thurs Is	9	1384	1583	761	2025	2254	2373	2180	722	535		58	703	853	2066	917	18414
Central	10	39	131	85	134	39	16	8	26	27		26	11	1	67	15	625
Warrior	11	15	751	341	459	335	193	17	5	0		0	22	46	12	231	2427
Warraber	12	192	200	372	595	452	244	154	92	49		260	302	253	28	137	3330
Adolphus	13	95	72	112	112	52	9	43	51	4		7	6	3	3	13	582
Great NE	14	135	138	188	126	186	212	106	86	21		15	10	89	47	235	1594
GBR	15	10	40	29	98	35	29	3	1	0		0	2	1	0	1	249
Darnley	16	77	245	127	263	121	0	45	30	10		0	3	3	11	39	974
Cumber	17	23	116	162	259	128	0	1	0	0		1	0	0	2	32	724
Total		2850	5486	3250	5310	4315	3211	2625	1792	968	0	1465	1705	1492	2442	1926	38837

(b) Total Number of DAYS_FISHED

AREA	AREA	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Northern	6	74	53	77	87	27	10	6	16	9		91	51	1	12	5	519
Mabuiag	7	552	1735	700	666	318	334	41	552	387		972	316	27	29	216	6845
Badu	8	378	1103	615	749	471	31	65	565	464		707	1011	648	288	313	7408
Thurs Is	9	1545	1719	802	2311	2364	2452	2296	730	554		59	711	859	2093	1086	19581
Central	10	76	159	115	141	57	16	10	31	34		53	33	2	89	21	837
Warrior	11	36	758	394	560	424	263	22	7	0		0	66	51	35	435	3051
Warraber	12	507	456	728	822	783	472	308	103	51		520	583	471	35	199	6038
Adolphus	13	183	143	161	155	92	13	99	58	6		7	7	3	5	16	948
Great NE	14	349	288	246	170	252	629	205	95	28		18	16	200	80	392	2968
GBR	15	23	73	46	139	69	33	5	1	0		0	5	1	0	4	399
Darnley	16	93	293	141	266	123	0	49	30	15		0	3	3	12	47	1075
Cumber	17	37	180	229	352	207	0	1	0	0		1	0	0	2	79	1088
Total		3853	6960	4254	6418	5187	4253	3107	2188	1548	0	2428	2802	2266	2680	2813	50757

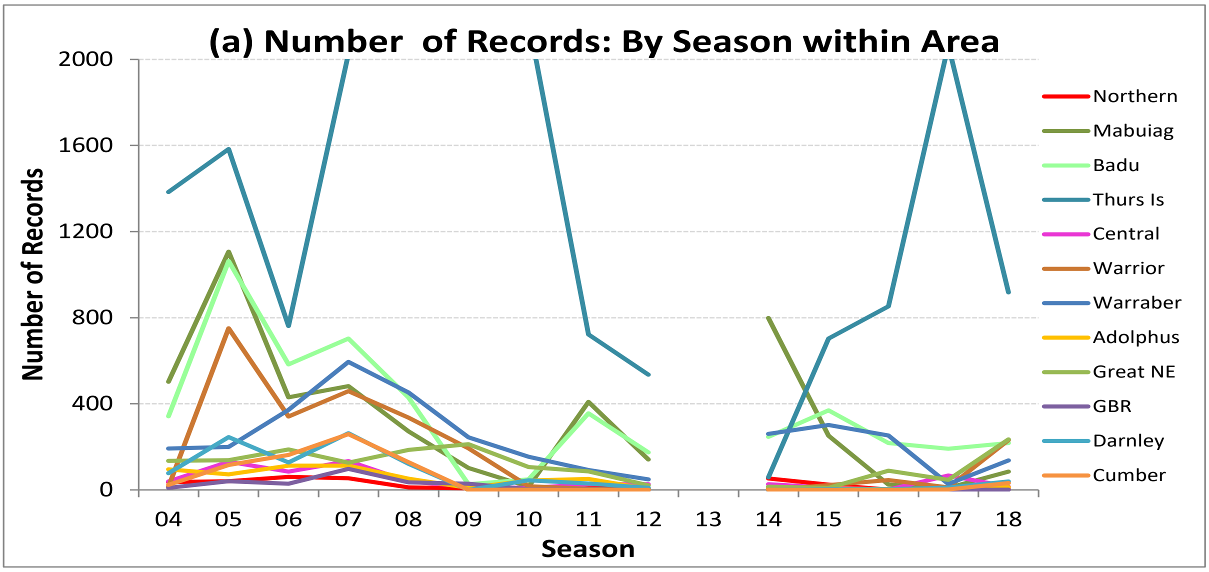
(c) Total CATCH_WEIGHT

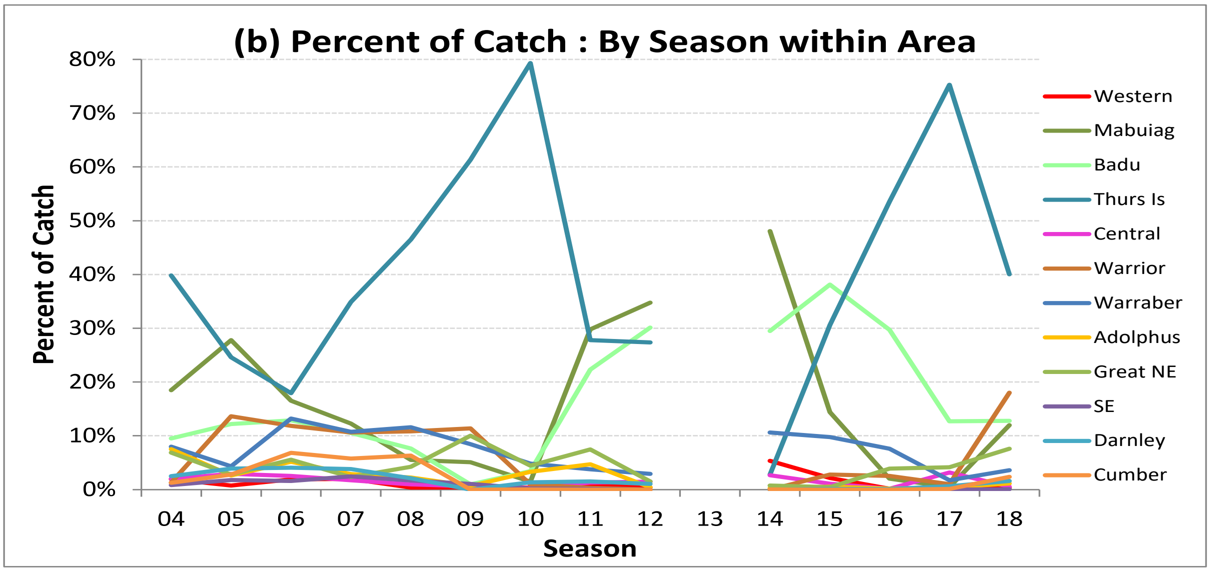
AREA	AREA	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Northern	6	2303	1982	2043	3920	553	503	333	915	237		3941	1353	99	323	247	18752
Mabuiag	7	21999	71500	17896	24174	8498	6001	1371	30682	20259		35484	9102	1385	306	9215	257872
Badu	8	11334	31390	13922	20703	11831	1138	3224	23002	17574		21767	24121	20364	8840	9839	219050
Thurs Is	9	47450	63302	19376	68655	71844	72268	74548	28615	15954		2076	19339	36708	52464	30858	603456
Central	10	2370	7465	2733	3415	1465	735	282	1336	847		1976	696	98	2201	409	26027
Warrior	11	1548	35041	12813	20843	16736	13395	916	352	0		0	1769	1739	708	13884	119745
Warraber	12	9483	11071	14282	21084	17940	9924	4531	3892	1698		7833	6163	5214	1191	2773	117077
Adolphus	13	8934	6690	5609	5624	3465	777	3118	4867	238		187	333	126	248	880	41096
Great NE	14	8208	7153	6008	4574	6577	11798	4175	7680	885		558	275	2675	2904	5848	69319
GBR	15	990	4502	1717	4814	2577	1256	196	135	0		0	27	54	0	50	16317
Darnley	16	2985	10061	4391	7506	3273	0	1271	1552	601		0	72	89	436	1221	33457
Cumber	17	1525	7140	7406	11364	9747	0	31	0	0		20	0	0	77	1833	39143
Total		119129	257297	108196	196676	154506	117795	93996	103028	58293	0	73842	63250	68551	69698	77057	1561311

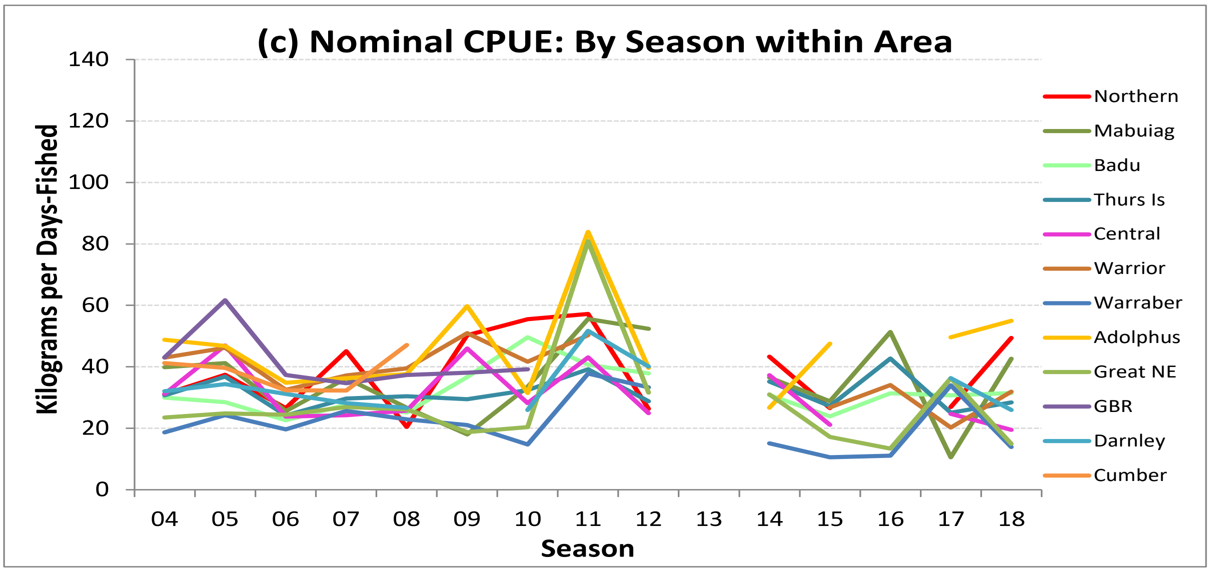
(d) Nominal CPUE

AREA	AREA	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Northern	6	31.1	37.4	26.5	45.1	20.5	50.3	55.5	57.2	26.3		43.3	26.5		26.9	49.4	36.1
Mabuiag	7	39.9	41.2	25.6	36.3	26.7	18.0	33.4	55.6	52.3		36.5	28.8	51.3	10.6	42.7	37.7
Badu	8	30.0	28.5	22.6	27.6	25.1	36.7	49.6	40.7	37.9		30.8	23.9	31.4	30.7	31.4	29.6
Thurs Is	9	30.7	36.8	24.2	29.7	30.4	29.5	32.5	39.2	28.8		35.2	27.2	42.7	25.1	28.4	30.8
Central	10	31.2	46.9	23.8	24.2	25.7	45.9	28.2	43.1	24.9		37.3	21.1		24.7	19.5	31.1
Warrior	11	43.0	46.2	32.5	37.2	39.5	50.9	41.6	50.3				26.8	34.1	20.2	31.9	39.2
Warraber	12	18.7	24.3	19.6	25.6	22.9	21.0	14.7	37.8	33.3		15.1	10.6	11.1	34.0	13.9	19.4
Adolphus	13	48.8	46.8	34.8	36.3	37.7	59.8	31.5	83.9	39.7		26.7	47.6		49.6	55.0	43.4
Great NE	14	23.5	24.8	24.4	26.9	26.1	18.8	20.4	80.8	31.6		31.0	17.2	13.4	36.3	14.9	23.4
GBR	15	43.0	61.7	37.3	34.6	37.3	38.1	39.2					5.4				40.9
Darnley	16	32.1	34.3	31.1	28.2	26.6		25.9	51.7	40.1					36.3	26.0	31.1
Cumber	17	41.2	39.7	32.3	32.3	47.1										23.2	36.0
Total		30.9	37.0	25.4	30.6	29.8	27.7	30.3	47.1	37.7		30.4	22.6	30.3	26.0	27.4	30.8

Appendix C (i). Number of GLM data records, percent of catch, and associated CPUE in each Season*Area strata. Note, nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.







Appendix C (ii). Number of GLM data records, total number of days fished, total catch weight, and associated CPUE in each Season*Month strata. Note, strata with less than 10 records are shaded (dark shading where number is zero) and nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.

(a) Number of TIB RECORDS

		Season															
Month	Month	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Dec	12	0	447	274	401	282	229	217	146	196		74	271	76	51	243	2907
Jan	1	289	321	250	576	351	331	204	237	230		128	130	70	184	212	3513
Feb	2	339	574	595	571	657	417	450	408	117		152	286	260	371	339	5536
Mar	3	447	659	658	1040	919	547	410	291	140		172	192	192	376	272	6315
Apr	4	227	649	443	564	611	409	330	114	65		153	192	152	263	285	4457
May	5	356	755	437	675	357	315	234	154	53		126	153	147	293	179	4234
Jun	6	347	726	214	509	325	310	266	156	75		139	158	147	244	168	3784
Jul	7	397	587	224	401	443	299	189	163	39		153	127	184	254	228	3688
Aug	8	283	414	96	312	208	201	219	81	35		204	109	167	260	0	2589
Sep	9	165	354	59	261	162	153	106	42	18		164	87	97	146	0	1814
Total		2850	5486	3250	5310	4315	3211	2625	1792	968	0	1465	1705	1492	2442	1926	38837

(b) Total Number of DAYS_FISHED

Month	Month	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Dec	12		532	342	488	327	265	266	154	212		122	390	142	54	390	3684
Jan	1	322	380	323	730	417	426	250	245	284		184	183	131	194	352	4421
Feb	2	394	703	685	652	739	550	477	413	238		264	451	378	426	406	6776
Mar	3	500	897	821	1249	1011	654	441	294	288		364	329	374	417	393	8032
Apr	4	300	854	613	647	715	525	376	157	125		314	311	237	283	410	5867
May	5	584	927	608	805	425	365	270	291	118		260	278	229	311	281	5752
Jun	6	513	896	346	644	431	433	321	240	144		228	289	199	271	268	5223
Jul	7	567	755	270	539	604	451	251	243	84		250	238	238	269	313	5072
Aug	8	452	579	158	360	323	362	289	109	37		261	185	219	288	0	3622
Sep	9	221	437	88	304	195	222	166	42	18		181	148	119	167	0	2308
Total		3853	6960	4254	6418	5187	4253	3107	2188	1548	0	2428	2802	2266	2680	2813	50757

(c) Total CATCH_WEIGHT

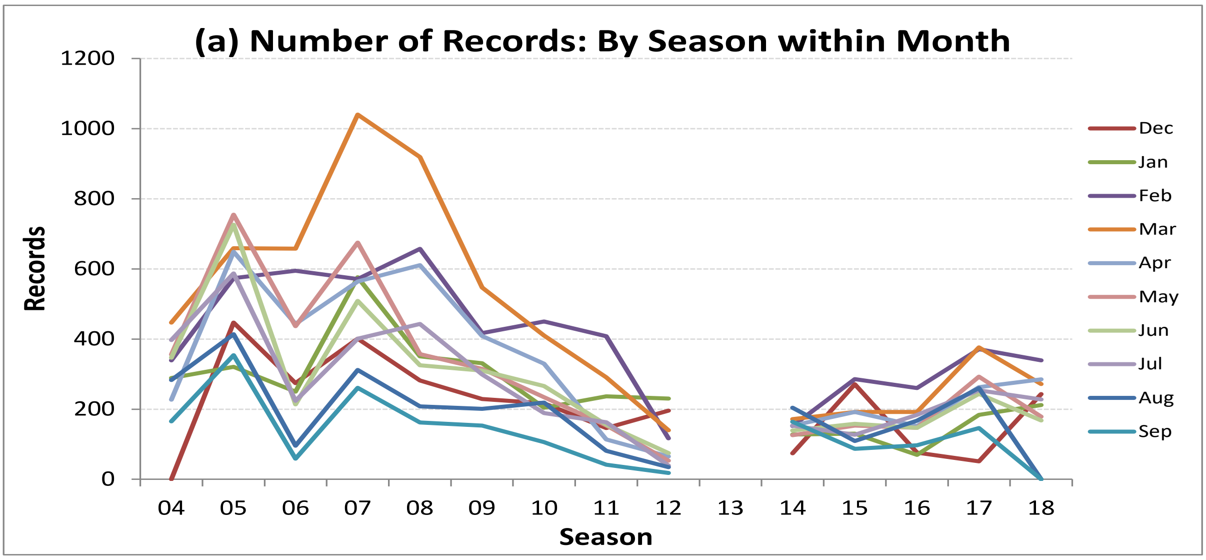
Month	Month	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Dec	12		14348	8792	13095	9198	7607	5128	5742	5634		4438	7251	2851	1198	9246	94528
Jan	1	9619	10498	7195	18559	11385	11833	4847	12306	7398		5640	3632	2906	4545	6782	117146
Feb	2	14636	29970	18553	19205	24185	16595	18247	20415	9490		8399	11035	12530	11280	11024	225565
Mar	3	18196	35730	21822	42928	30872	20555	13935	17776	14318		11665	6813	11018	11174	10489	267293
Apr	4	9737	35605	15571	22240	21233	17615	12849	8175	5012		10323	9126	7333	7872	11985	194677
May	5	17958	39627	14676	24832	13835	12130	9208	12881	4731		7145	5722	7881	8514	7942	187081
Jun	6	15533	33197	8111	21095	12190	10868	9962	9257	5766		6506	6631	6872	6589	8182	160760
Jul	7	14330	27713	7026	14964	19342	9980	6725	10645	3399		6693	6023	7019	7845	11409	153111
Aug	8	12929	18362	4271	11446	7152	6518	8470	4095	1550		7874	4306	7329	7579	0	101880
Sep	9	6191	12245	2179	8310	5112	4092	4625	1737	995		5159	2712	2811	3101	0	59269
Total		119129	257295	108196	196674	154504	117793	93996	103029	58293	0	73842	63251	68550	69697	77059	1561310

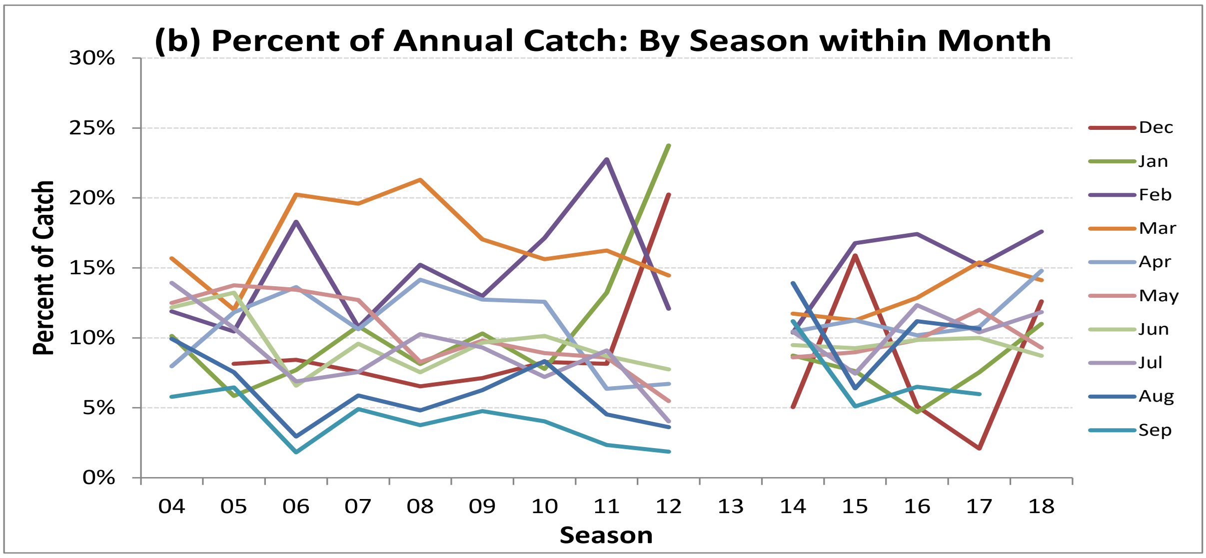
5

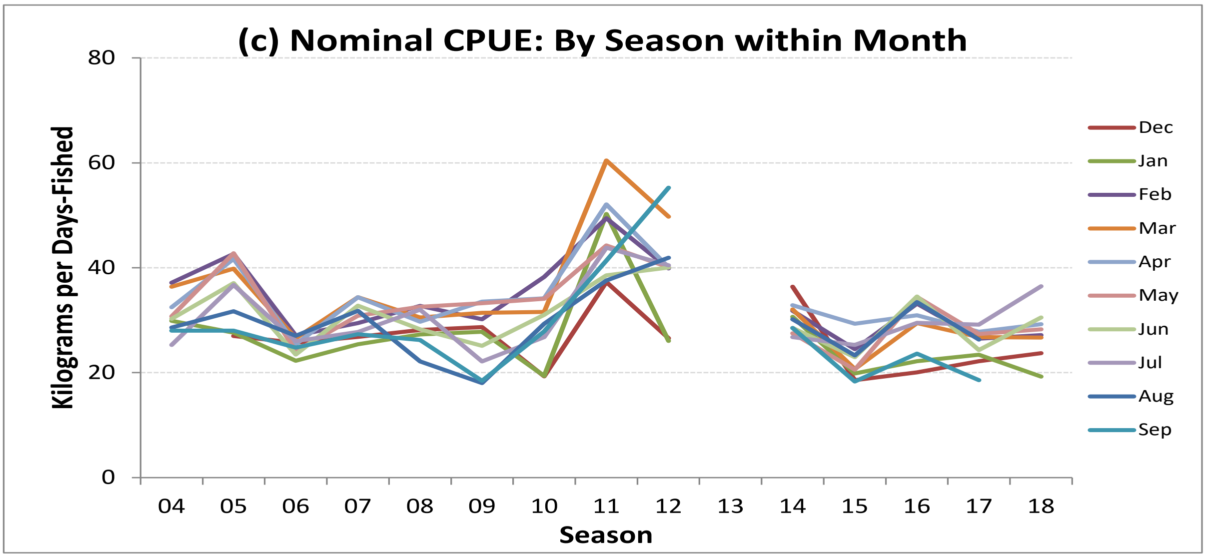
(d) Nominal CPUE (where Days-Fished > 4 days)

Month	Month	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	Total
Dec	12		27.0	25.7	26.8	28.1	28.7	19.3	37.3	26.6		36.4	18.6	20.1	22.2	23.7	25.7
Jan	1	29.9	27.6	22.3	25.4	27.3	27.8	19.4	50.2	26.0		30.7	19.8	22.2	23.4	19.3	26.5
Feb	2	37.1	42.6	27.1	29.5	32.7	30.2	38.3	49.4	39.9		31.8	24.5	33.1	26.5	27.2	33.3
Mar	3	36.4	39.8	26.6	34.4	30.5	31.4	31.6	60.5	49.7		32.0	20.7	29.5	26.8	26.7	
Apr	4	32.5	41.7	25.4	34.4	29.7	33.6	34.2	52.1	40.1		32.9	29.3	30.9	27.8	29.2	
May	5	30.8	42.7	24.1	30.8	32.6	33.2	34.1	44.3	40.1		27.5	20.6	34.4	27.4	28.3	
Jun	6	30.3	37.1	23.4	32.8	28.3	25.1	31.0	38.6	40.0		28.5	22.9	34.5	24.3	30.5	
Jul	7	25.3	36.7	26.0	27.8	32.0	22.1	26.8	43.8	40.5		26.8	25.3	29.5	29.2	36.5	
Aug	8	28.6	31.7	27.0	31.8	22.1	18.0	29.3	37.6	41.9		30.2	23.3	33.5	26.3		28.1
Sep	9	28.0	28.0	24.8	27.3	26.2	18.4	27.9	41.4	55.3		28.5	18.3	23.6	18.6		25.7
Total		30.9	37.0	25.4	30.6	29.8	27.7	30.3	47.1	37.7		30.4	22.6	30.3	26.0	27.4	30.8

Appendix C (ii). Number of GLM data records, percent of catch, and associated nominal CPUE in each Season*Month strata. Note, nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.







Appendix C (iii). Number of GLM data records, total number of days fished, total catch weight, and associated CPUE in each Area*Month strata. Note, strata with less than 10 records are shaded (dark shading where number is zero) and nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.

(a) Number of TIB RECORDS

	AREA	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Northern	6	17	35	47	45	56	26	27	40	18	10	321
Mabuiag	7	365	482	725	840	431	368	415	415	285	303	4629
Badu	8	303	410	874	930	618	567	454	430	224	158	4968
Thurs Is	9	1202	1575	2738	2972	2135	2074	1785	1763	1276	894	18414
Central	10	79	89	99	121	59	51	34	34	34	25	625
Warrior	11	363	250	327	352	299	224	197	189	146	80	2427
Warraber	12	295	302	325	495	394	397	375	380	281	86	3330
Adolphus	13	33	46	86	54	69	75	78	61	54	26	582
Great NE	14	87	116	124	216	173	224	219	199	143	93	1594
GBR	15	12	29	32	34	26	20	40	27	12	17	249
Darnley	16	112	119	115	132	107	112	72	53	70	82	974
Cumber	17	39	60	44	124	90	96	88	97	46	40	724
	Total	2907	3513	5536	6315	4457	4234	3784	3688	2589	1814	38837

(b) Total Number of DAYS_FISHED

	AREA	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Northern	6	29	63	76	85	79	33	41	71	29	13	519
Mabuiag	7	429	609	1049	1218	734	627	655	653	449	422	6845
Badu	8	447	562	1173	1379	941	944	717	666	340	239	7408
Thurs Is	9	1339	1776	2836	3105	2230	2223	1903	1883	1361	925	19581
Central	10	99	111	106	170	83	61	53	76	51	27	837
Warrior	11	498	309	414	420	351	287	269	233	176	94	3051
Warraber	12	434	496	558	848	755	758	724	769	556	140	6038
Adolphus	13	56	54	116	71	113	132	132	83	130	61	948
Great NE	14	153	196	212	366	295	402	440	352	354	198	2968
GBR	15	19	44	45	50	32	35	60	59	20	35	399
Darnley	16	131	132	121	145	117	124	75	61	79	90	1075
Cumber	17	50	69	70	175	137	126	154	166	77	64	1088
	Total	3684	4421	6776	8032	5867	5752	5223	5072	3622	2308	50757

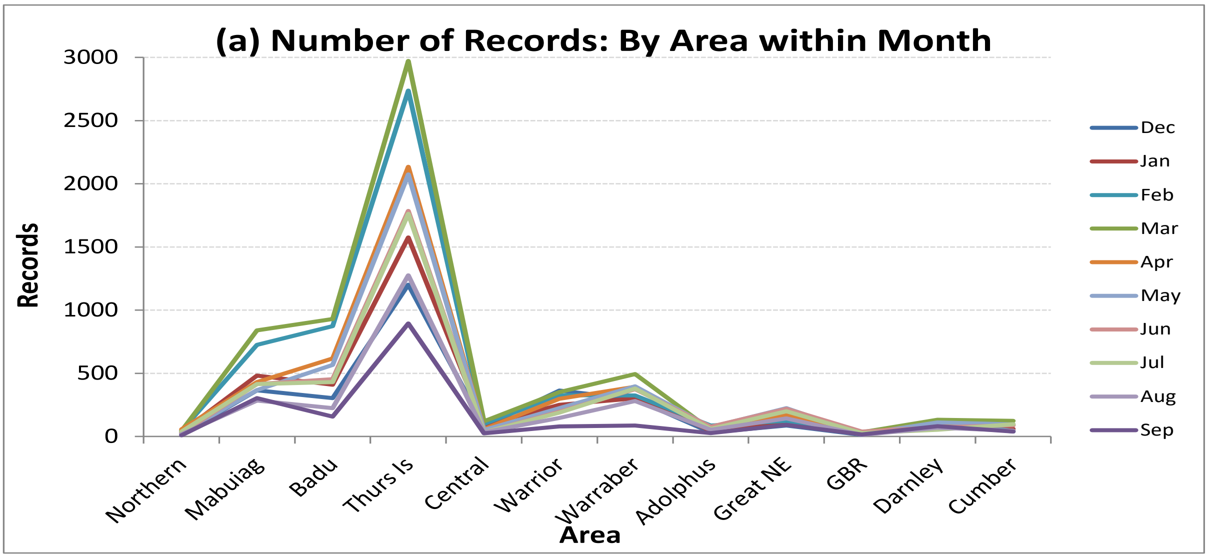
(c) Total CATCH_WEIGHT

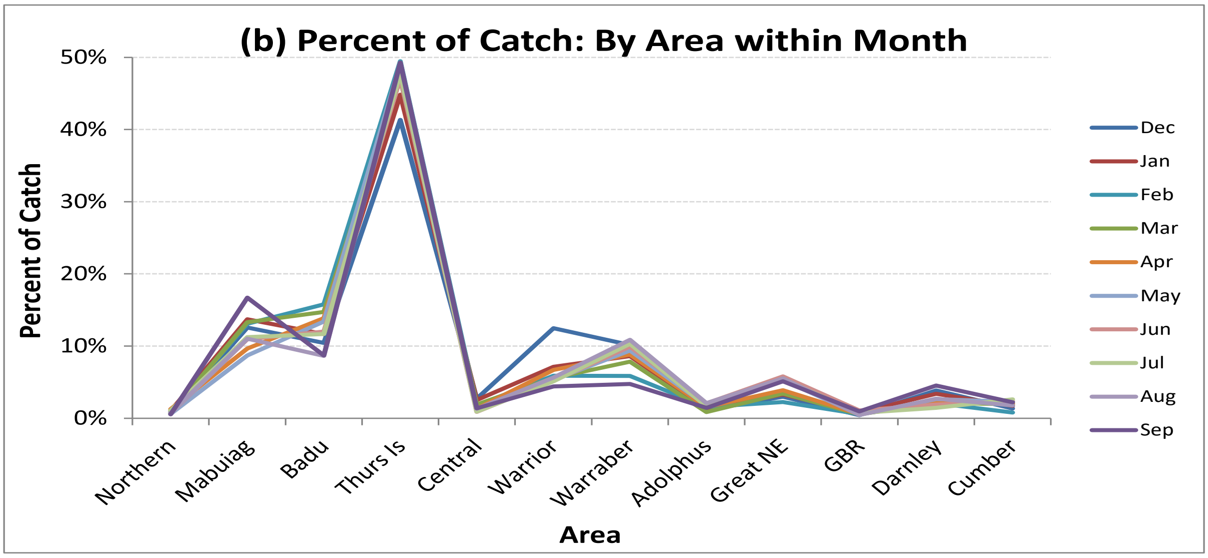
	AREA	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Northern	6	954	2190	3382	2833	3462	1581	1364	1634	832	519	18752
Mabuiag	7	13635	23181	45964	52315	27820	24793	23528	21418	14431	10787	257872
Badu	8	11613	16323	36543	43815	29128	27750	20123	17763	10234	5758	219050
Thurs Is	9	29604	40133	95983	105041	76683	72506	61557	57910	39654	24385	603456
Central	10	2699	2868	3152	5186	3004	2194	2203	2014	1656	1050	26027
Warrior	11	16942	10903	14665	14348	15365	13772	12100	11586	7044	3020	119745
Warraber	12	7932	9690	10802	17736	13929	15218	14019	15269	10327	2157	117077
Adolphus	13	1526	1782	4074	3395	6732	7334	5490	4214	4545	2003	41096
Great NE	14	3112	3624	3855	10525	7703	10811	9483	9002	7289	3914	69319
GBR	15	540	1275	1541	2622	1913	1960	2346	2616	677	827	16317
Darnley	16	4186	3505	3788	4219	4335	3857	2218	2093	2347	2910	33457
Cumber	17	1784	1672	1816	5260	4602	5307	6329	7591	2844	1938	39143
	Total	94527	117146	225565	267295	194676	187083	160760	153110	101880	59268	1561311

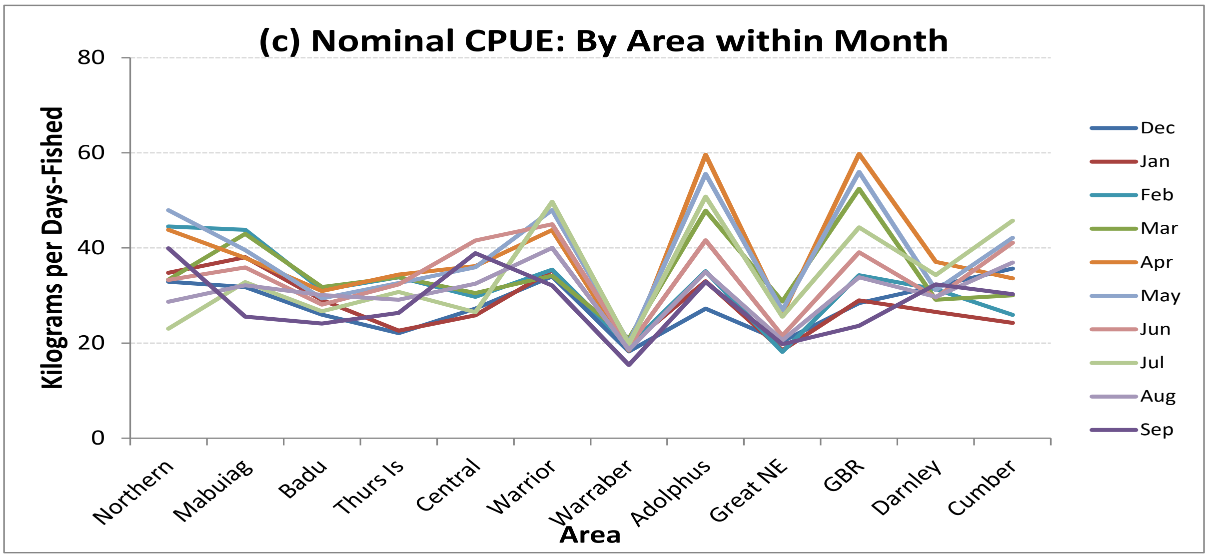
(d) Nominal CPUE

	AREA	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Northern	6	32.9	34.8	44.5	33.3	43.8	47.9	33.3	23.0	28.7	39.9	36.1
Mabuiag	7	31.8	38.1	43.8	43.0	37.9	39.5	35.9	32.8	32.1	25.6	37.7
Badu	8	26.0	29.0	31.2	31.8	31.0	29.4	28.1	26.7	30.1	24.1	29.6
Thurs Is	9	22.1	22.6	33.8	33.8	34.4	32.6	32.3	30.8	29.1	26.4	30.8
Central	10	27.3	25.8	29.7	30.5	36.2	36.0	41.6	26.5	32.5	38.9	31.1
Warrior	11	34.0	35.3	35.4	34.2	43.8	48.0	45.0	49.7	40.0	32.1	39.2
Warraber	12	18.3	19.5	19.4	20.9	18.4	20.1	19.4	19.9	18.6	15.4	19.4
Adolphus	13	27.3	33.0	35.1	47.8	59.6	55.6	41.6	50.8	35.0	32.8	43.4
Great NE	14	20.3	18.5	18.2	28.8	26.1	26.9	21.6	25.6	20.6	19.8	23.4
GBR	15	28.4	29.0	34.2	52.4	59.8	56.0	39.1	44.3	33.9	23.6	40.9
Darnley	16	32.0	26.6	31.3	29.1	37.1	31.1	29.6	34.3	29.7	32.3	31.1
Cumber	17	35.7	24.2	25.9	30.1	33.6	42.1	41.1	45.7	36.9	30.3	36.0
	Total	25.7	26.5	33.3	33.3	33.2	32.5	30.8	30.2	28.1	25.7	30.8

Appendix C (iii). Number of GLM data records, percent of catch, and associated CPUE in each Area*Month strata. Note, nominal CPUE is only shown for strata where the number of the days fished is 5 or greater.







Appendix D Diagnostic plots - Size distributions from TS rock lobster research surveys

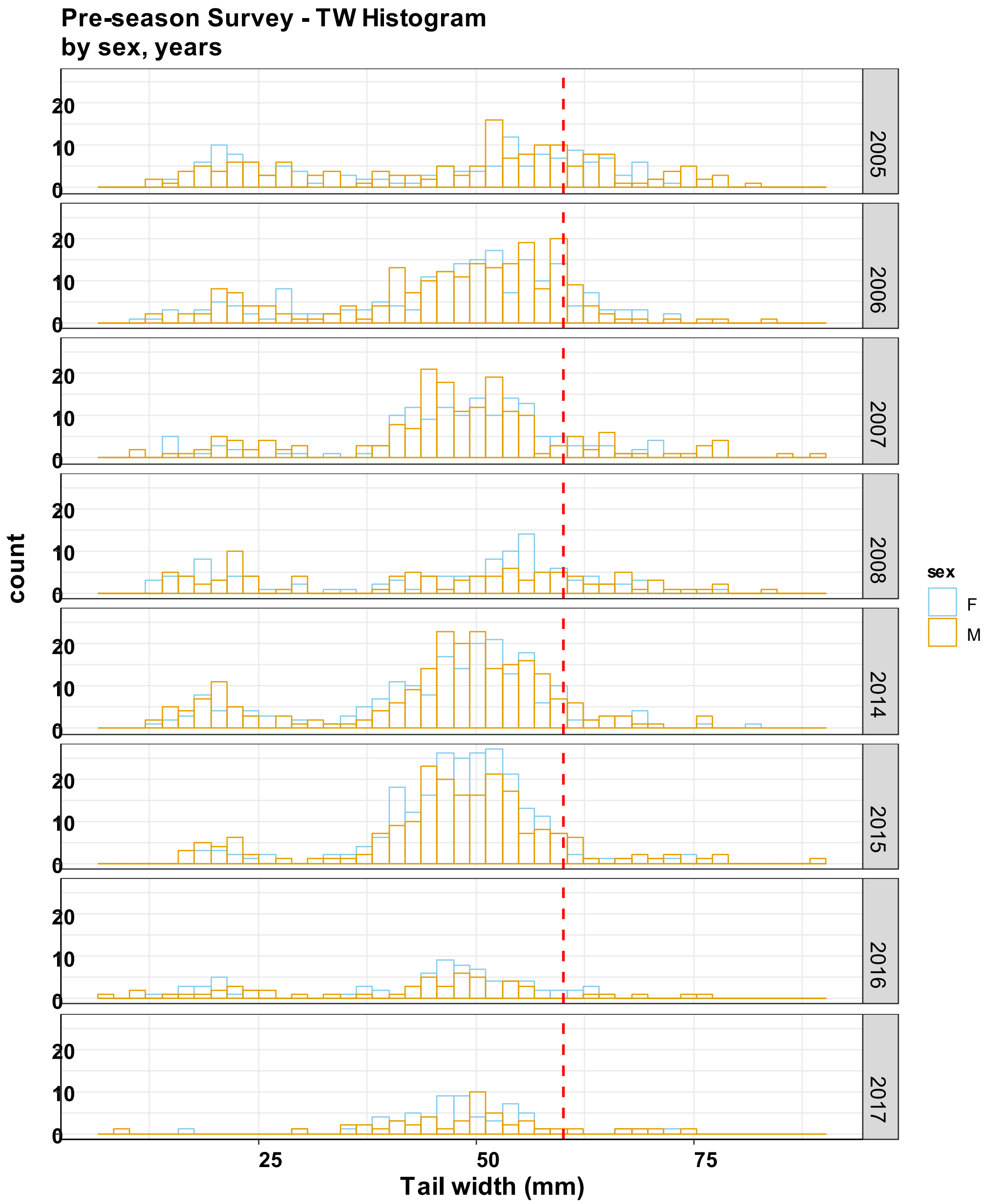


Figure D1. Pre-Season Survey – Histogram (counts) of TS rock lobster TW by sex, years (2005 to 2008, 2014 to 2017).

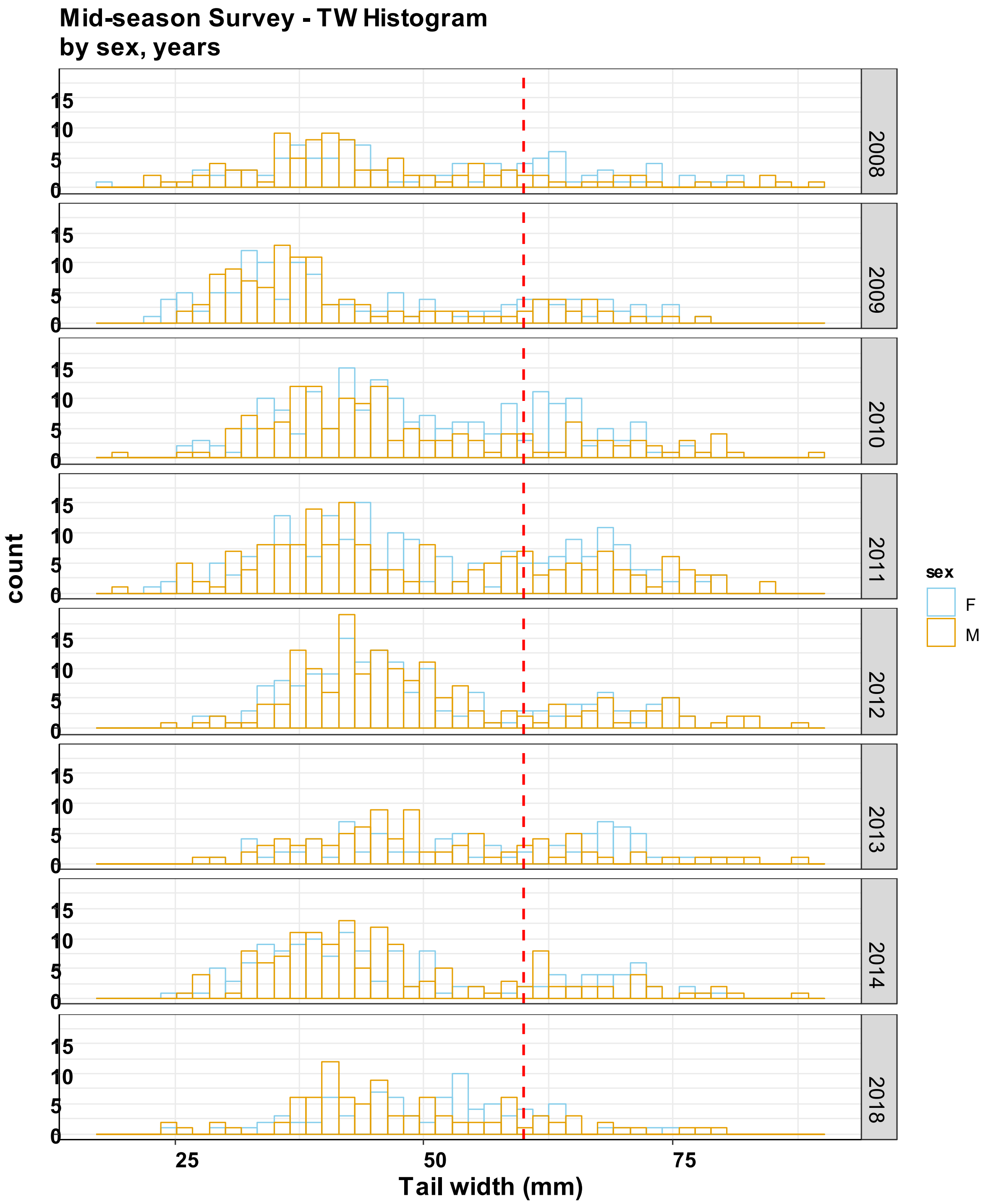


Figure D2. Mid-Season Survey – Histogram (counts) of TS rock lobster TW by sex, years (2008 to 2014, 2018).

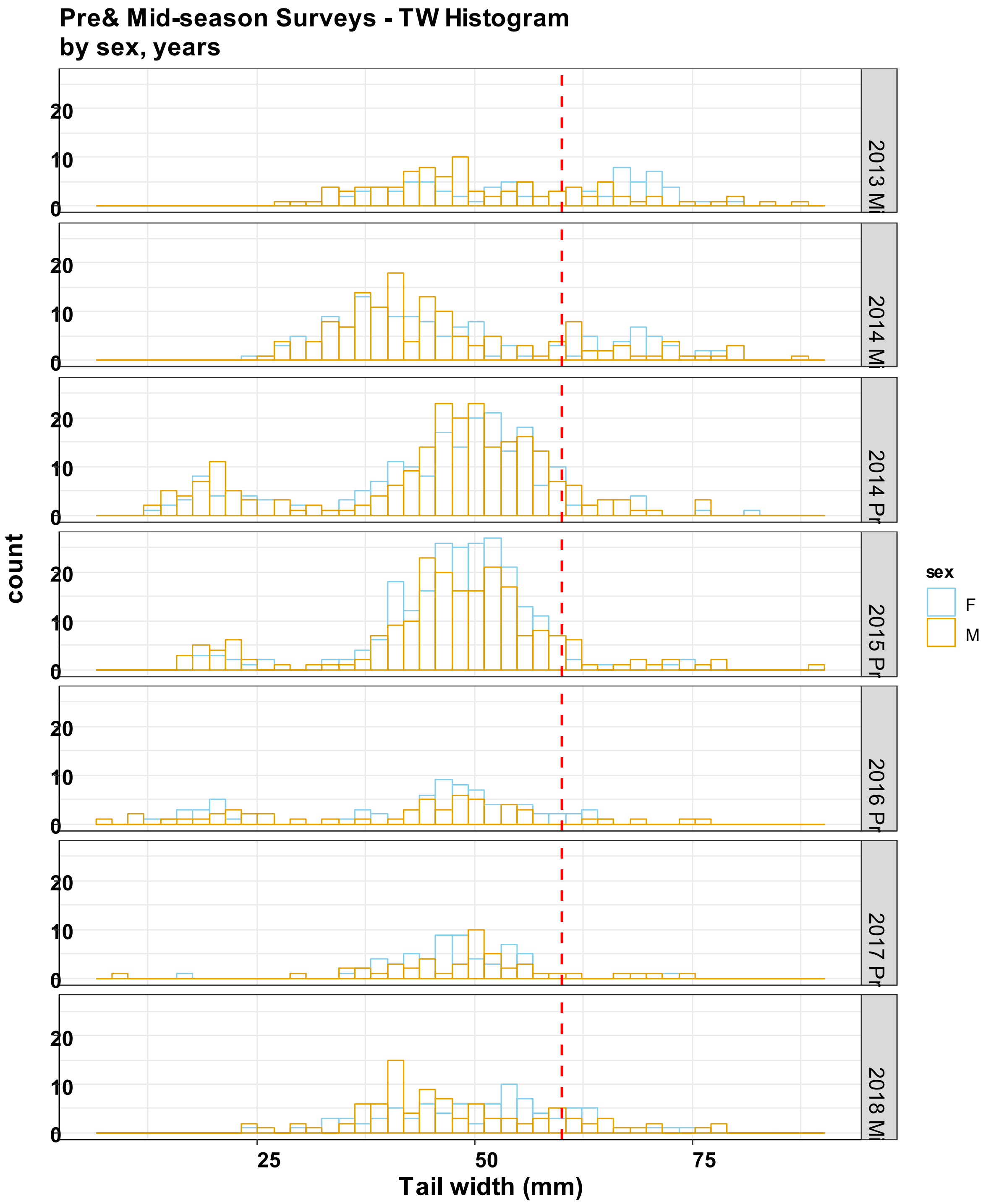


Figure D3. Pre- and Mid-Season Surveys – Histogram (counts) of TS rock lobster TW by sex, years surveyed (since 2013).

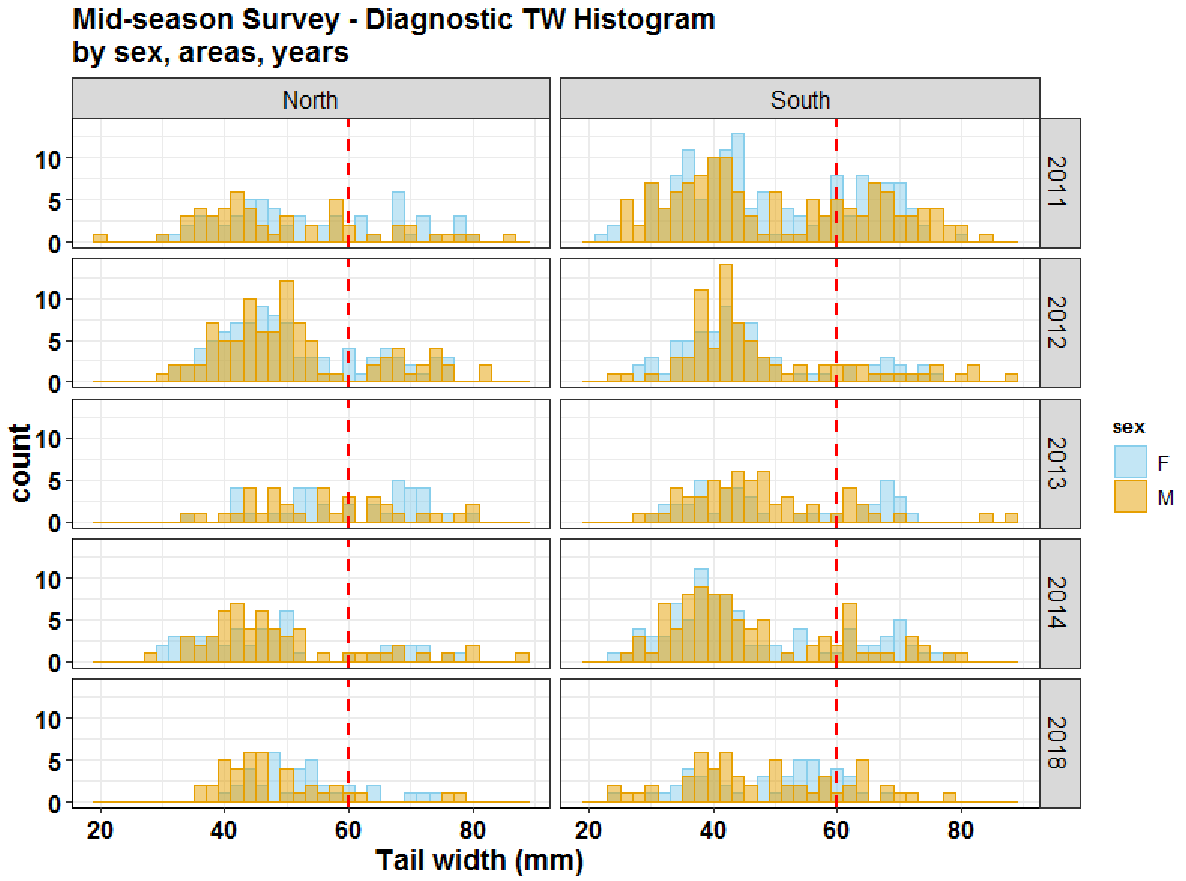


Figure D4. Mid-Season Survey - Histogram (counts) of TS rock lobster tail width (TW) by sex and areas (North and South), 2018 and recent years surveyed.

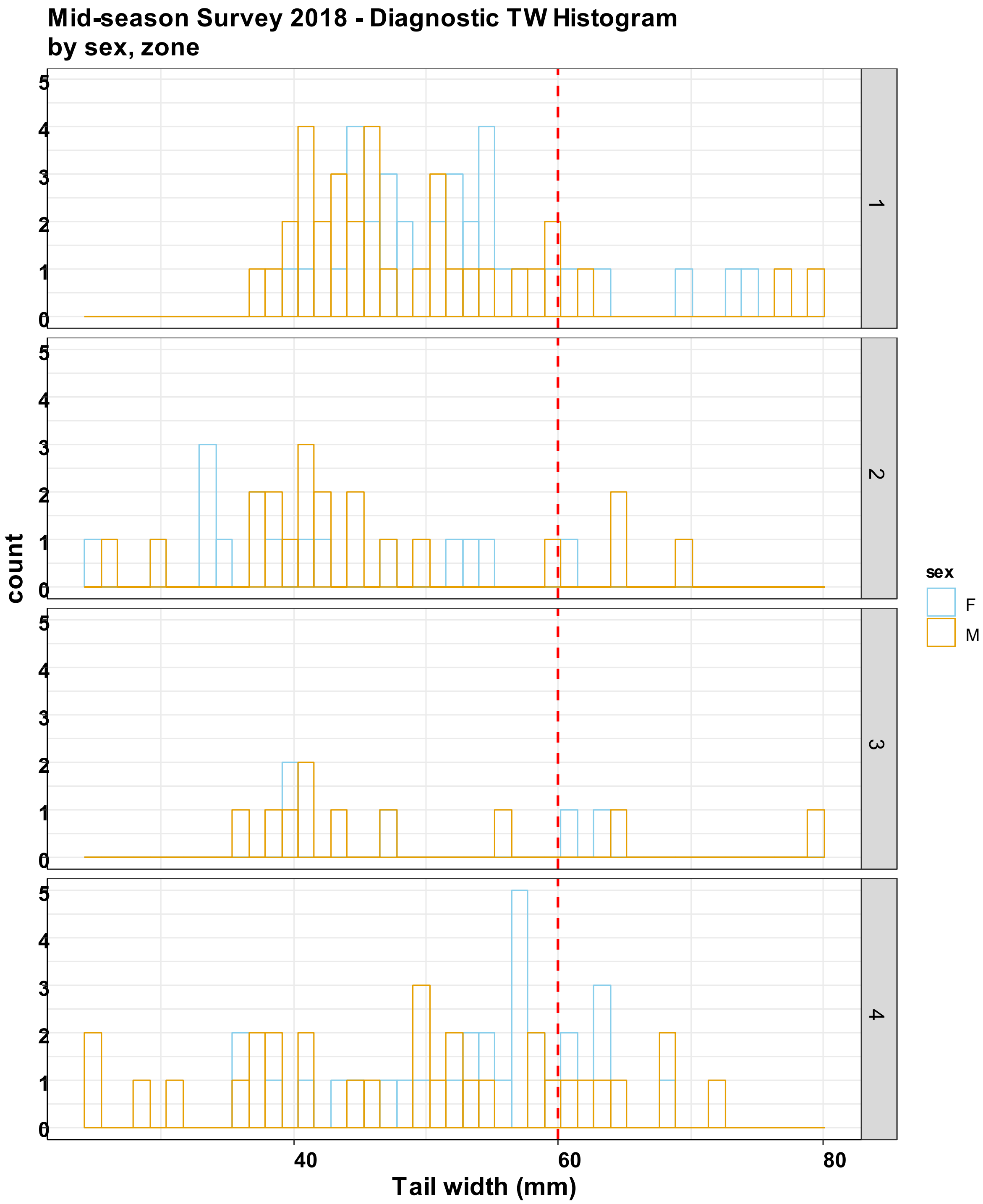


Figure D5. Mid-Season Survey 2018 - Histogram (counts) of TS rock lobster tail width (TW) by sex and zone). Zones: 1=North West, 2=South West, 3=Central, 4=South East.

Appendix E TS rock lobster size distributions from commercial fishery catches

Acknowledgments

Data was provided by MG Kailis Pty Ltd Cairns and we are very grateful to the many staff members for their valuable contributions to this research project. We are particularly grateful to the fishers, stakeholders, managers and scientists attending TRL RAG and TRL WG meetings for their expert advice on the analysis of the size data and interpretation of the results.

E.1 Introduction

The size distributions of commercial ornate rock lobster *Panulirus ornatus* catches taken in Torres Strait have been documented during several historical studies to determine timing of emigration (Skewes et al. 1994), adult growth (Skewes et al. 1997) and assessment of stocks (Pitcher et al. 1997). During 1988 to 2001 the size distribution of the island-based commercial lobster catch was monitored in central Torres Strait as a component of research documenting catch and effort of the Torres Strait islander fishery. This monitoring project concluded in 2001 with the subsequent introduction of the Torres Strait docket book program, designed to capture commercial catch data from processing facilities at all island communities. However, size monitoring was not included in the docket book program.

Monitoring of the size distribution of the Queensland east coast commercial tropical rock lobster catch was initiated at the MG Kailis Pty Ltd premises in Cairns in July 2001 as a component of FRDC funded research on the biology and stock assessment of the Queensland east coast lobster population (Pitcher et al. 2005). This program was concluded in March 2003 at the end of the research project.

Subsequently, several owners of TVH vessels operating in Torres Strait proactively provided further size distribution data during 2004 and 2005 to supplement data obtained during annual scientific population surveys for stock assessment research. The collection of this data prompted a discussion amongst the stakeholders as to the strategic and tactical need for commercial catch size monitoring and the most cost effective way to collect the data.

In 2006 a coordinated monthly program of monitoring the size distributions of both Torres Strait and QLD east coast commercial catches was initiated, based at the MG Kailis Pty Ltd premises in Cairns. This method was identified as more efficient than the previous method reliant on voluntary collection of data by individual vessel owners. Initially a total of ~600 lobsters were measured each month to determine the resolution of the size distributions. The number of lobsters measured from both the Torres Strait and QLD east coast fisheries was then reduced to 200 in 2008 and this monitoring program has continued to date.

Although not comprehensive spatially the ongoing monitoring program provides consistent monthly size data that can be used to compare size and age compositions of both Torres Strait and

QLD east coast populations between years. The size at age data is used in the Torres Strait fishery model to determine selectivity of the commercial fishery and also to provide information on inter-annual growth.

In addition to the direct application of this information for stock assessment, size at age data also informs managers and stakeholders on important external influences that affect lobster growth and recruitment timing. Major environmental perturbations such as Coral Sea cyclones, seagrass dieback and thermal induced bleaching have all occurred during the timeframe of monitoring at the MG Kailis Pty Ltd facility. To date there appears remarkable consistency in size and age of the TRL population, despite these influences, but future influences are far less certain. Model forecasts of the influence of ocean warming indicate there will be both positive and negative impacts for Torres Strait lobsters (Norman-Lopez et al. 2013), through increased individual growth and survival offset by increased growth of larval predators. The actual impacts of future warming scenarios are much less certain, but it is likely the population and hence the fishery will be impacted. The ongoing size monitoring program outlined in this report will allow managers and stakeholders to directly assess changes in lobster population size structure; which will in turn allow any necessary changes in management.

Effort in the TVH-sector is recorded as hours fished by a tender during each set. The hours fished for the majority of tender sets are between 0.5 and 12 hours, while the hours fished is not recorded for fewer than ~10% of tender sets. The effort recorded for the remainder of tender sets (<0.5 or >12 hours) is considered not reliable.

E.2 Methods

Historically, ornate rock lobsters (*Panulirus ornatus*) taken commercially in Torres Strait and on the QLD east coast have been measured by CSIRO and PNG researchers to address various aspects of the life history of this species. However, prior to 2000 there was no ongoing monitoring of the size distributions of commercial catches.

During 2001 to 2003 lobsters landed at the MG Kailis Pty Ltd facility in Cairns, QLD were sub-sampled by staff monthly and measured (carapace length to the nearest millimetre) and sexed to provide data for a FRDC co-funded project (Project No. 2002-008). Subsequently, during 2004 and 2005 to extend this data-set for Torres Strait lobsters, several fishers provided voluntary measures (carapace length or tail width to the nearest millimetre).

In 2006 the scope of the ongoing Torres Strait research program was broadened to include a component to monitor the size distributions of the Torres Strait and QLD east coast catches. By this time a greater proportion of the catch was taken live, in contrast to previous years when most was sold as frozen tails. Hence, all lobsters sub-sampled since 2006 have been weighed whole (to the nearest 10 grams).

We standardised all length and weight measurements using morphometric relationships developed using historical data from several research projects (Table E-1). The relationships were all highly correlated (R2>0.95). As carapace length is globally the most commonly used measure for spiny lobsters, we used carapace length in this report.

Table E-1 Relationships between several commonly measured morphometric features of the ornate rock lobster (*Panulirus ornatus*) from Torres Strait and the QLD east coast. TW = tail width (mm), CL = carapace length (mm), TL = tail length (mm), Tailwt in grams, Totwt in grams.

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
All	Totwt/tailwt	TOTWT=2.677*TAILWT		0.994
	or	TAILWT=37.35% of TOTWT		

These size data are stored in a Microsoft Access database on a shared server maintained by CSIRO.

E.3 Results

E.3.1 Temporal changes in mean lobster size

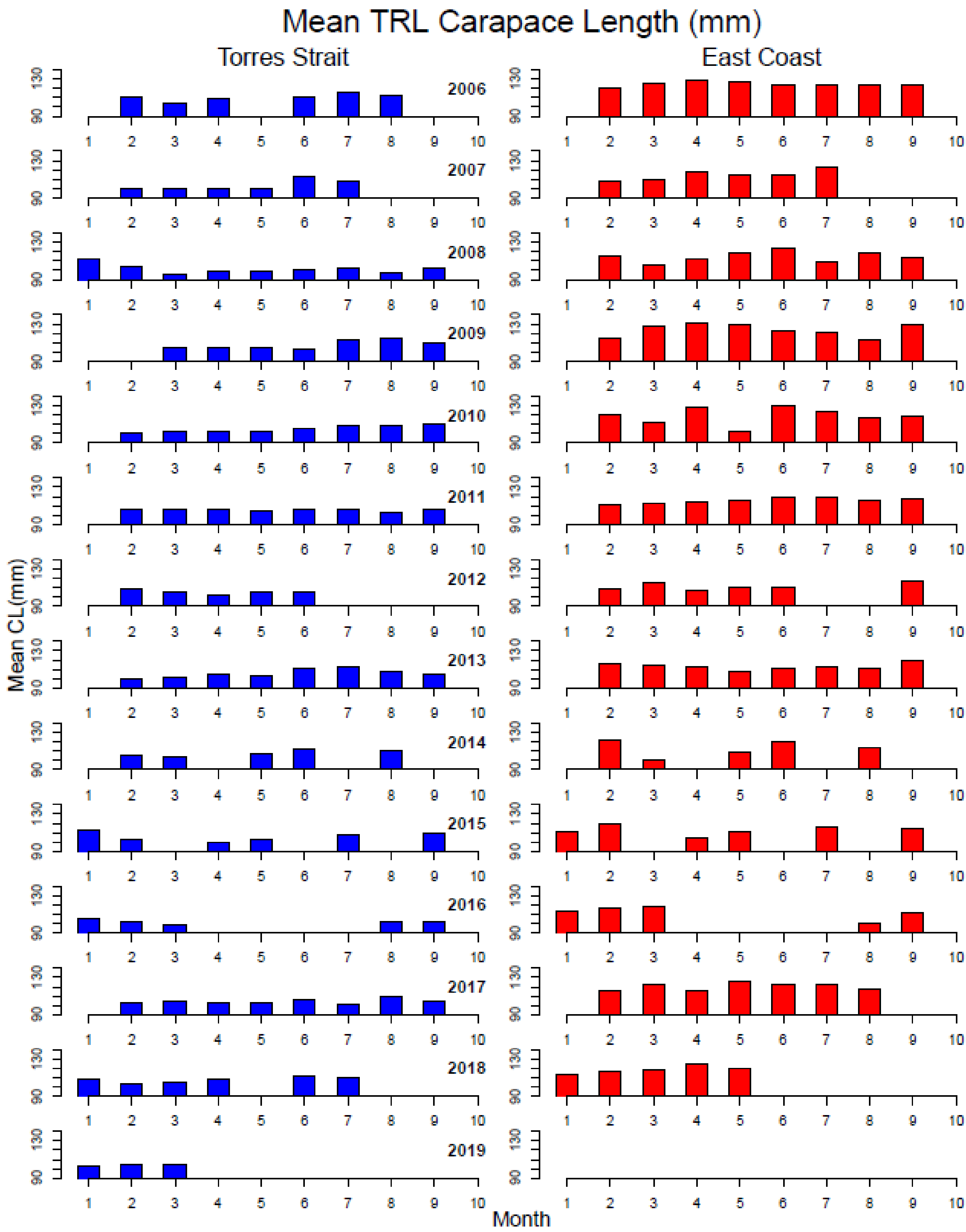


Figure E-1. Mean size (carapace length mm) of lobsters *Panulirus ornatus* from commercial catches taken each month in Torres Strait (blue) and on the QLD east coast (red).

E.3.2 Torres Strait lobster size distributions

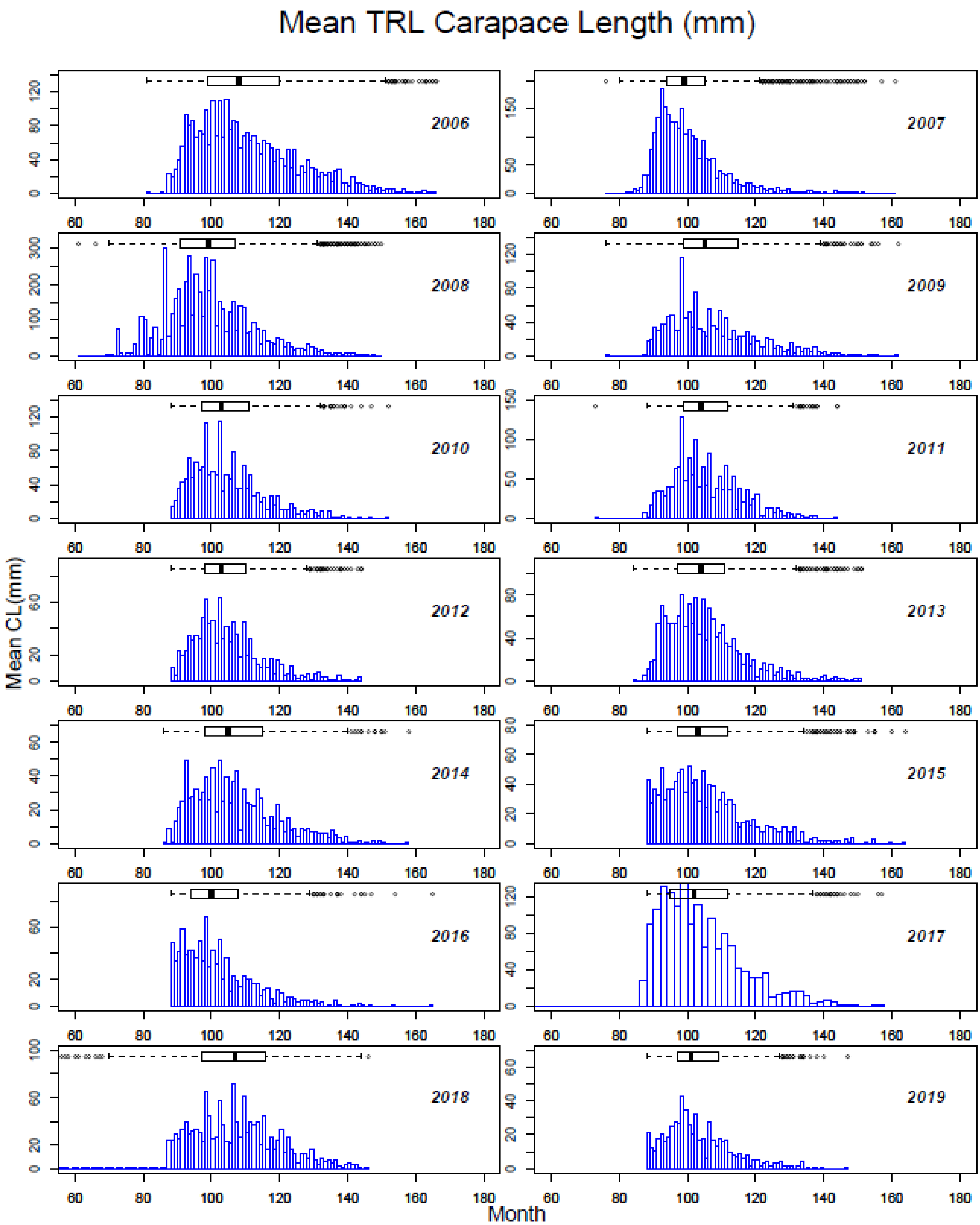


Figure E-2. Size frequency distributions of ornate rock lobsters (Panulirus ornatus) taken in commercial catches in Torres Strait between 2006 and 2019.

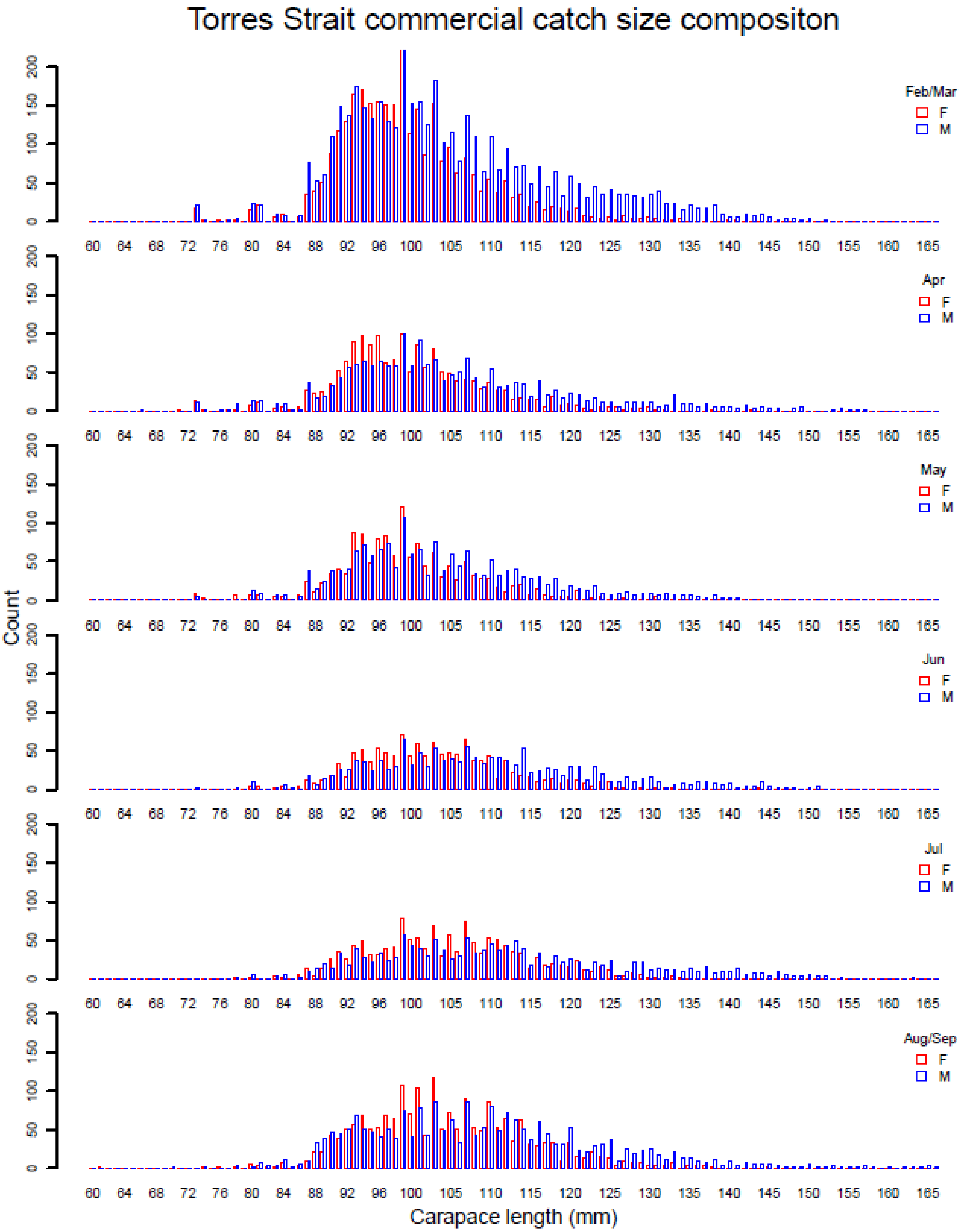


Figure E-3. Size frequency distributions of ornate rock lobsters (Panulirus ornatus) taken in monthly commercial catches in Torres Strait for all years (2006- 2019) combined. Red bars indicate females, blue bars indicate males.

E.3.3 QLD east coast lobster distributions

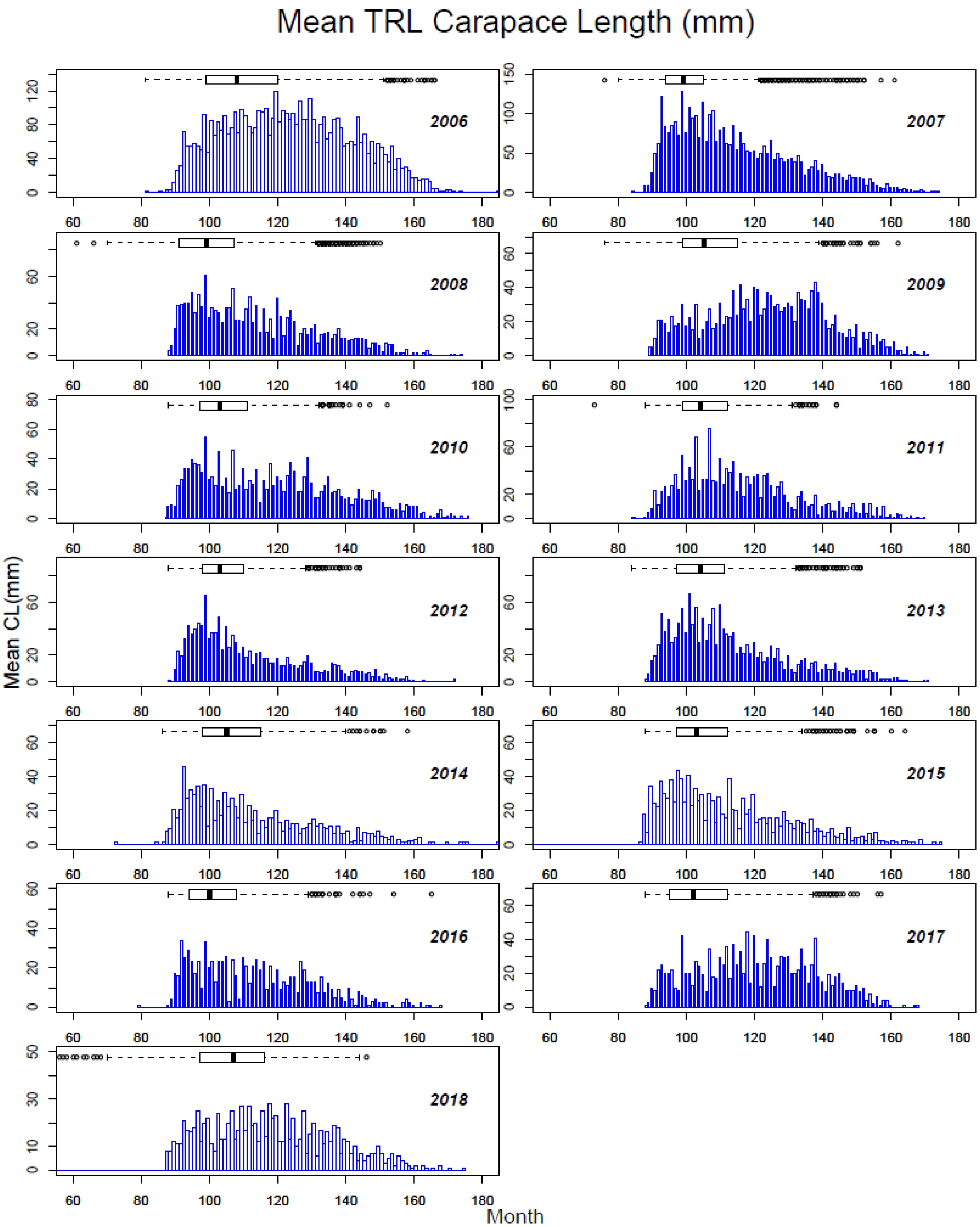


Figure E-4. Size frequency distributions of ornate rock lobsters (*Panulirus ornatus*) taken in commercial catches on the QLD east coast between 2006 and 2018.

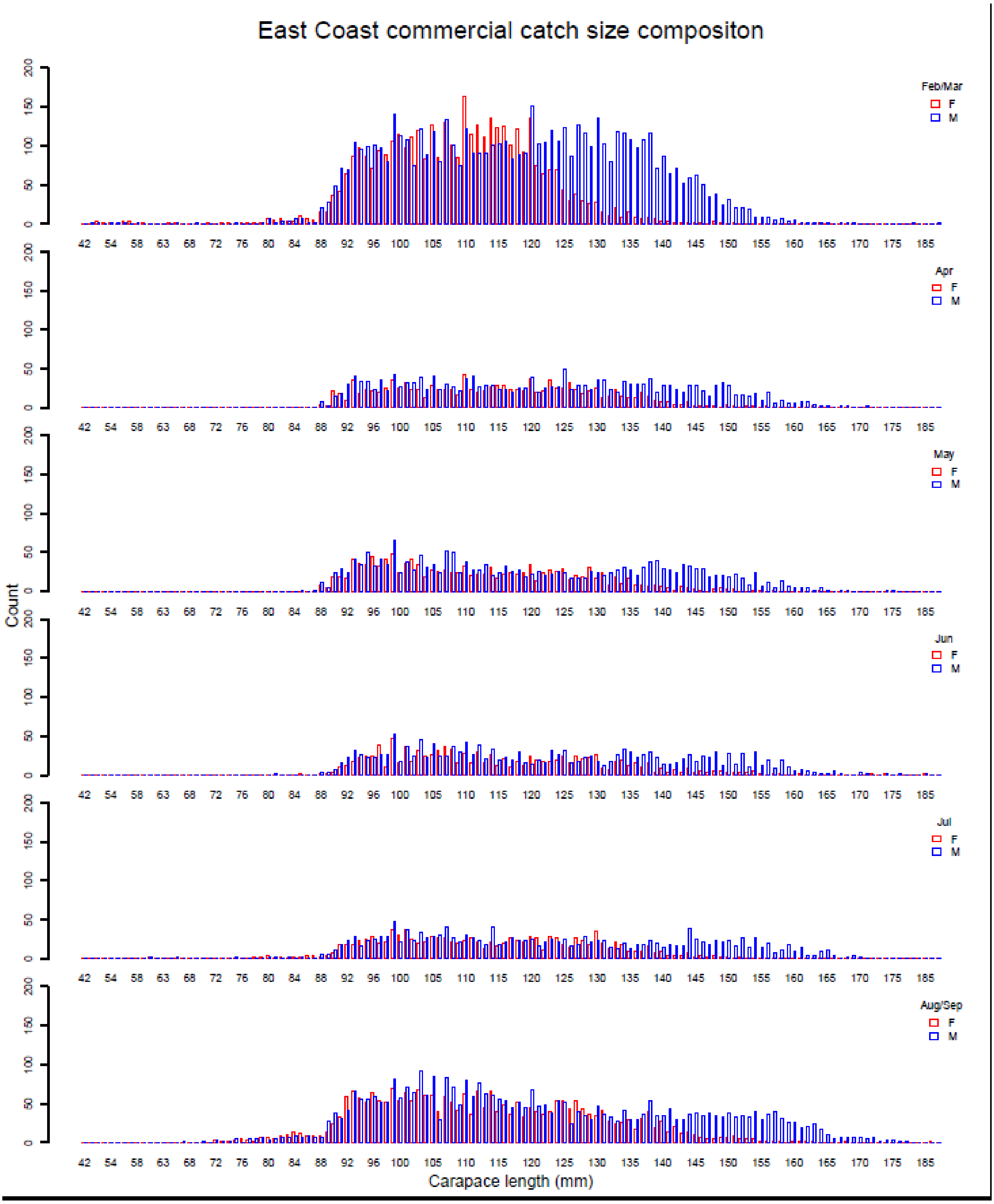


Figure E-5. Size frequency distributions of ornate rock lobsters (*Panulirus ornatus*) taken in monthly commercial catches on QLD east coast for all years (2006 – 2019) combined. Red bars indicate females, blue bars indicate males.

E.3.4 Comparative seasonal trends

The long-term seasonal trends in mean sizes of ornate rock lobsters (*Panulirus ornatus*) taken in commercial catches on the QLD east coast and in Torres Strait differ markedly (Figure E-6). However, this difference is primarily due to the different age compositions of these populations; QLD east coast comprising more than 4 year-classes (Figure E-4) cf. Torres Strait comprised almost entirely of only one year-class (Figure E-2).

The pattern observed in Torres Strait shows a drop from January to February, remaining consistent through until May, then increasing in June and remaining relatively consistent for the remainder of the fishing season. Whereas the pattern on the QLD east coast was less defined, although as for the Torres Strait catches there was a significant increase in mean CL from May to June.

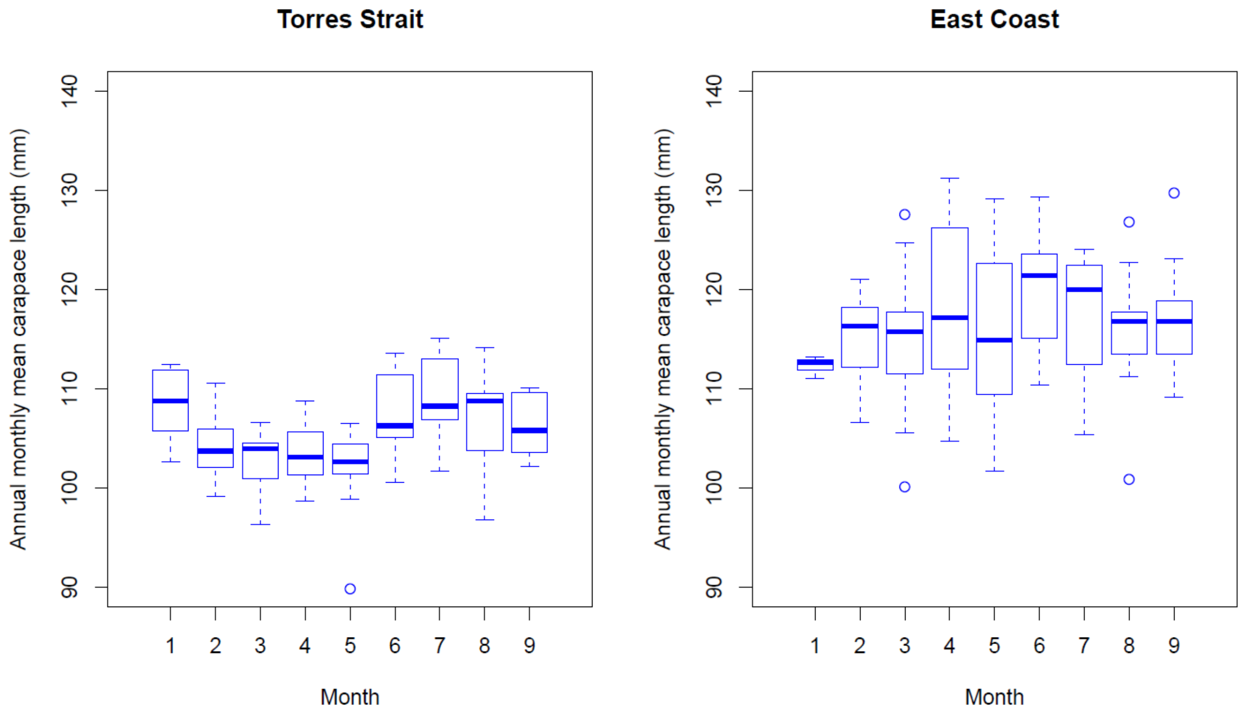


Figure E-6. Boxplots of monthly mean sizes of ornate rock lobsters (*Panulirus ornatus*) taken in commercial catches on QLD east coast and Torres Strait for all years sampled.

E.3.5 Temporal and spatial trends in lobster sex ratios

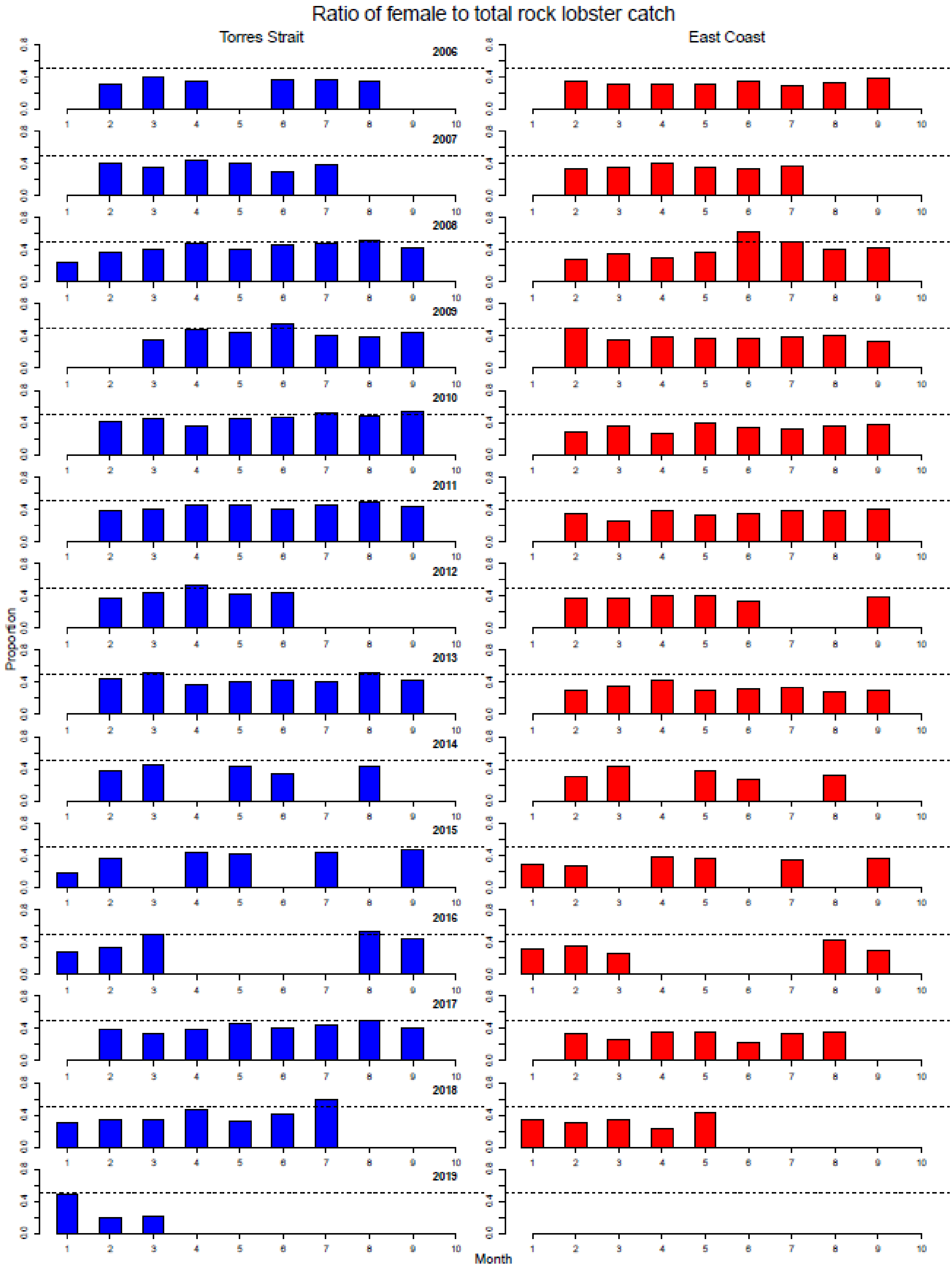


Figure E-7. Percent females from monthly commercial catches of ornate rock lobsters (*Panulirus ornatus*) taken in Torres Strait (blue bars) and on the QLD east coast (red bars) between 2006 and 2019.

Appendix F Extended analysis of pre-season survey data to calculate the annual index for 0+ lobsters

Rob Campbell, Éva Plagányi, Judy Upston, Mark Tonks, Nicole Murphy, Roy Deng

Introduction

The assessment model used to assess the status of Torres Strait rock lobsters is unable to satisfactorily fit the 2017 0+ index because it is too low to explain the 1+ numbers observed during both the mid-year and pre-season surveys conducted in 2018. However the 0+ index has some weight in the model (likelihood contribution depends on the variance) as apart from the 1+ indices it is the only direct prediction of 2018 1+ numbers, and unfortunately the 2018 pre-season 1+ index has relatively high variance also due to the spatial variability (mainly Buru). That means the model doesn't fit the 1+ index satisfactorily.

The TRLRAG agreed that the 2017 0+ index is anomalous and not a true reflection of the abundance possibly because (as outlined in the hypotheses table) of an environmentally-mediated change in distribution over that period. Note that although less reliable than the 1+ index, the 0+ index is fitted reasonably well in all previous years. Hence the RAG agreed that it should be down-weighted in the model in order to adequately fit the 1+ index. We agreed not to discard it entirely and are wanting an objective justifiable method for down-weighting it. For example it can be shown that if we double the associated variance for that year, the model is able to adequately fit the 1+ index (a minimum criterion given it is the key information that determines the TAC). But we don't want to adjust the variance in an ad hoc manner, especially as it makes a big difference to the RBC.

Given this situation, this paper investigates an alternative analysis of the pre-season survey data using General Linear Models (GLMs). In comparison to the present method used to calculate the annual index of 0+ lobsters based on the pre-assessment survey conducted each year, the use of GLMs allows for additional factors which may influence the number of lobsters observed and counted during any survey transect to be taken into account. Factors which may influence the number of observed lobsters include the depth of the survey transect, current speed and water visibility, each of which have been coded for when each transect was undertaken. An outline of the data and models used to undertake these alternative analyses is first described in the next two sections before the results are presented.

Data

The surveys analysed in this paper are limited to the pre-season surveys conducted during the nine years 2005-2008 and 2014-2018 and the 82 distinct sampling sites commensurate with those sampled during the mid-year surveys together with the five additional sites sampled in 2018. In total this gave a total of 678 survey transects (c.f. Figure F1). During each survey, together with the number of 0+ lobsters observed, the following additional information was also collected: i) length of transect, ii) width of transect, iii) water depth, iv) current speed, and v) visibility. While the transect width was 4 meters for all sampled sites, the length of the transect varied between 216 and 500 meters (being 500m for 625 sites, or 92.2% of all sites). For those sampled sites where the transect length was less than 500m the number of lobsters observed was scaled (or standardised) to represent the number within a 2000 m^2 area. This scaling assumes that mean density of lobsters along the entire 500m is similar to that along the surveyed transect. Histograms of the distribution of raw (i.e. unstandardized) number of 0+ lobsters observed at each sample site is shown in Figure F2a, while histograms of the distribution of water depth, current speed and visibility recorded for all sampled sites is shown in Figures F2b-d. For each sample site the associated value of the Southern Oscillation Index and phase of the moon (coded as the number of days after a full moon) corresponding to the date each site was sampled were also obtained and the histograms of the distributions of these values are shown in Figures F2e-f.

Finally, as a long term member of the diving team left the project after 2016, a question has been raised as to whether the absence of this experienced diver during the past two years may have influenced the number of 0+ lobsters observed. While there has been sixteen divers listed as participating in the 678 sites sampled above, where a two person diver team surveys each site, a simple analysis was conducted where these dive teams were divided into the following two groups: Team-1 included all two-person teams which included the experienced diver mentioned above while Team-2 included all teams which did not include this diver. Across the 678 sites, Team-1 surveyed 213 sites while Team-2 surveyed 465 sites. The number of sites surveyed by each team in each year is shown in Figure F3a while a comparison of the mean number of 0+ lobsters counted by each team within each year is shown in Figure F3b.

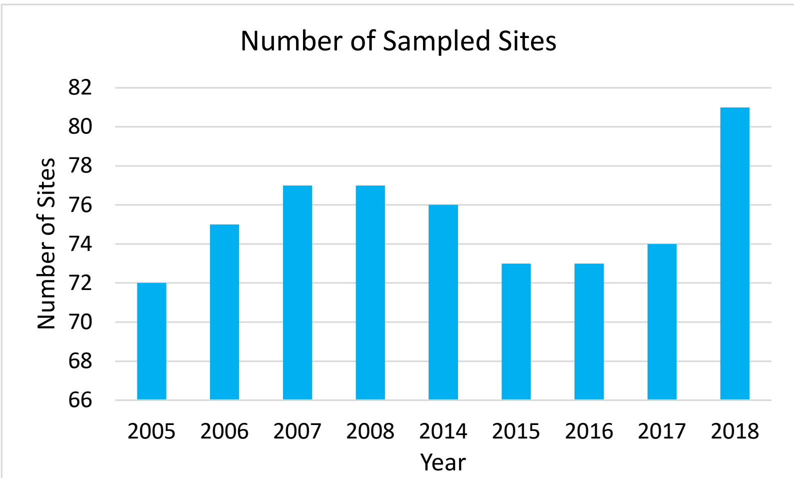


Figure F1. Number of sampling sites visited during each of the annual pre-season surveys.

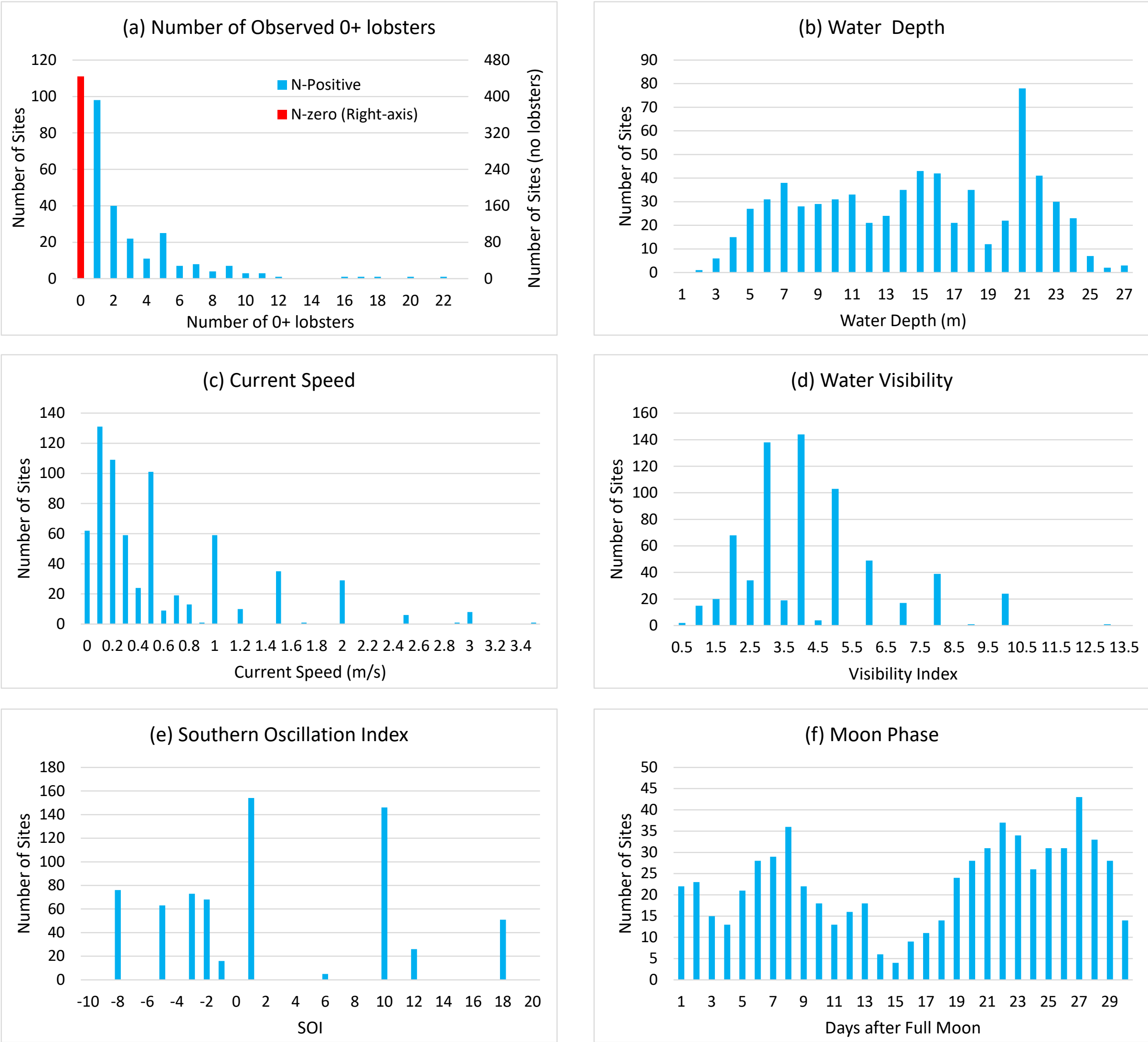


Figure F2. Data summary. Histograms of (a) number of 0+ lobsters observed, (b) water depth, (c) current speed, (d) water visibility, € southern oscillation index, and (f) moon-phase at each of the 678 sampled sites.

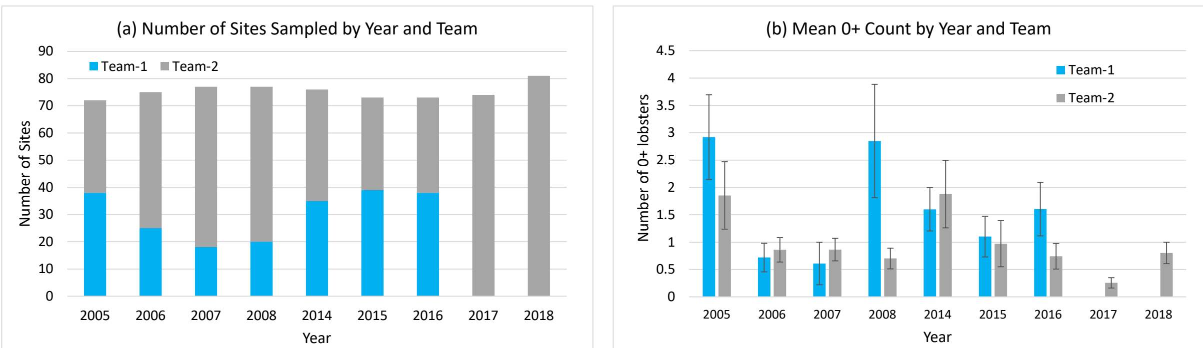


Figure F3. (a) Number of sites surveyed and (b) the mean number of 0+ lobsters counted by each team within each year (with standard errors also shown).

Method

Due to the high number of zero observations of 0+ lobsters across all sampled sites (444 of the 678 sampled sites, or 65%) it was considered best practice to standardise the number of observed 0+ lobsters as a two stage process: one stage being concerned with the pattern of occurrence of positive observations, and the other stage with the mean size of the positive counts. We also assume that both the probability of a positive catch and the size of a positive catch rate can be modelled as linear combinations of the factors described in the previous section. Once this is done, we can combine the means from the two distributions to give an overall mean standardised index of lobster counts.

A small example helps illustrate this approach. Consider a survey season for which there are n sampled sites with an observed number of 0+ lobsters, C_i, recorded against each site. The average number of 0+ lobsters across all sites can be expressed as follows:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} C_i = \frac{1}{n_S + n_F}\sum_{i=1}^{n_s} C_i = \frac{n_S}{n_S + n_F}\frac{1}{n_S}\sum_{i=1}^{n_s} C_i = p_S \mu_S$$

where n_S is the number of positive count sites obtained (C_i>0), n_F is the number of counts (C_i =0), p_S is the proportion of positive count sites and μ_S is the average of the positive counts. This result shows that the overall mean catch rate can be expressed as the combination of the parameters from the distributions used to model the probability of a successful catch and that used to model the non-zero counts. A similar approach was used in the estimation of egg production based on plankton surveys (Pennington 1983, Pennington and Berrien 1984) and for estimating indices of fish abundance based on aerial spotter surveys (Lo et al 1992).

Stage 1: Prob(positive count)

The Binominal distribution is used to model the probability of a non-zero lobster count where we model each observation as either a success (C_i >0) of a failure (C_i =0), with the probability of either expressed as follows:

Pr(C_i >0) = p_S and Pr(C_i =0) = 1- p_S

Associated with each observation is a vector of covariates or explanatory variables X_j thought likely to influence the probability of a positive catch. Furthermore, we assume that the dependence of p_S occurs through a linear combination $\eta = \sum \beta_j X_j$ of the explanatory variables. In order to ensure that 0≤ p_S≤1 we use the logit link function which takes the following form:

$$\eta = \log\left(\frac{p_S}{1-p_S}\right)$$

The inverse of this relation gives the probability of a positive sighting as a function of the explanatory variables:

$$p_S = \frac{e^\eta}{1+e^\eta} = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}{1+\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}$$

The following model was then fitted to the data using the SAS GENMOD procedure (SAS, 2008):

MODEL p_S = *Intercept +Year*Strata +Team*

+Water-Depth + Current-Speed + Visibility + SOI + Moon-Phase

/ dist=binomial link=logit

where *Year* refers to the sampling year, *Strata* refers to the seven regions used to stratify the sampled sites (Buru, Kircaldi, Mabuiag, Reef-Edge, South-East, TI-Bridge and Warraber) and * represents an interaction between these two variables. After fitting the above model to the data the standardised probability for a positive catch, p_S, was then calculated for each spatio-temporal strata (year, strata) against a standard set of model factors.

Stage 2: Mean Size of Positive Catch Rate

Having fitted the above model to the probability of obtaining a positive catch, a separate model was fitted to the distribution of positive catch rates, μ_S. For this purpose a log-Gamma model was adopted, such that the μ_S was assumed to have a gamma distribution with a log link to the vector of covariates or explanatory variables X_j. The data fitted to the model were limited to those observations having a positive catch.

As before, the following model was then fitted to the data using the SAS GENMOD procedure:

MODEL μ_S = *Intercept* + *Year*Strata* + *Team*

+ Water-Depth + Current-Speed + Visibility + SOI + Moon-Phase

/ dist=gamma link=log

A standardised mean positive catch rate, μ_S, was then calculated for each spatio-temporal strata (year, quarter and area) against a standard set of model factors.

Note: the continuous gamma distribution is used here as the fitted count may no longer be an integer after being scaled to represent the number of lobsters observed over a 2000 m^2 area.

In each of the two models described above, the explanatory variables Water-Depth, Current-Speed, Visibility and SOI were fitted as linear covariates (each standardized to have a mean of zero over all data) while Team and Moon-phase were fitted as a categorical variables, with the latter having ten equally spaced levels between 1 and 30. After fitting each model, the explanatory variables with the largest Type-III chi-square probability greater than 0.05 was removed. This process was repeated until no explanatory variables remained with a Type-III chi-square probability greater than 0.05.

Abundance index

The above two models were fitted to the data-sets defined below for each species and the results used to calculate the standardized index, *I*, in each year and stratum:

$$I(year,y;\ stratum,s) = p_S(y,s) * \mu_S(y,s)$$

An annual index of abundance, *Index(year)*, was then determined by calculating the area-weighted sum of the standardized index across all *NA* strata as follows:

$$Index(year, y) = \sum_{s=1}^{NA} Size_s * ps(y,s) * \mu s(y,s)$$

where $Size_s$ is the spatial size of the individual stratum. The annual index for all years was scaled so that the mean of the annual index over the entire time-series was equal to 1. Associated standard errors were also calculated using the method described in Campbell (2015).

Finally, the standardised index was compared with the nominal CPUE defined as follows:

$$Nominal\ Index(year, y) = \sum_{s=1}^{NA} Size_s * \left[\frac{\sum_{i=1}^{n_{y,s}} C_{y,s,i}}{n_{y,s}}\right]$$

where $C_{y,s,i}$ refers to the number of lobsters observed in the i^{th} site sampled in Stratum s and Year y and $n_{y,s}$ is the number of sites sampled in Stratum s and Year y. Again, the index was scaled so that the mean over the entire time-series was equal to 1.

Results

After fitting both models described above, apart from the highly significant *Year*Strata* interaction term, only the *Team* effect (0.0285) was found to be significant at the 5% level in the Binomial model and only the *Visibility* effect (0.0122) was found to be significant in the Gamma model. The Type-1 analyses for both the Binomial and the Gamma models are shown in Table F1.

Table F1. Type-1 analysis for both the Binomial and the Gamma GLM analyses.

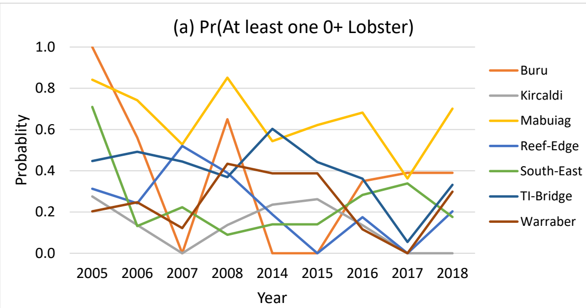
(a) Binominal Analysis

Source	Deviance	DF	Chi-Square	Pr > ChiSq
Intercept	873.781			
YEAR*STRATA	704.834	62	168.95	<.0001
TEAM	700.036	1	4.8	0.0285

(b) Gamma Analysis

Source	2*LogLikelihood	DF	Chi-Square	Pr > ChiSq
Intercept	-1020.7998			
YEAR*STRATA	-912.2869	53	108.51	<.0001
VISIB	-906.0102	1	6.28	0.0122

The results of the GLM analysis for (a) the mean probability of observing at least one 0+ lobster, and (b) the mean number of 0+ lobsters observed per transect surveyed in each strata and year are shown in Figure F4. Across all nine years, the strata having the highest average probability (0.65) of observing at least one 0+ lobster is Mabuiag while the strata having the lowest probability (0.13) is Kircaldi. This spatial pattern is also found for the average number of 0+ lobsters observed within each strata across all years, with Mabuiag and Kircaldi having the highest (3.93) and lowest (0.75) mean number of lobsters respectively.



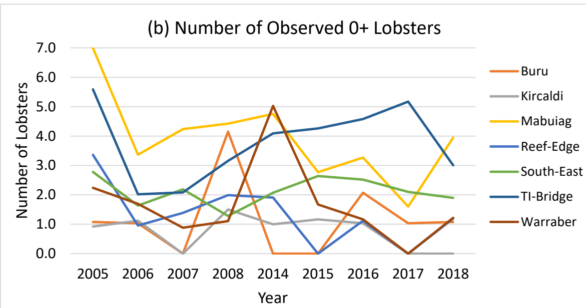


Figure F4. Results of GLM analysis: (a) the mean probability of observing at least one 0+ lobster, and (b) the mean number of 0+ lobsters observed per transect surveyed in each strata and year.

Finally, the annual index (and associated standard error) of 0+ lobster abundance across the nine survey years is listed in Table F2 and displayed in Figure F5 (known as the GLM analysis). Also shown is the annual index based on the method which has been used in recent years for analysing the survey data (known as the ORACLE analysis). Also shown is the Nominal annual index based on the method described in the previous section together with the results of an alternative GLM analysis which used a log-Normal distribution instead of a log-Gamma distribution in the Stage-2 model described previously.

As expected, the Nominal and ORACLE based indices are very similar (and provides a useful check) as the two associated methods are both similar. The two GLM-based indices are also similar indicating that the result is not sensitive to the type of distribution assumed for the analysis. The Gamma distribution is recommended as it assumes a more general variance structure. A comparison of the GLM and ORACLE based indices is shown in Table F2 and indicates that the two indices have the greatest relative difference in the last two years, where the former GLM index is around 34% and 27% higher respectively. The standard error associated with the 2017 GLM-based index is also appreciably higher (84%) than that associated with the ORACLE-based index and this result may help overcome the issue of the anomalously low variance associated with the 2017 index described in the Introduction.

Table F2. Annual index (and standard error, SE) for the abundance of 0+ lobsters based on various analysis of the pre-season survey data.

	GLM Analysis		ORACLE Analysis		GLM vs ORACLE Analysis		Nominal Analysis	GLM Normal
Year	Index	SE	Index	SE	Index	SE	Index	Index
2005	2.044	0.365	1.987	0.376	2.84%	-3.03%	1.991	2.106
2006	0.846	0.185	0.914	0.200	-7.40%	-7.13%	0.869	0.896
2007	0.711	0.193	0.624	0.149	13.94%	29.68%	0.636	0.721
2008	1.385	0.289	1.473	0.375	-5.96%	-23.03%	1.424	1.388
2014	1.144	0.253	1.355	0.293	-15.57%	-13.52%	1.347	1.151
2015	0.791	0.171	0.745	0.192	6.25%	-11.04%	0.750	0.712
2016	0.928	0.214	1.007	0.242	-7.80%	-11.42%	1.060	0.906
2017	0.262	0.134	0.195	0.073	33.86%	84.45%	0.206	0.241
2018	0.888	0.189	0.700	0.168	26.94%	12.41%	0.717	0.878
Mean	1.00		1.00				1.00	1.00

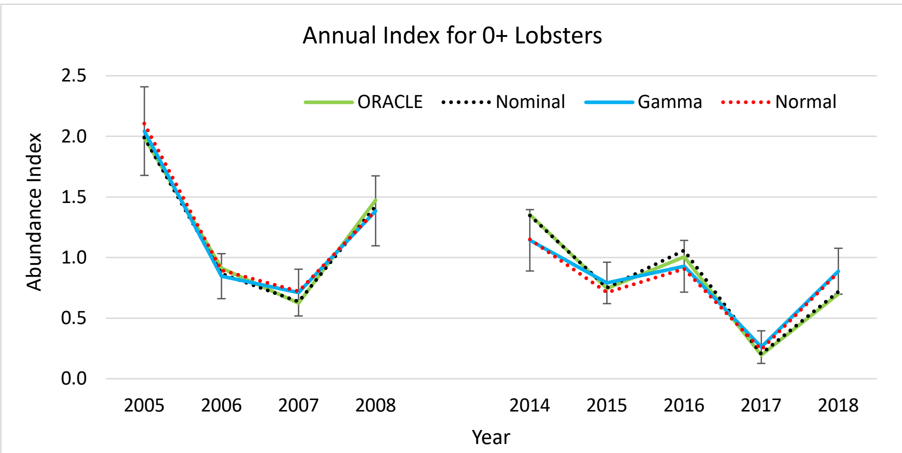


Figure F5. Annual index for the abundance of 0+ lobsters based on various analysis of the pre-season survey data. The standard error is shown for the GLM-Gamma index.

Discussion

The approach outlined in this paper describes an alternative approach to analysing the data associated with the annual surveys conducted for the Torres Strait rock lobster and used to construct an annual abundance index for use in the associated stock assessments and harvest strategies. While this approach has only been used here to construct an annual index for 0+ lobsters based on the pre-season surveys, there is no reason why this method could not also be used to construct annual indices for the other age classes using both the mid-year and pre-season surveys. The results presented here should nevertheless be seen as preliminary as the approach used to assess the *Team* effect is rather simple and further investigations should be undertaken to assess the possible influence of other divers. For example, we have not addressed the issue of counts by teams for each transect being paired (counts are not independent), which can influence estimation of errors and conclusions about differences between teams Furthermore, for the purpose of this preliminary analysis we have assumed that the *Team* effect does not vary between years and this should be tested in future analyses. Also, there has been no investigation of the residuals associated with the analyses presented above to assess the suitability of the assumed Gamma distribution. Finally, it would also be useful to add further explanatory variables to account for changes in the in-situ environment (e.g. water temperature) and, in particular, the habitat data which has been routinely collected during the surveying of each sampled site.

Appendix G Tropical Rock Lobster abundance surveys – data conflicts and different analysis approaches

Judy Upston, Éva Plagányi, Mark Tonks, Rob Campbell, Nicole Murphy, Roy Deng

Summary

This paper investigates whether the anomalous 2017 0+ tropical lobster survey index (discussed in Chapter 8 of this report) could be explained by varying counts by dive teams which differ in their experience of doing the surveys and observing cryptic 0+ lobsters. Results from a random effects negative binomial regression model including an interaction term for team*year showed no evidence for dive teams reporting significantly different 0+ tropical lobster counts, apart from two early years, 2006 and 2007. Thus other reasons for anomalous 2017 pre-season 0+ count. Whilst there may still be a component of sampling error, such as increased variation arising from reduced sampling sites since 2015, the 0+ lobster survey pre-season index is only anomalous for 2017 (when compared to 1+ lobsters present in the 2018 mid-season survey) which also points to possible process error not as yet modelled, such as variation in the environment or other factor(s) impacting on distribution of 0+ lobsters. Following from this, we consider data weighting approaches that have been used when including survey indices in stock assessments.

Methods

The research survey methods are outlined in Chapter 6 of this report. Two groups of dive teams, 'GS' and 'OT', were assigned 2-person dive teams based on the number of years of experience participating in the lobster research surveys. The 'gold standard' reference (GS) dive team included the most experienced diver who was also thought to be the most capable of sighting cryptic 0+ lobsters, however the other dive team (OT) also had considerable experience with the surveys. We compared only 0+ lobster counts where a standard 500m x 4m transect was swum, and when both teams in our study were operating on the same day for the years in which the pre-season survey has been completed (2005 to 2008 and 2014 to 2016). The data selections avoid having to scale counts for non-standard transects based on an assumed distribution of lobsters along a transect. Further, they control for an implicit day effect due to differences in visibility, current, weather or other factors that may impact 0+ lobster counts, as well as providing an objective way to balance the experimental design, otherwise observations by the 'OT' team dominate in some early years.

The plots, data summary and statistical analyses were produced using Stata Vers. 15.1 (StataCorp LLC 2017).

The negative binomial regression model A included an interaction term for team*year and a random effects term for transect, allowing for variation in 0+ counts due to transect, which is a proxy for site (each a different location with varying bottom habitat). The random effects negative binomial regression model B, which excluded the interaction term for team*year, was considered to be a mis-specified model but is included for completeness (Table G2). Under this model differences in 0+ lobster counts by the dive teams are assumed not to vary between years, which is not accepted based on model A results.

Results

A plot of the frequency of 0+ tropical lobster counts showed that the data are not normally distributed, so we assumed a negative binomial distribution for statistical analyses (Figure G1). Summary statistics that are reported in Table G3 and Table G4 also supported this.

A plot of 0+ lobster counts (on natural log scale) by dive team and year shows no notable differences (as gauged by overlapping error bars for each GS OT and year group) apart from 2006 and 2007 (Figure G2).

Significantly lower 0+ lobster counts were recorded by dive team OT compared to the GS reference team for two early years, 2006 and 2007 (Table G1 random effects negative binomial model A, p=0.012 and p=0.002 respectively).

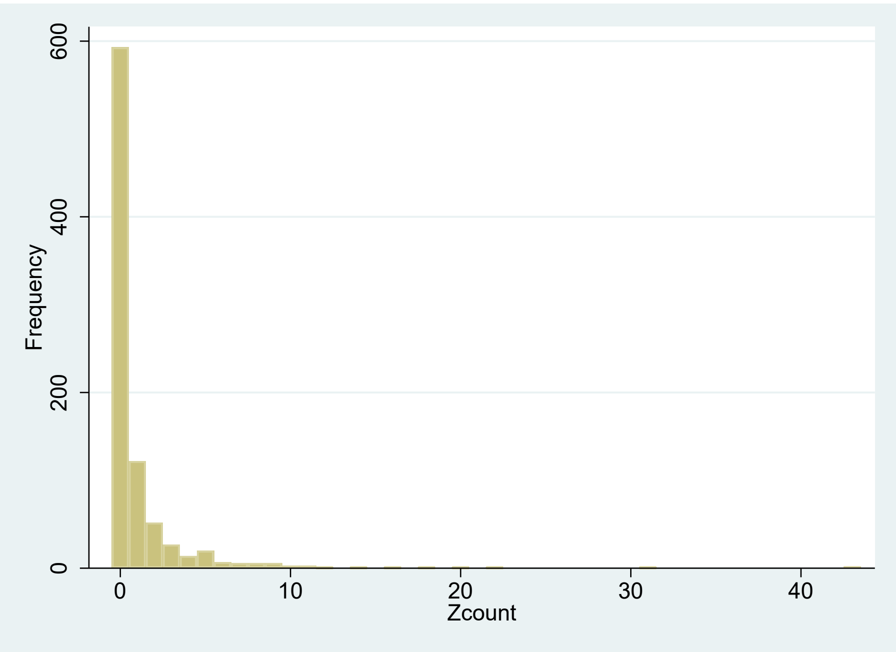


Figure G1. Frequency plot of 0+ tropical lobster counts (Zcount) showing that the data are skewed towards 0, so we have assumed a negative binomial distribution for statistical analyses.

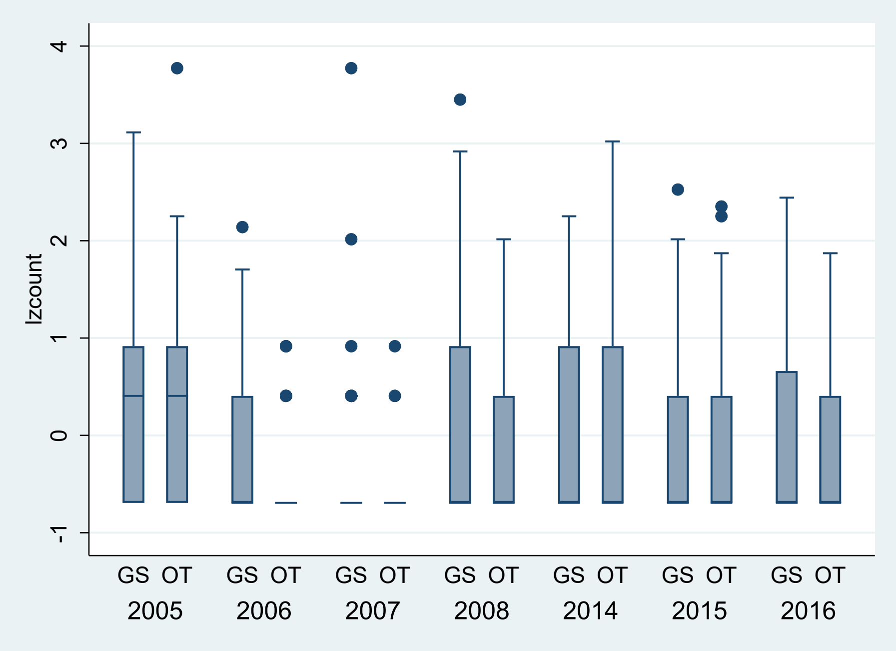


Figure G2. Plot of ln(0+) tropical lobster count (lzcount) by dive team (GS = 'gold standard' reference dive team including most experienced diver, OT = other dive team who also have considerable experience with the surveys). Note the y-axis shows natural log of count + 0.5. A log scale is shown as it is closer to how we model the data.

Table G1. Results for Model A - random effects negative binomial regression model that included an interaction term team*year and a random error term for transect.

```
Random-effects negative binomial regression     Number of obs     =        675
Group variable: id                              Number of groups  =        192

Random effects u_i ~ Beta                       Obs per group:
                                                             min =          1
                                                             avg =        3.5
                                                             max =          7

                                                Wald chi2(13)     =      48.35
Log likelihood  = -821.46411                    Prob > chi2       =     0.0000

------------------------------------------------------------------------------
      zcount |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     teamcode |
          OT  |   -.108411   .2763205    -0.39   0.695    -.6499892    .4331672
             |
        year |
        2006  |  -.7459344   .2956686    -2.52   0.012    -1.325434   -.1664347
        2007  |  -1.039837   .3310574    -3.14   0.002    -1.688698   -.3909768
        2008  |  -.3794791   .2998937    -1.27   0.206      -.96726    .2083018
        2014  |  -.4713264   .2591745    -1.82   0.069     -.979299    .0366463
        2015  |  -.5605094   .2909495    -1.93   0.054     -1.13076    .0097412
        2016  |  -.5806957   .3209313    -1.81   0.070    -1.209709    .0483181
             |
teamcode#year |
     OT#2006  |  -.7523268   .5008517    -1.50   0.133    -1.733978    .2293246
     OT#2007  |  -1.617399    .701545    -2.31   0.021    -2.992402   -.2423958
     OT#2008  |  -.2827527   .4681303    -0.60   0.546    -1.200271    .6347657
     OT#2014  |   .0099772   .4039394     0.02   0.980    -.7817295    .8016839
     OT#2015  |   -.526921   .4914396    -1.07   0.284    -1.490125     .436283
     OT#2016  |  -.1629118   .4794761    -0.34   0.734    -1.102668    .7768441
             |
       _cons |   .0285866   .2336074     0.12   0.903    -.4292754    .4864487
-------------+----------------------------------------------------------------
       /ln_r |   .7213463    .186602                       .3556131    1.087079
       /ln_s |   .8178625   .3007503                       .2284028    1.407322
-------------+----------------------------------------------------------------
           r |   2.057201   .3838778                       1.427055      2.9656
           s |   2.265652   .6813955                       1.256591    4.085002
------------------------------------------------------------------------------
LR test vs. pooled: chibar2(01) = 65.71              Prob >= chibar2 = 0.000
```

Table. G2. Results for mis-specified Model B –random effects negative binomial regression model without a team*year interaction term. A random error term for transect is included in the model.

```
Random-effects negative binomial regression     Number of obs      =       675
Group variable: id                              Number of groups   =       192

Random effects u_i ~ Beta                       Obs per group:
                                                               min =         1
                                                               avg =       3.5
                                                               max =         7

                                                Wald chi2(1)       =     10.52
Log likelihood  = -847.01418                    Prob > chi2        =    0.0012

------------------------------------------------------------------------------
      zcount |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    teamcode |
         OT  |  -.4468405   .1377934    -3.24   0.001    -.7169105   -.1767705
       _cons |  -.4656838   .1637022    -2.84   0.004    -.7865341   -.1448334
-------------+----------------------------------------------------------------
       /ln_r |   .5448048   .1725857                      .2065431    .8830664
       /ln_s |   .5293699   .2776077                     -.0147312    1.073471
-------------+----------------------------------------------------------------
           r |   1.724272   .2975846                      1.229421    2.418304
           s |   1.697862   .4713396                      .9853768    2.925516
------------------------------------------------------------------------------
LR test vs. pooled: chibar2(01) = 75.48                Prob >= chibar2 = 0.000
```

Table G3. Summary statistics for early survey years, 2005 to 2008. An initial look at the count data showed that the variance is much greater than the mean. Thus the errors were not normally distributed and a negative binomial model was instead assumed for statistical models.

```
------------------------------------------------------
-> year = 2005, team = GS

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  2.333333  17.20755        54
--------------------------------------------

------------------------------------------------------
-> year = 2005, team = OT

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  2.512195   46.8561        41
--------------------------------------------

------------------------------------------------------
-> year = 2006, team = GS

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  .7241379   2.30853        58
--------------------------------------------

------------------------------------------------------
-> year = 2006, team = OT

  variable |      mean  variance         N
-------------+------------------------------
    zcount |        .2  .2644068        60
--------------------------------------------

------------------------------------------------------
-> year = 2007, team = GS

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  1.086207  32.36086        58
--------------------------------------------

------------------------------------------------------
-> year = 2007, team = OT

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  .0666667  .0971751        60
--------------------------------------------

------------------------------------------------------
-> year = 2008, team = GS

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  2.552632  35.38905        38
--------------------------------------------

------------------------------------------------------
-> year = 2008, team = OT

  variable |      mean  variance         N
-------------+------------------------------
    zcount |  .9459459  3.052553        37
--------------------------------------------

------------------------------------------------------
```

Table G4. Following from Table G3 - Summary statistics for recent survey years, 2014 onwards. The errors are not normally distributed and a negative binomial model was instead assumed for statistical models.

-> year = 2014, team = GS			
variable | mean variance N			
-------------+-----------------------------			
zcount | 1.129032 3.589635 62			
--			

-> year = 2014, team = OT			
variable | mean variance N			
-------------+-----------------------------			
zcount | 1.645161 13.57694 62			
--			

-> year = 2015, team = GS			
variable | mean variance N			
-------------+-----------------------------			
zcount | 1.225 5.614744 40			
--			

-> year = 2015, team = OT			
variable | mean variance N			
-------------+-----------------------------			
zcount | .9428571 5.878992 35			
--			

-> year = 2016, team = GS			
variable | mean variance N			
-------------+-----------------------------			
zcount | 1.555556 9.28254 36			
--			

-> year = 2016, team = OT			
variable | mean variance N			
-------------+-----------------------------			
zcount | .8235294 1.907308 34			
--			

Discussion

We found no evidence for dive teams which differ in their experience of doing surveys reporting significantly different 0+ tropical lobster counts, apart from two early years, 2006 and 2007. Whilst there may still be a component of observation (sampling) error, such as increased variation arising from reduced sampling sites since 2015, the 0+ lobster survey pre-season index is only anomalous for 2017 which also points to possible process error not as yet modelled, such as variation in the environment or other factor(s) impacting on distribution of 0+ lobsters.

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). One approach suggested by Francis (2011) is to run alternative assessments in which possibly unrepresentative data sets are excluded, and this uncertainty be communicated to fishery managers. We consider in Box G1 data weighting approaches that have been used when including survey indices in stock assessments.

Box 1 – Approaches for weighting data/ accounting for process error (see Maunder et al 2017 for a review):

-iterative re-weighting based on the estimated variance from an integrated stock assessment model. This is a standard approach which was taken in current assessment;

-other approaches include estimating this variance outside model and adding the variance to the CV of the index;

-model as a change in catchability (random error or environmental covariate);

-retrospective analyses to potentially detect unmodelled temporal changes in modelled processes (Carvalho et al. 2017), and the information used to revise a stock assessment model (see Punt 2017 on inclusion of process variation and data weighting);

-include process variation via random effects or state-space modelling (Francis 2017);

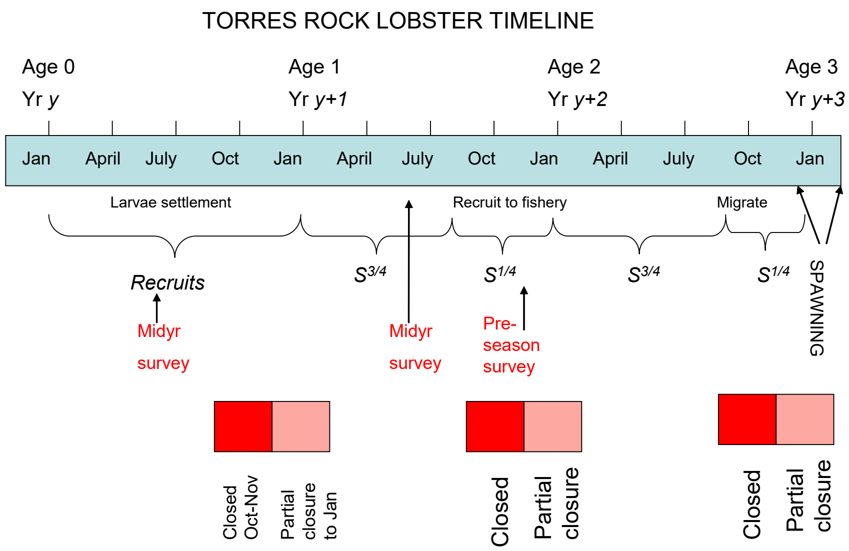
-other approaches for stock assessment are outlined in Maunder et al. 2014, 2016 (The CAPAM workshop series on stock assessment methodology)

Appendix H Stock Assessment Model Equations

H.1 Stock Assessment Equations

Introduction

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 (Apx Figure H-1). A schematic summary timeline underlying the new Integrated model is presented in Apx Figure H-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 the Torres Straits 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.



Apx Figure H-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:

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

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 2010 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.

$$N_{y,1}^{mid} = N_{y,1} e^{-M_1/2} \qquad 16$$

$$N_{y,2}^{mid} = N_{y,2}\, e^{-M_2/2} - C_{y,2} \qquad 17$$

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

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

$$N^{pre}_{y,2} = N^{mid}{}_{y,2}\, e^{-5M_2/12} \quad 19$$

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

$$F^{1+}_y = C^{1+}_y \;/ B^{exp,1+}_y \quad 20$$

$$F^{2+}_y = C^{2+}_y \;/ B^{exp,2+}_y \quad 21$$

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

$$C^{1+}_y = p_{y,1+}C_y \quad 22$$

and

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

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:

$$C_{y,1} = S_{y,1}F^{1+}_y N_{y,1}e^{-3M_a/4} \qquad \text{for } a = 1\text{, and} \quad 24$$

$$C_{y,2} = S_{y,2}F^{2+}_y N_{y,2}e^{-M_a/2} \qquad \text{for } a = 2 \quad 25$$

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:

$$B^{sp}_{y_0} = \theta \cdot K^{sp} \quad 27$$

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 (- $\ell \mathrm{n} L$) 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:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell \mathrm{n}\left(I_y^i\right) - \ell \mathrm{n}\left(\hat{I}_y^i\right) \qquad 31$$

where

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

$\hat{I}_y^i = \hat{q}_s \widehat{N}_y^{survey}$ is the corresponding model estimate, where $\widehat{N}_y^{survey}$ 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:

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

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:

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

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

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

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

and

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

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

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:

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

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:

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

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

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

$(\sigma_y)^2 = \ln\left(1 + (CV_y)^2\right)$ 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:

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

where

$\lambda_y = \varepsilon_y$ is the recruitment residual for year y, which is estimated for year $y1$ to $y2$ (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.

H.2 2018 Revised Reference Case model stock recruitment residual estimates and 90% Hessian-based confidence intervals

	Val	onfidence interval	
1985	0.08	-0.34	0.51
1986	0.03	-0.65	0.72
1987	0.02	-0.50	0.54
1988	0.70	0.46	0.95
1989	-0.05	-0.29	0.19
1990	-0.01	-0.24	0.21
1991	0.25	0.04	0.47
1992	0.29	0.07	0.51
1993	0.09	-0.12	0.31
1994	0.33	0.09	0.56
1995	0.08	-0.14	0.30
1996	0.05	-0.15	0.26
1997	0.16	-0.05	0.38
1998	-0.60	-0.84	-0.36
1999	-0.21	-0.45	0.03
2000	-0.83	-1.12	-0.55
2001	-0.35	-0.59	-0.11
2002	0.11	-0.10	0.33
2003	0.23	0.01	0.45
2004	0.27	0.06	0.48
2005	-0.67	-0.88	-0.47
2006	0.25	0.03	0.47
2007	-0.09	-0.30	0.12
2008	-0.24	-0.42	-0.06
2009	0.03	-0.19	0.26
2010	0.47	0.26	0.68
2011	0.44	0.23	0.66
2012	0.37	0.13	0.61
2013	-0.04	-0.26	0.18
2014	0.01	-0.23	0.24
2015	0.22	-0.01	0.45
2016	-0.40	-0.64	-0.15
2017	-0.61	-0.86	-0.37
2018	0.07	-0.20	0.35

Glossary

AFMA	Australian Fisheries Management Authority
CPUE	Catch Per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Agency
eHCR	Empirical Harvest Control Rule
RBC	Recommended Biological Catch
TAC	Total Allowable Catch
TIB	Traditional Inhabitant Boat sector
TRL	Tropical Rock Lobster
TSSAC	Torres Strait Scientific Advisory Committee
TVH	Transferrable Vessel Holder (Licence)
TRL RAG	Tropical Rock Lobster Research Advisory Group
PNG	Papua New Guinea

References

Anon. (2007). Commonwealth Fisheries Harvest Strategy Policy-draft guidelines. DAFF. 59 pp.

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., Plaganyi, 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., Plaganyi, 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., Plaganyi, 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. Plaganyi, 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., Plaganyi, 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, Plaganyi 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 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

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 RC (2017) Revisiting data weighting in fisheries stock assessment models. Fish Res 192:5-15

Harley, S.J., Myers, R.A., and Dunn, A. (2001) Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisherieas 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

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.

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

Plaganyi, 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*

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

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

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

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.

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.

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

StataCorp (2017) website: www.stata.com

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, Plaganyi 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.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

AT CSIRO, WE DO THE
EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today – for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australia's catalyst for innovation.

CSIRO. WE IMAGINE. WE COLLABORATE.
WE INNOVATE.

FOR FURTHER INFORMATION

CSIRO Oceans and Atmosphere Flagship
Dr Éva Plagányi
Principal Research Scientist
t +61 7 38335955
e Eva.Plagányi-lloyd@csiro.au
w http://people.csiro.au/P/E/Eva-Plaganyi-Lloyd

Mark Tonks
Experimental Scientist
t +61 7 38335973
e Mark.Tonks@csiro.au
w www.csiro.au