Torres Strait Reef Line Fishery:

Coral trout (*Plectropomus* spp.) catch rate analysis, with data to June 2022

November 2023

Queensland Government

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Summary

Following the 2019 preliminary stock assessment in Hutton et al. (2019), an updated analysis of coral trout (*Plectropomus* spp.) abundance indices in the Torres Strait Finfish Fishery was conducted using logbook data up to June 2022. The primary goal of this analysis was to identify trends in standardised commercial annual catch weights. A generalised linear model was used to standardise catch weights in kilograms per operation-day. Despite data limitations due to the small size of the fishery, catch rates have remained generally steady over the last decade and appear stable under current fishing pressure.

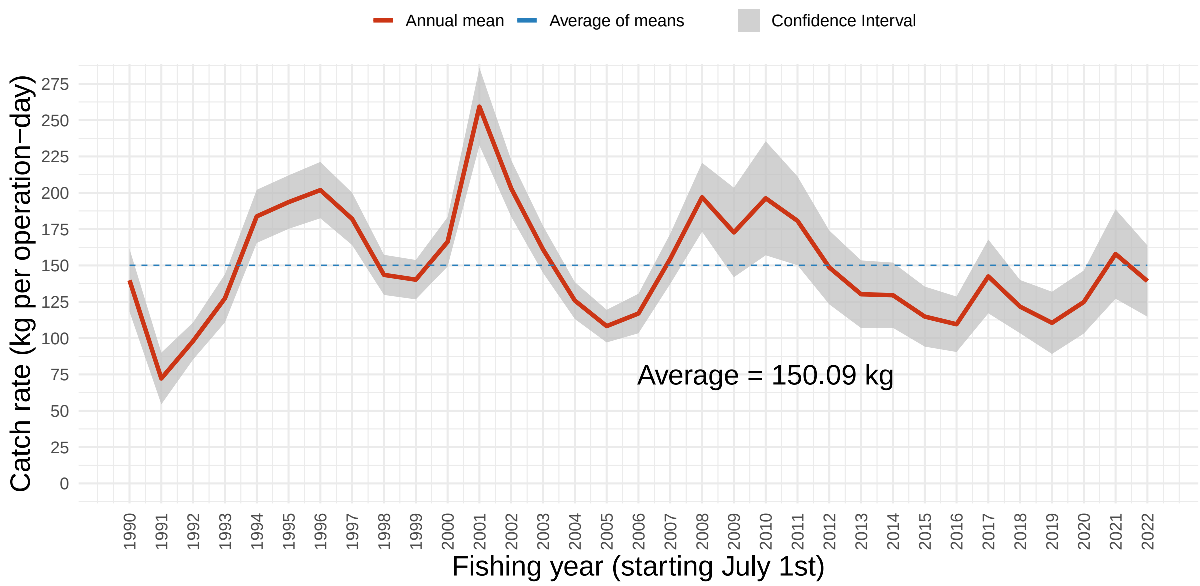

Figure 1: Commercial sector ("sunset") average catch weight (kg per sunset operation-day) by fishing year with 95% confidence intervals

Acknowledgements

The authors proudly acknowledge First Nations (Aboriginal peoples and Torres Strait Islanders) and the Traditional Owners of the country on which we live and work.

The authors acknowledge the continuing custodianship of Torres Strait fisheries by Islanders and Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Torres Strait waters for future generations.

The project team also gratefully respect and thank past and present Torres Strait islanders, communities, scientists, and fishers who supplied information and knowledge on Torres Strait coral trout.

Special thanks to:

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Results from this project inform the Protected Zone Joint Authority (PZJA, https://www.pzja.gov.au/) through its committees. The PZJA is responsible for management of commercial and traditional fishing in the Australian area of the Torres Strait Protected Zone (TSPZ) and designated adjacent Torres Strait waters. A number of Government Ministers and Agencies supports the PZJA: The Australian Fisheries Management Authority (AFMA), The Department of Agriculture and Water Resources (DAWR), The Queensland Department of Agriculture and Fisheries (DAF) and The Torres Strait Regional Authority (TSRA).

Glossary

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences.
AFMA	Australian Fisheries Management Authority.
Age	Age group representing a cohort of fish born in the same year. Age group was determined by counting growth rings in fish otoliths (ear bones).
BOM	Bureau of Meteorology, Australian Government.
Catchability *q*	The ability to catch fish. It was the average probability of catching a kilogram of fish with a single unit of standardised fishing effort.
Catch rate	Annual index of legal sized fish abundance. Catch rates were standardised in a GLM.
CDR	Catch disposal record. Verified landings on fish catch weights per primary operation.
DAF	Department of Agriculture and Fisheries, Queensland.
Fishery	The assessment covered all Torres Strait managed waters and fishing sectors.
Fishing year	Financial year from 1 July to 30 June.
GLM	Generalised linear model. The method used to standardise catch rates.
Harvest rate *u*	Fraction of vulnerable aged fish harvested each year. This signifies the fishing mortality F.
Hyperstability	When catch rates or age frequencies remain consistent as fish abundance declines.
Hyperdepletion	When catch rates or age frequencies decline as fish abundance remains consistent.
IUU	Illegal, unreported and unregulated fishing. For example, foreign fishing.
kg	Weight measured in kilograms.
Naigai	Naigai is the season of hot dry weather and calm winds (Sept–Nov).
Operation day	A single day of fishing by a primary vessel operation, using a number of dories, crew, hours and locations fished. Also called a boat day.
Over-dispersion	In statistics, over-dispersion is the presence of greater variability in the data than would be normally expected.
Overfishing	When a fish population is experiencing too much fishing effort, and the removal rate exceeds the target level.
PZJA	Protected Zone Joint Authority. www.pzja.gov.au
Quantile	A set of values which divide a frequency distribution into equal groups.
R	Free computer programming language for statistical computing and graphics.
Sector	A term used to distinguish types of fishing activity or fleets.
Sunset Sector	A leased commercial licence primary-tender package. Historically they were called Transferable Vessel Holder (TVH) boats. They were operated by non-traditional inhabitants.
Symbol	A single sunset operator operating a single mothership. This is one of the primary variables used in standardisation.
t	Metric unit of weight equal to 1000 kilograms.
TL	Fish total length in centimetres (cm).
Tender	Tender is a small open boat used for fishing. Usually 1–5 tenders were associated with a parent vessel (symbol). They are also known as dories.
TIB Sector	Torres Strait traditional inhabitant commercial fishing boat licence.
Trout	Used as a generic term for all species in the genus *Plectropomus* harvested in the Torres Strait (not the freshwater sport fish *Oncorhynchus*).
TSFRAG	Finfish Resource Assessment Group, PZJA scientific committee.
TSFWG	Finfish Working Group, PZJA committee for fishery management.
TSRA	Torres Strait Regional Authority.
wt	The daily weight in kilograms of harvested trout per operator.
Zone	A stock assessment region in the Torres Strait. Five zones were stratified (z2,..., z6). See Figure E.1 .

1 Introduction

The name "coral trout" refers to species in the genus (or species complex) *Plectropomus* found throughout the Indo-Pacific. Four coral trout species in the genus are commonly harvested in the Torres Strait. A summary of their biological characteristics can be found in Section 3.3. When combined *Plectropomus* account for the majority of species harvested in the Torres Strait finfish reef line fishery [1].

The commercial fishery is divided into two sectors, traditional inhabitant boat (TIB) and non-traditional (known as the "sunset" sector), centred around the reefs of the eastern Torres Strait. The sunset sector accounts for the majority of the annual harvest. Non-traditional commercial access to the fishery is granted through a temporary annual "sunset" licence, leased from the Torres Strait Regional Authority (TSRA). Sunset fishers usually operate a number of small single person boats known as "tender" from a larger mothership. Each mothership is associated with a single licence holder or "symbol".

Peaking in terms of total commercial harvest and number of active fishers in the early to mid 2000s, the Torres Strait reef line fishery is still an active fishery providing income to both mainland commercial fishers and traditional inhabitants. Moreover, *Plectropomus* spp. are an important staple catch for many communities and individuals in the Torres Strait where the distinction between commercial, recreational and subsistence fishing is often blurred (Lalancette 2017). Maintaining healthy *Plectropomus* spp. stocks is thus critical to preserving the unique culture of the Torres Strait.

In May 2023, the Australian Fisheries Management Authority (AFMA) requested a write-up and a final published report on the coral trout catch rate analysis completed for the Torres Strait Finfish Fishery Resource Assessment Group (TSFFRAG) and the Torres Strait Finfish Working Group (TSFFWG) late in 2022. The work and this report provide updated information to management agencies and stakeholders on trends in the commercial Torres Strait coral trout fishery, to support stock status reporting and classification by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Patterson et al. 2022).

[1] The management nomenclature can be confusing: The "finfish reef line fishery" covers commercial bottom line fishing in the Torres Strait. The Torres Strait Spanish Mackerel fishery is managed as a separate fishery, despite the fact Spanish Mackerel (a fish with fins) are also caught (near reefs) using trolled lures (attached to lines).

2 Methods

2.1 Data sources

Table 2.1 gives a summary of the data sources used in this analysis. Currently, the estimated standardised annual catch rates from sunset logbook data is the best available indicator of stock abundance. The catch disposal record (CDR) data estimated annual harvests from 2018–2022, to tally onto the pre-2018 series estimated in Hutton et al. (2019). Annual harvest is considered supplementary and not an index of abundance in and of itself.

Table 2.1: Summary of the data collated for coral trout reporting

Type	Fishing year	Source
Commercial harvest	1990–2022	Sunset catch rates from commercial AFMA and Queensland logbooks.
	2019–2022	CDR version TDB02 records for sunset harvests and TIB harvests and catch rates.

2.2 Catch rate data preparation

AFMA provided two CSV files on 8/11/2022 containing sunset catch weight data from 1990 to 2006. The first, 'Qld data' contained coral trout harvests reported only in Fisheries Queensland logbooks. The second, the 'Qld boat table', contained vessel and license codes, aiding data alignment with separate fishing-operations recorded in AFMA logbook records. AFMA's logbook included coral trout catch rate data for 1990–2022, retrieved from the Spanish mackerel AFMA project 2020/0815. Combining both AFMA and Queensland data completed the catch rate times series for analysis and standardisation.

CDR data, also from project 2020/0815, verified fish harvest weights from sunset and TIB fishing operations. The CDR reports calculated annual harvest tonnages since 2018 (for the sunset CDR summary, see Appendix B Table A.1). Annual harvests pre-2018 were summarised from the estimates in the Hutton et al. (2019).

Aspects of the AFMA logbook and CDR data tables were previously described in Spanish mackerel stock assessment reports (Begg et al. 2006; O'Neill and Tobin 2018; Hutton et al. 2019; Buckworth et al. 2021; O'Neill et al. 2022). These reports detailed the methods for summarising catch rates per operation day. There was one important change in units: coral trout harvests were mostly recorded in kilograms (kg) and mackerel harvests were in numbers of fish.

The sunset combined AFMA and Queensland logbook data were structured to form records of each operation's daily harvest, together with the associated variables for the main vessel name (anonymous codes were used), date, fishing zone, number of specified tenders, weight of coral trout harvested in kilograms, lunar phase and wind components.

Analyses of harvests at the primary symbol-operation-day unit matched the daily recording format. This avoided correlations in catch rates between tenders on an operation day (which may not be independent), artificially increasing the number of data into per tender-day units, bias towards operations using more tenders and mixed recording of fisher/crew names operating each tender.

The following aspects describe the combined sunset daily catch rate data:

- The data grouped each symbol-operation (symbol refers to motherships, not tenders), day and record number for line fishing. Operations were filtered for vessels harvesting coral trout. Line fishing in the Queensland data had many fishing codes, which included the method types “Line fishing”, “Handline”, “Dropline (Demersal longline)”, “Trotline (Demersal longline)”, and “Demersal longline” and “Trolling”. This was due to the Qld data originating from two historical logbook types of “LINE” and “MIXED”.

- The coral trout species codes, for aggregating *Plectropomus* spp., were 1) “Coral Trout” and “Common Coral Trout” in the AFMA logbook data, 2) “CORAL TROUT” in the Qld data, and 3) “Common Coral Trout”, “Bluespotted Coral Trout”, “Coral trout”, and “Passionfruit Coral Trout” in the CDR data. Only the CDR data implemented in 2017 makes a distinction between species.

- Wind, lunar phase and seasonal components data were calculated for each fishing date.

- Five fishing zones (labelled 2 to 6) were analysed in catch rates. The zones were calculated and categorised using latitude and longitude decimal degree data. The calculation used a custom R function `Regionfun(longitude, latitude)` developed by Hutton et al. (2019). The most western data, including zone 1, had few data, and was grouped into zone 2. The same situation was for zone 7 in the east and was grouped into zone 6. For a map of the regions see Figure E.1.

- The AFMA logbook which recorded harvests of coral trout were in two different data fields: 1) number of fish n, and 2) weight of fish in kilograms calculated based on different product forms (e.g, fillets, gutted, whole). The data for kg of fish was used as the primary recorded information, like in the Qld data. Records of zero harvest were not analysed. Table 2.2 lists the conversions used in the AFMA data.

- The final catch rate data grouped records identifying different dories and fishing sessions to form records of each symbol operation’s daily harvest. The catch rate data removed symbol operations that had fished less than 20 days over all years analysed and had fished in only one year. Reported bulk trip harvests, for more than one day, were excluded from the catch rates analysis (but not from annual harvest). In total, these filters removed about 5% of catch rate data.

- The tallied number of tenders used each day by each fishing operation typically ranged 0–7. The final catch rate analysis did not use this data. This was due to missing information in all years.

Table 2.2: Equations for converting sunset numbers of fish (n) and weights (w in kg) harvested per sunset operation day.

Equation	Parameters	Condition
$w_{new} = n \times wt$	where wt was the mean weight (kg) of a whole fish over years from AFMA logbook data = 1.644 kg. About 7% of AFMA records were in this form.	$n > 0$, $w_{old} = 0$
$wt_{new} = (wt_{old}/pc_{old}) \times pc_{new}$	where pc_{old} was the original and pc_{new} was the corrected product conversion weights (fillets = 2, gilled = 1.048 or whole = 1). About 93% of the data was in kg.	$w_{old} > 0$

Torres Strait wind and rainfall data was sourced from the Bureau of Meteorology (BOM), for the Horn Island weather station (Station ID: 94174; the nearest station with a complete series of data for the period of interest). Daily averages of wind speed (in km/h) and direction (in degrees, indicating the originating direction) were computed based on measurements taken between 6 am and 6 pm. The averages were then converted to north-south (windns) and east-west (windew) wind components:

$$\begin{aligned} \text{windns} &= \text{km hr}^{-1} \times \cos(\text{radians(degrees)}), \\ \text{windew} &= \text{km hr}^{-1} \times \sin(\text{radians(degrees)}). \end{aligned} \tag{2.1}$$

The component functions considered the BOM-defined wind directions as degrees measured clockwise from true north (0 degrees = North, 90 degrees or $\pi/2$ radians = East, 180 degrees or π radians = South, and 270 degrees or $3\pi/2$ radians = West). An additional binary factor variable 'goodwind' was defined as goodwind $= 1$ (TRUE) if the wind speed was below 35 km/h (approximately 18.89 knots), and goodwind $= 0$ (FALSE) otherwise. Windspeeds around 17–21 knots generally give rise to moderate waves with many white caps making line fishing particularly difficult.

The lunar phase (luminance) data was a calculated measure of the moon cycle with values ranging between 0 (new moon) and 1 (full moon) for each catch date. The data were calculated using the *lunar* R software package, for illumination values with a shift setting of 9.5 hours (Lazaridis 2014). The luminance measure (lunar) followed a sinusoidal pattern and was advanced 7 days ($\approx$ quarter lunar cycle) into a new variable (lunaradv) to quantify the cosine of the lunar data (O'Neill and Leigh 2006). The two variables were modelled together to estimate the variation in catch rate according to the moon phase (contrasting waxing and waning patterns of the moon).

The seasonality of *Plectropomus* spp. catchability was modelled using sinusoidal data to standardise catch rates for the time of year. The data were calculated and used to minimise the number of parameters in the catch rate analysis, and to avoid any temporal confounding with the zone and vessel data. In total, six trigonometric covariates were used, which together modelled the seasonal patterns of catch (Marriott et al. 2013):

$$\begin{aligned} c12 &= \cos\left(2\pi d_y/T_y\right),\ cs12 = \sin\left(2\pi d_y/T_y\right) \\ c6 &= \cos\left(4\pi d_y/T_y\right),\ cs6 = \sin\left(4\pi d_y/T_y\right) \\ c4 &= \cos\left(6\pi d_y/T_y\right),\ cs4 = \sin\left(6\pi d_y/T_y\right) \end{aligned}$$

where $d_y \in [1, \cdots, T_y]$ numbers were the cumulative day of the year and $T_y = 365$ (or $= 366$ for leap years). The reason for using both cosine and sine data together was the same as for modelling lunar phases, where the data operated together in pairs to identify the period in the cycle. The pairs of data were in order such that $cs12$ and $c12$ first tested for a 12-month cycle, $cs6$ and $c6$ for a 6-month cycle, and $cs4$ and $c4$ for a 4-month cycle. This approach essentially constitutes a third-order Fourier series. The result of combining the three pairs of data quantified the seasonal patterns of catch rates (Figure B.1).

2.3 Catch rate standardisation

2.3.1 Sunset

The sunset standardised catch rates time series is considered an indicator of annual changes in the abundance of legal sized coral trout in the Torres Strait. In comparison to TIB, the sunset sector harvests more fish and catch records cover more years.

Nominal catch rates can vary with spatio-temporal changes in fishing effort and fish catchability. The purpose of standardisation is to remove influences that are not related to fish abundance (Hilborn and Walters 1992). In layperson's terms, the goal of standardisation is to predict the catch weight of an average fisher fishing on an average day.

A generalised linear model (GLM) was used to model daily harvest weight (wt) as a response variable of a number predictor variables. wt was modelled as a quasi-Poisson process with a log-link function. The model was fitted using the software R (R Core Team 2020). Standard errors were calculated for all estimates. The importance of individual model terms was assessed formally using F statistics by dropping individual terms from the full model.

Annual changes in wind and rainfall in the Torres Strait are heavily influenced by the (usually) nearby Southern Pacific Convergence Zone (Brown et al. 2020). Torres Strait wind speed, rainfall and wind direction are highly correlated as shown in Figure E.2. This high degree of correlation was quantitatively confirmed using Pearson correlation coefficient (Table 2.3). Rainfall data at Horn Island is incomplete for the entire length of the catch rate analysis.

	c12	cs12	windspeed	winddegrees	goodwind
c12	1.00	-0.13	-0.32	0.26	0.03
cs12	-0.13	1.00	-0.33	0.26	0.03
windspeed	-0.32	-0.33	1.00	-0.26	-0.30
winddegrees	0.26	0.26	-0.26	1.00	0.02
goodwind	0.03	0.03	-0.30	0.02	1.00

Table 2.3: Pearson correlation coefficient between a number of seasonal and meteorological variables

The decision was made to remove windspeed and directional variables from the model. The variable 'goodwind' was kept in the model as it did not significantly correlate with any season variables and can reasonably be assumed to influence catchability. Approximately 2% of entries were recorded as having 'goodwind = 0' [1].

[1] There is a slight subtlety here: 2% of the fishing days in the data occurred on days with wind speeds above 35 km/h. This does not imply that only 2% of days throughout the year have wind speeds above 35 km/h: Fishers are far less likely to go fishing in the first place if it is too windy.

The R equation form of the commercial sunset GLM was:

$$\begin{aligned} \mathrm{wt} \sim \exp(&\mathrm{year} + \mathrm{zone} + \mathrm{symbol} + \mathrm{c12} + \mathrm{cs12} + \mathrm{c6} + \mathrm{cs6} + \mathrm{c4} + \mathrm{cs4} + \\ &\mathrm{lunar} + \mathrm{lunaradv} + \mathrm{goodwind}) \end{aligned} \tag{2.2}$$

where the GLM type and variables are outlined in Table 2.4.

Table 2.4: Summary of variables used to model Catch weights.

Symbol	Description
wt	daily harvest per boat operation of coral trout (all species) in (kg)
year	Financial years, 1990 to 2022
zone	One of 5 spatial zones with the Torres Strait. (See Figure E.1)
symbol	Anonymous codes for license holders
c12	$\cos\left(\frac{2\pi \mathrm{d}_y}{365}\right)$
cs12	$\sin\left(\frac{2\pi \mathrm{d}_y}{365}\right)$
c6	$\cos\left(\frac{4\pi \mathrm{d}_y}{365}\right)$
cs6	$\sin\left(\frac{4\pi \mathrm{d}_y}{365}\right)$
c4	$\cos\left(\frac{6\pi \mathrm{d}_y}{365}\right)$
cs4	$\sin\left(\frac{6\pi \mathrm{d}_y}{365}\right)$
Lunar	Lunar illumination given a specific date
LunarAdv	The value of Lunar illumination 7 days previous
goodwind	TRUE if windpeed < 35 km/h (any direction)

Predictions were generated using R's `predict` function. For factor variables, weights were assigned based on the frequency of each level in the original dataset. For continuous variables specific values were chose using methodologies detailed below. These predictions were subsequently averaged to produce standardised catch rates, expressed in kilograms per boat-operation-day—the unit used in the logbook.

- *year*: Predictions were made for each year in the dataset.
- *zone*: Weights were assigned based on the frequency of each spatial zone in the original dataset.
- *symbol*: Weights were assigned based on the frequency of each boat-operation in the original dataset.
- *goodwind*: Weights were assigned based on the frequency of good wind conditions in the original dataset.
- *cs12 (and c12) to cs4 (and c4)*: For these seasonality variables, values were calculated using the mean day from the data within the primary fishing season, which spans from 1 July to 31 December.
- *lunar* and *lunaradv*: Values were selected based on their median effect over a lunar cycle.

This methodology yields a robust estimate of the catch weight for an average fisher, under average conditions, on an average day for each year.

2.3.2 TIB

The CDR included TIB catch rate data. The TIB sector recorded no catch rate data before 2019. Similar GLM and prediction methods were employed for TIB catch rates of coral trout as for sunset.

The TIB catch rate data consisted of weights of fish (>0; kg) harvested per fisher boat-day. Explanatory model terms included main effects for the fishing years, anonymous fisher code, and seasonality . Other model data/terms, like in the sunset analysis, were not significant in the relatively short time series of data.

The equation form of the commercial TIB GLM was:

$$\text{wt} \sim \exp(\text{year} + \text{fisher} + \text{c12} + \text{cs12}) \tag{2.3}$$

where the prediction settings were::

- *wt*: daily harvest per fisher-boat (kg)
- *year*: fishing year 2019 to 2022 (factor)
- *fisher*: anonymous codes for different fisher (factor)
- *cs12 (and c12)*: two seasonality variables defined by cosine and sine functions (variates)

A quasi-Poisson with log-link was also employed. The resulting predictions were standardised kg of coral trout per fisher-boat-day (the CDR reporting unit). The prediction settings for the annual index of fish abundance by year were:

- *year*: all years predicted.
- *fisher*: marginal weights for an average fisher boat.
- *cs12 and c12*: seasonality variables calculated for the mean day number fished (= 67, for early March)

3 Results and Discussion

3.1 Annual commercial harvest

Estimates of the total commercial harvest of coral trout considered data from both TIB and sunset sectors. Figure 3.1 shows the total harvest using data from Hutton et al. (2019) up to 2017 and CDR data from 2018 to 2022. CDR records began but were incomplete in 2017. Prior to the introduction of CDR, the estimates in Hutton et al. (2019) used a number of data sources, with the majority of harvest records coming from Queensland and AFMA logbooks.

Note that in this analysis of catch rates, "fishyear" corresponds to financial years (starting 1 July). However, to align with Hutton et al. (2019), estimates of total harvest use calendar years (starting 1st January).

The estimated harvest increased significantly in the mid-1990s. Of note is a decline in harvest around 2005, three years before a 2008 licence buyback and after a decade of sustained higher harvest. This not necessarily related to a decline in stocks but rather a decline in total effort, as visible in Figure A.1.

Harvest estimates do not consider illegal, unreported, and unregulated fishing, which, in the Torres Strait, is historically known to have targeted high-value species like rock lobster, bêche-de-mer as well as pelagic fish using drift nets.

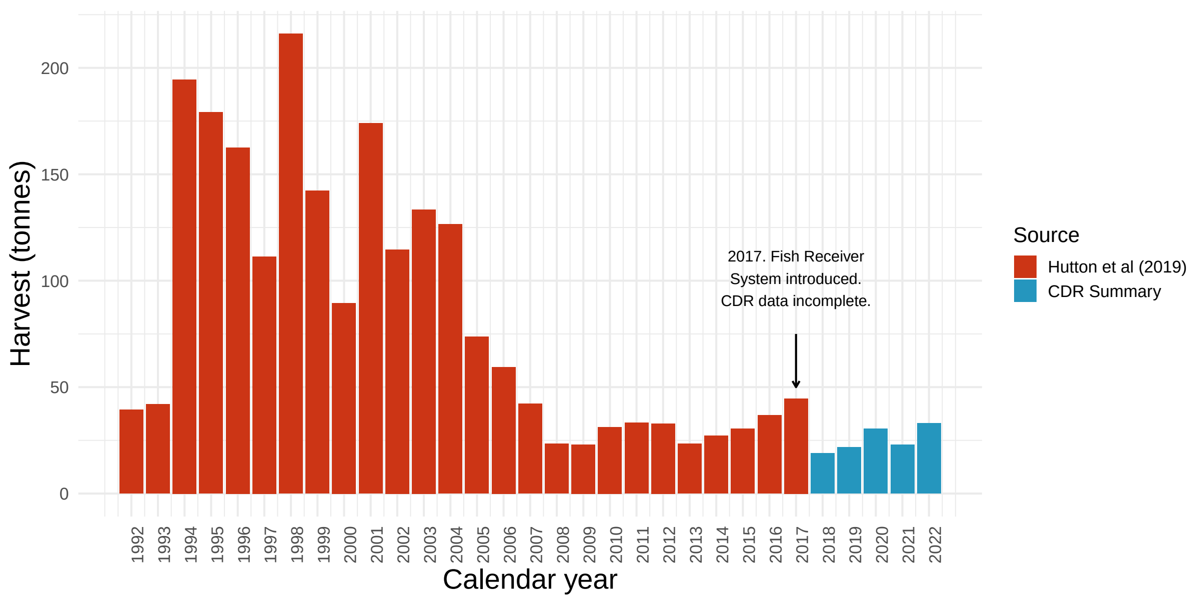

Figure 3.1: Estimated Annual Commercial Harvest, 1992-2022: Data for 1992-2017 sourced from Hutton et al. (2019); 2018-2022 based on CDR data

3.2 Catch rates

3.2.1 Sunset catch rates

As discussed, standardised catch rates are an important indicator of annual changes in the abundance of legal size coral trout in the Torres Strait. The primary assumption was that catch rates are proportional to abundance.

The use of a log link function appeared appropriate to standardise catch rates. This is consistent with past assessments, maintains past assumptions, and allows for multiplicative effects. Using a GLM allows the response variable to remain unchanged (i.e., not transformed by a power transform).

Figure 1 in the summary shows the sunset standardised catch rates for fishing years 1990–2022. Figure 3.2 shows the effect of incrementally adding variables to catch rate standardisation. Results include:

- The standardised catch weight across all years was approximately 150 kg per day.
- Catch rates experienced temporal cycles with statistical differences between years (Table C.1).
- Catch rates varied significantly across years but stabilised since 2008.
- Since 2008, standardised catch weights have been consistently below nominal catch weights, suggesting better-catching operators have remained in the fishery. This is supported by Figure B.2.

Figure B.1 shows lunar influence to be quite influential on daily (as opposed to annual) catch weights. Considering the spawning habits of *Plectropomus* spp., this is a reasonable result (Frisch et al. 2016).

Figure 3.2 shows the effects of adding additional effects to standardisation, with symbol being the most influential and lunar being almost negligible. Note this is not because lunar is not statistically significant but because it is consistent across years.

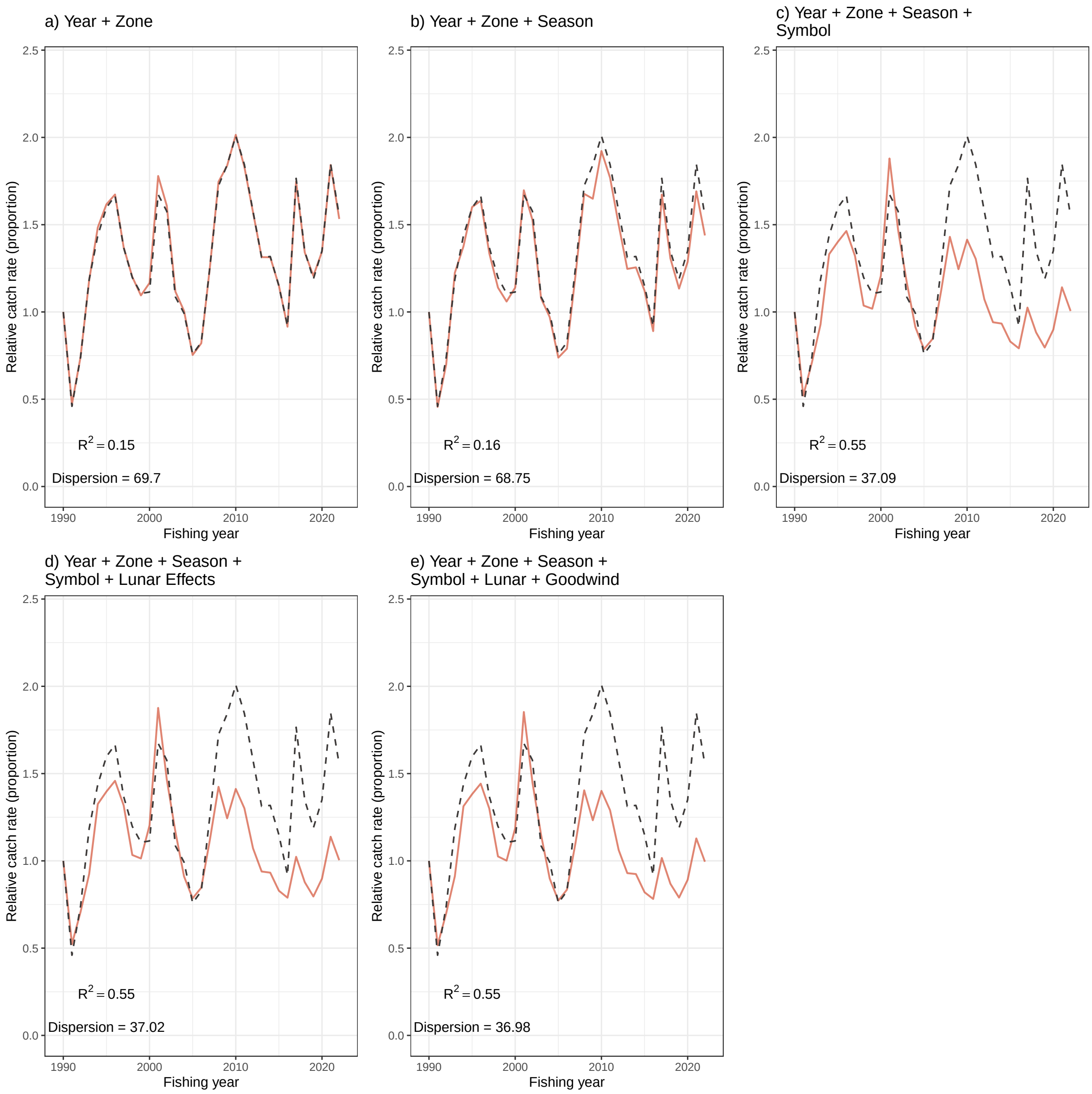

Figure 3.2: Sequential comparison of standardised catch rates as influenced by incremental additions of predictor variables. The red line in each panel represents the model with the set of predictors indicated in the title, while the grey dashed line represents nominal catch rates. Both adjusted R^2 and dispersion values, annotated within each panel, serve as indicators of model fit and spread of catch weight, respectively.

Historically most sunset operators have held both Spanish mackerel and trout catch allowances. It is conceivable that some operators who target trout during the year may concentrate their efforts on Spanish Mackerel during mackerel season, introducing a selection bias. This bias might manifest when small, sporadic bycatches of trout, caught while targeting mackerel, are recorded in logbooks. This would cause a seasonal component that is skewed away from the peak of the mackerel season, instead of reflecting any genuine seasonal variation in trout catchability.

Following the line of reasoning in Hilborn and Walters (1992, p. 181), once catch rates begin to decline at a particular reef, it is reasonable to assume that fishers will move onto other reefs. If fishers start at reefs of high coral trout abundance, and move onto reefs of lower abundance, catch rates may decrease even though the total population size is little changed. This is a phenomenon known as hyperdepletion.

On the other hand, it is possible that fishing of spawning aggregations can cause catch rates to stay high when population size is decreasing (see section 3.3).

A more thorough understanding of the dynamics of fishing of *Plectropomus* spp., coupled with finer-resolution fisher location data, could be used to better understand how well annual catch rates reflect abundance.

3.2.2 TIB catch rates

Figure 3.3 illustrates the seasonal component and annual standardised catch rate for the TIB sector. With only three years of data available, the TIB dataset is too limited at this stage to derive any definitive conclusions; however, the standardised catch rates appear to remain stable, with no significant decline observed since 2019. Notably, the seasonal component within the TIB sector does not correspond to the pattern observed in the sunset sector. The reasons for this divergence are may involve a combination of factors such as economic, cultural, meteorological, or technological influences. Determining the exact cause is beyond the scope of this analysis.

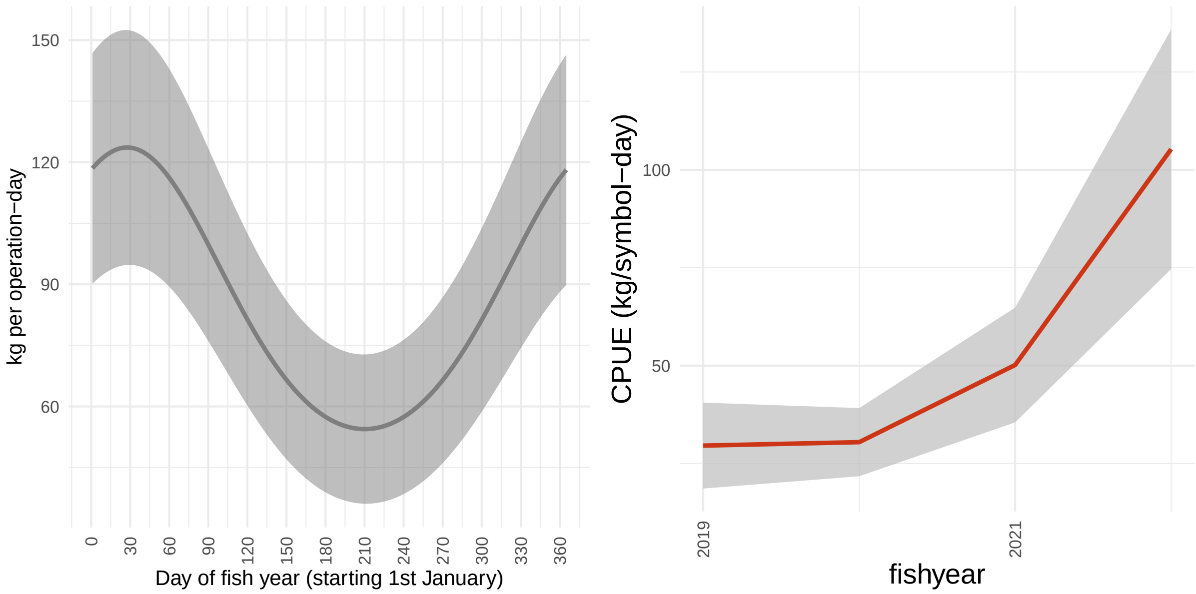

Figure 3.3: TIB catch rates with 95% confidence intervals along with a plot of seasonal influence with confidence intervals for TIB catch rates.

3.3 Multispecies considerations

Unlike Queensland's reef line fishery where the majority (but not totality) of commercial *Plectropomus* spp. harvest comprise common coral trout (*P. leopardus*), significant portions of Torres Strait harvest comprise an additional three separate yet sympatric species [1],

- barcheek coral trout (*P. maculatus*)
- passionfruit coral trout (*P. areolatus*)
- bluespotted coral trout (*P. laevis*)

Despite cosmetic similarities, these species have different biologies, phenologies, ecological niches and behaviours. Research by Matley et al. (2017) notes these different species populations will likely react differently to fishing pressure and environmental changes and stresses the importance of partitioning stock assessments to a species level. Historically no distinction between species was made in commercial logbooks. Current logbooks have a section for an estimate of the percentage of trout species composition (see Figure E.3), however, the potential for misidentification is high[2]. As such, *Plectropomus* spp. catch rates were analysed as a single stock in the Torres Strait.

A review of the literature on biological parameters such as asymptotic lengths, growth coefficients, and von Bertalanffy growth parameters for the genus can be found in Frisch et al. (2016). These biological parameters can vary considerably across different studies, which may in part be attributed to regional variations. A study of the age and size of *Plectropomus* spp. using harvest samples specifically from the Torres Strait was published in Trappett et al. (2021).

Genetically, common coral trout (*P. leopardus*) in the Great Barrier Reef (GBR) – including the Torres Strait – form a single genetic stock, although the exact nature of the genetic interconnectivity of GBR populations is complex (Payet et al. 2022).

P. laevis is less commonly harvested in the Torres Strait, it tends to grow slower, asymptotically larger, and have lower mortality than other species (Payet et al. 2020). Spawning for all species is generally observed to occur during the spring and summer around new moons, however recent research does demonstrate year-round spawning in *P. maculatus* in the southern GBR (Harrison et al. 2023). *P. areolatus* tend to spawn in larger and fewer aggregations offshore leading to increased genetic interconnectivity of populations (Ma et al. (2018)). This tendency to form larger aggregations could make this particular species more susceptible to hyperstability and stock collapse (Sadovy and Domeier 2005; Hamilton et al. 2016) [3].

As detailed in Williams et al. (2008), the species composition of landed catches in the Torres Strait can change dramatically over changing latitude and reef type. *P. maculatus* tends to dominate inshore reefs, possibly due to adaptations to low visibility. *P. leopardus* tends to dominate mid and outer shelf reefs and *P. laevis* dominates offshore reefs (Harrison 2023). *P. areolatus* is more common in the northern regions and seems to prefer sheltered inner reefs. However these are very broad general observations. Anecdotally, local fishers have reported different species being more prevalent than others over different years on the same reef, adding a temporal dimension that would further complicate any analysis that

[1] The ranges of *P. oligacanthus* and *P. pessuliferus* are reported in some sources to extend to sections of the Torres Strait (Bray 2018) however they are absent from harvest records.

[2] See Trappett et al. 2021, Appendix 4 for an identification chart

[3] Sadovy and Domeier (2005) specifically mentions *P. leopardus* as possibly being less prone to hyperstability due to spawning in small aggregations but does not address *P. areolatus*.

aimed to statistically differentiate between species catch rates with current data. Research by Matley et al. (2017) indicates that different sympatric species of *Plectropomus* spp. occupy different yet similar trophic and ecological niches and that the exact nature of the similarity and differences between their niches can vary in time and space. Further complicating the matter, a study of GBR populations showed hybridisation between species to be ubiquitous, produce fertile offspring and span generations (Harrison et al. 2017).

4 Conclusion

Ultimately this fishery is relatively small with only two consistent sunset operators over the last decade. As a result data is limited and any results will be subject to high degree of statistical noise. However standardised catch rates appear stable at current fishing pressure.

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Appendix A Harvest tables and figures

Table A.1: Annual harvest from sunset sector using CDR data.

Calendar year	Harvest (kg)
2018	18 862
2019	21 806
2020	30 387
2021	22 989
2022	33 074

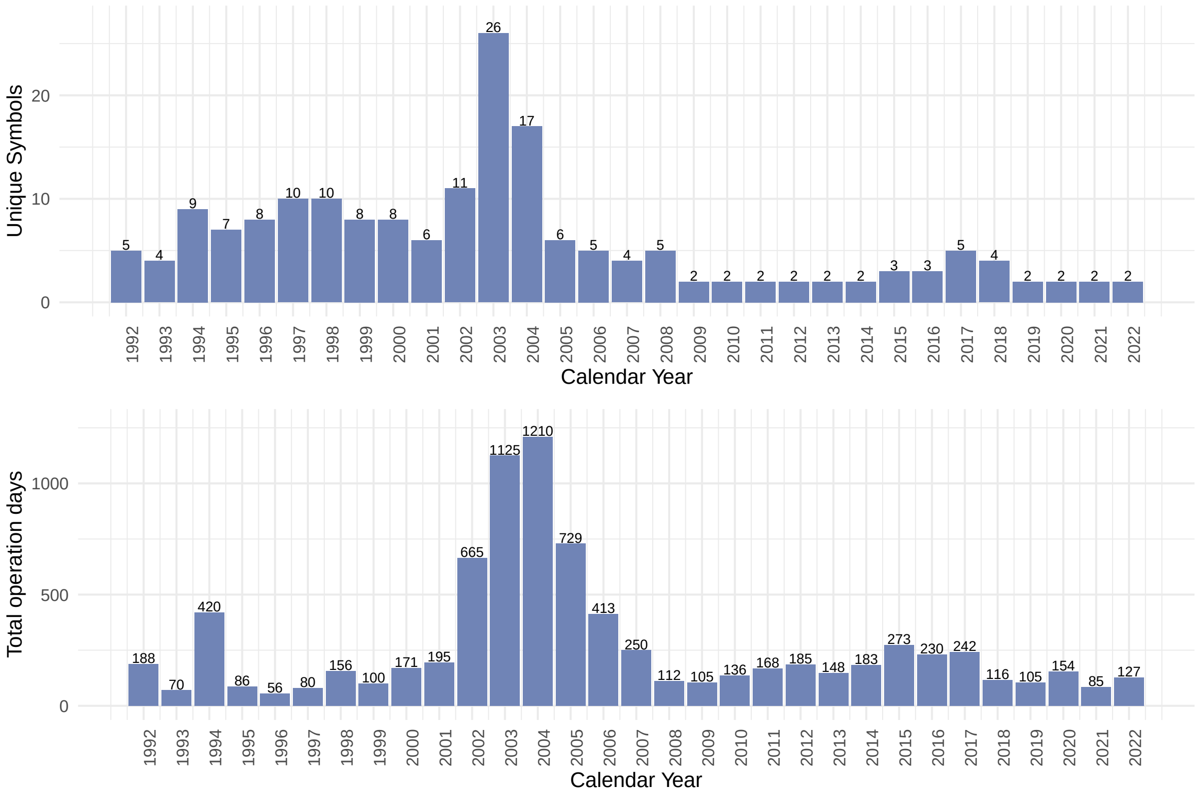

Figure A.1: Sunset logbook reports of total fishing effort by calendar year a) number of unique primary operations, and b) combined total operation days.

Appendix B Sunset catch rates tables and figures

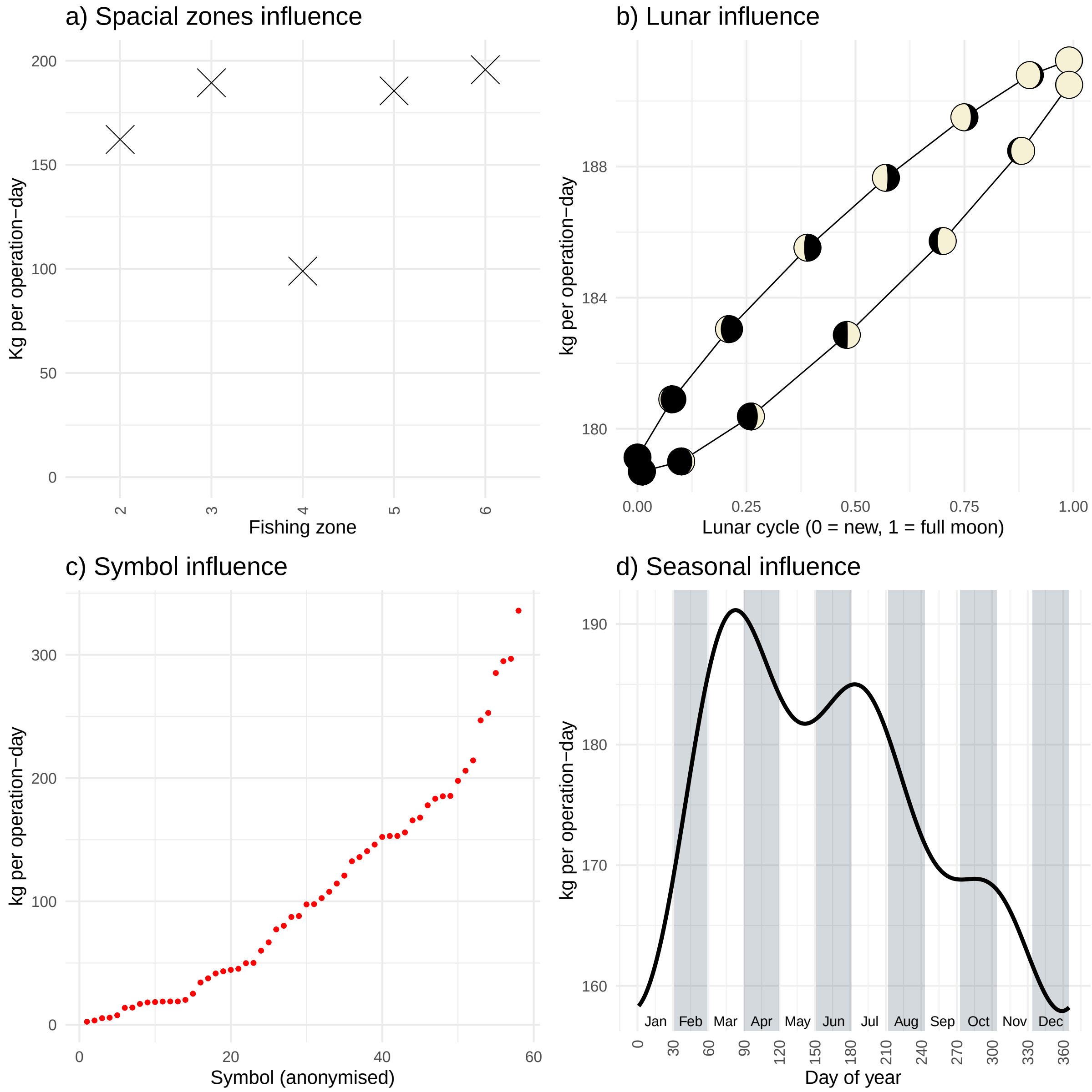

Figure B.1: Influence plots showing the effects of changes in predictors on catch weights—Symbol proves to be by far the most influential

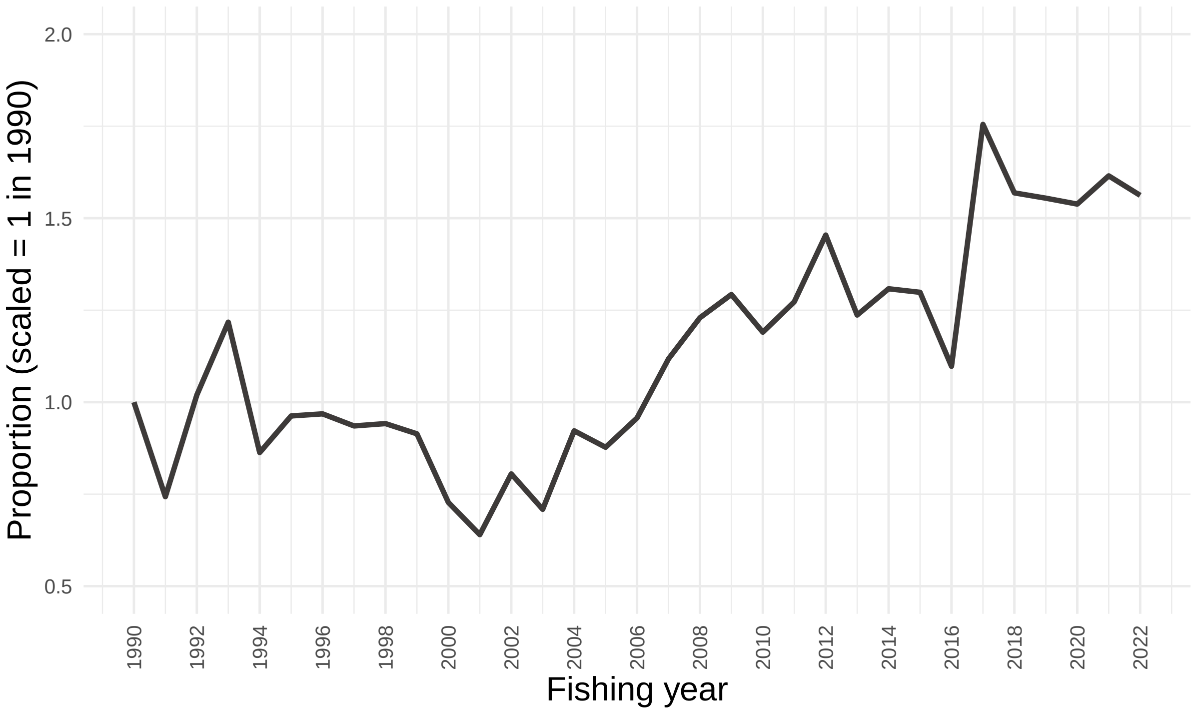

Figure B.2: Relative average sunset-fleet fishing-power by year as estimated from the GLM symbol factor

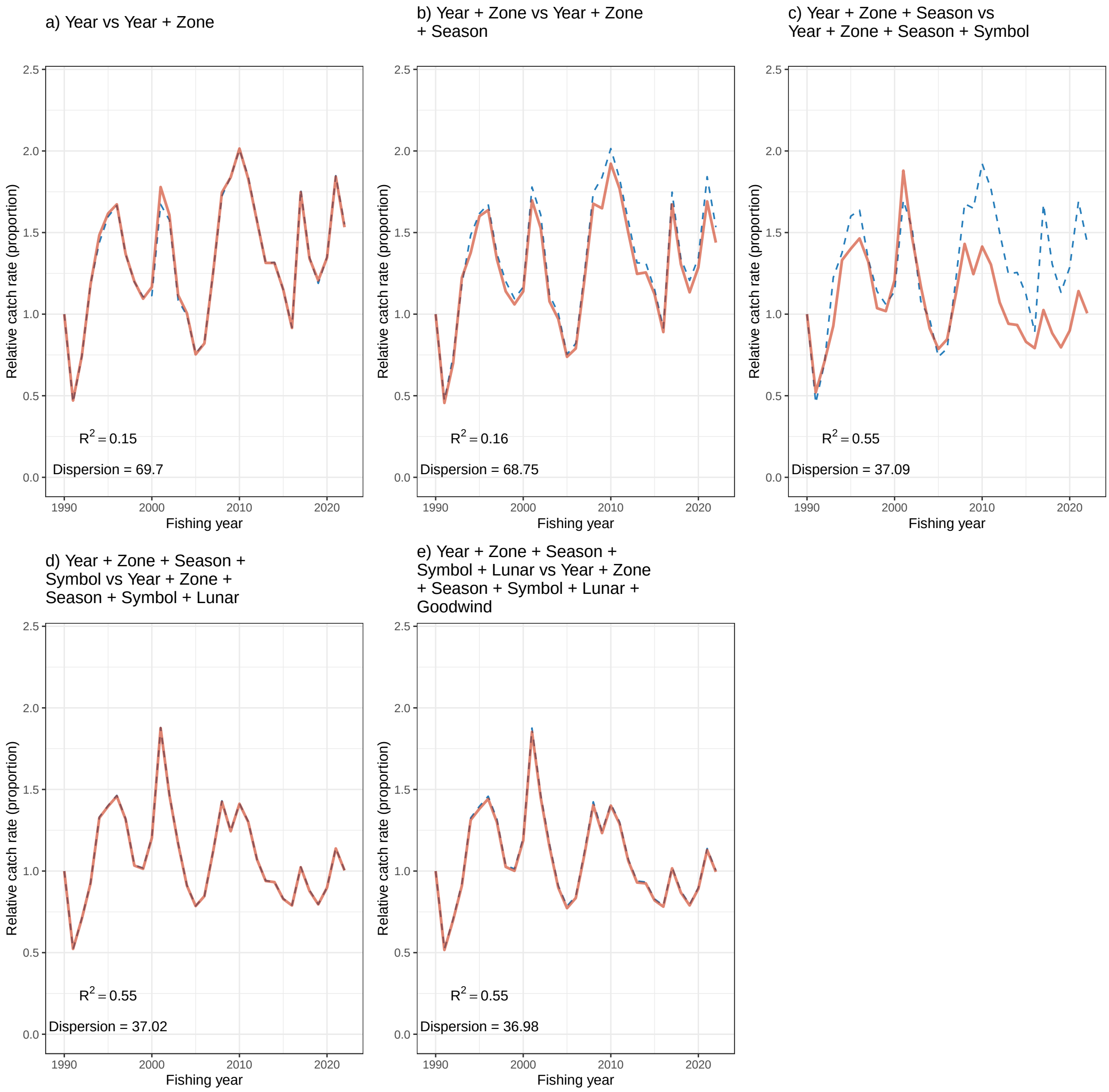

Figure B.3: Sequential comparison of standardised catch rates influenced by incremental additions of predictor variables. Panel a) contrasts nominal catch rates in blue (with year as the only predictor) against a GLM incorporating both zone and year (orange). Subsequent panels introduce additional predictors, as indicated in their titles. Dashed blue lines represent the model from the previous panel for comparison. Both adjusted R^2 and dispersion values, annotated within each panel, improve with the inclusion of more terms.

Appendix C Sunset diagnostics

	Df	Deviance	F value	Pr(>F)
residuals	14058	519808		
fishyear	32	588339	57.92	0.00
zone26	4	523587	25.56	0.00
symbol	57	968424	212.85	0.00
lunar	1	520955	31.04	0.00
lunaradv	1	519917	2.96	0.08
good_wind	1	520412	16.34	0.00
c12	1	520903	29.62	0.00
cs12	1	522051	60.68	0.00
c4	1	520279	12.76	0.00
cs4	1	519906	2.68	0.10
c6	1	520136	8.90	0.00
cs6	1	519893	2.32	0.13

Table C.1: Analysis of variance table for the sunset catch rate analysis. F statistics were derived from the R `drop1` procedure.

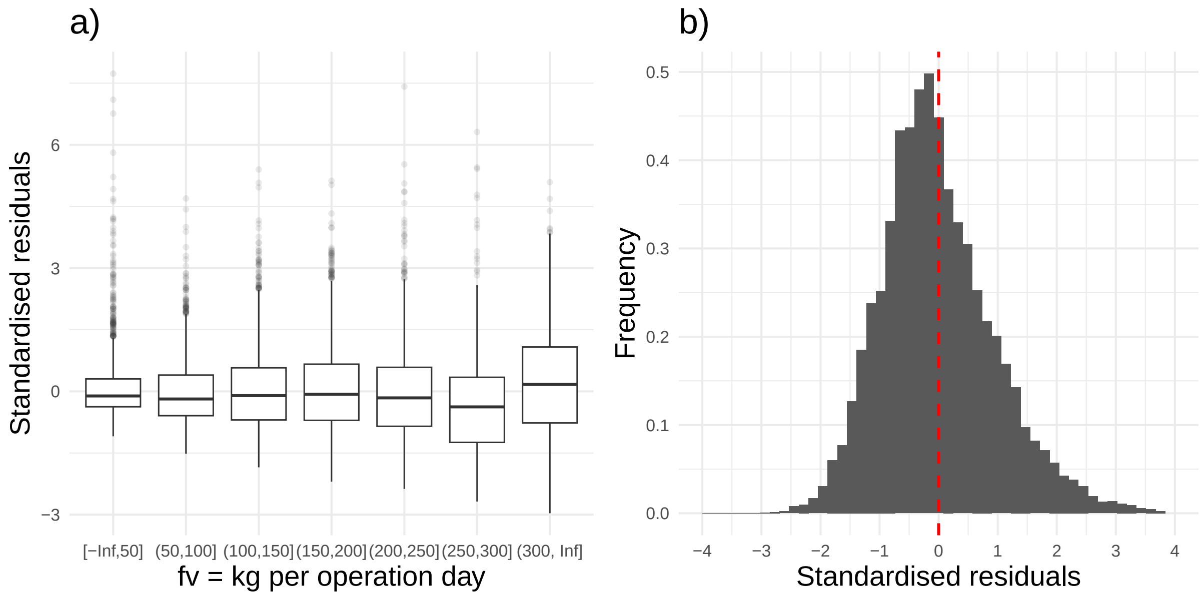

Figure C.1: Sunset catch rate residual plots. a) box plot of fitted values and residuals, and b) histogram.

Appendix D TIB diagnostics

	Df	Deviance	F value	Pr(>F)
residuals	213	3222		
fishyear	3	4382	25.56	0.00
client	16	6531	13.67	0.00
c12	1	3526	20.05	0.00
cs12	1	3322	6.58	0.01

Table D.1: Analysis of variance table for the TIB catch rate analysis–F statistics were derived from the R `drop1` procedure.

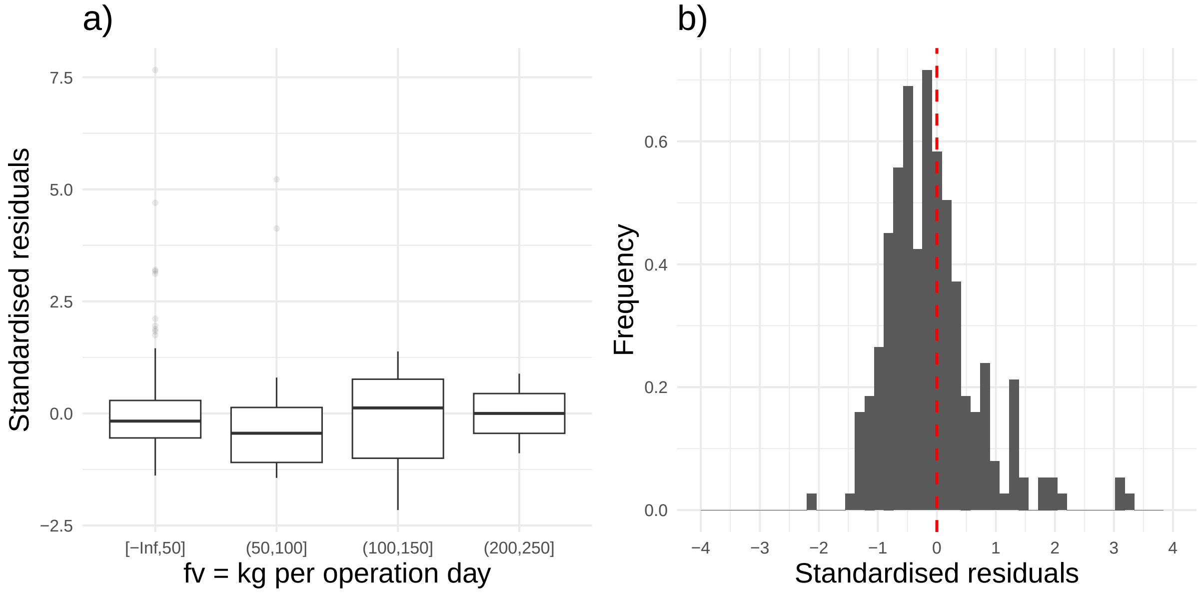

Figure D.1: TIB catch rate residual plots. a) box plot of fitted values and residuals, and b) histogram

Appendix E Additional figures

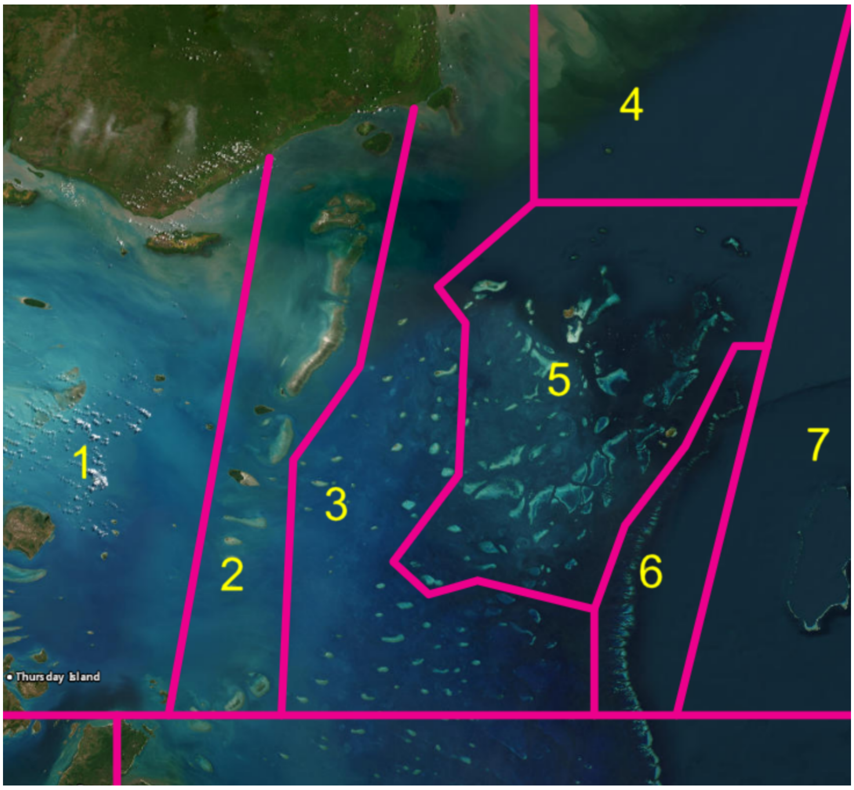

Figure E.1: Landsat satellite image of Torres Strait, with numbered Regions shown. Source: qldglobe.information.qld.gov.au. Map material © State of Queensland 2023. Imagery includes material © CNES reproduced under license from Airbus DS, © 21AT, © Earth-i, and © Planet Labs PBC, 2023.

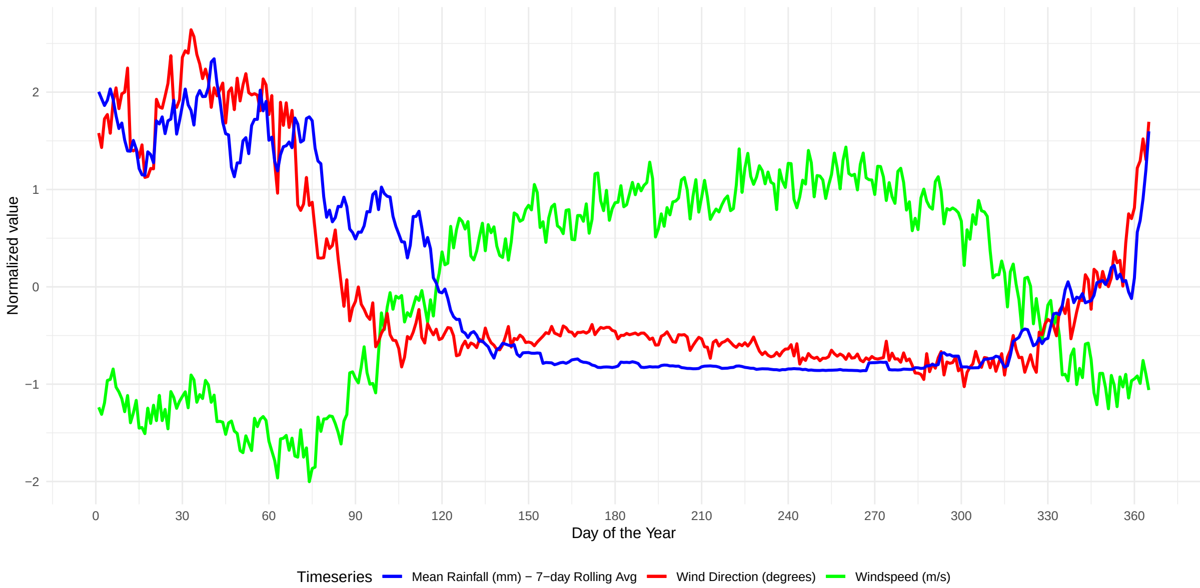

Figure E.2: Visualisation of yearly mean wind speed, direction, and 7-day rolling mean of rainfall at Horn Island station (2000-2022). All time series are normalised. The plot aims for exploratory correlation analysis rather than rigorous climate research.

CORAL TROUT INFORMATION		No.	Ave kg	fish/ carton	No.	Ave kg	fish/ carton
Carton Totals:	Plate						
	Medium						
	Large						
Estimate % species split: (number)	Common						
	Islander						
	Leopard						
	Bluespot						

Figure E.3: Coral trout species composition section of AFMA's Torres Strait Finfish Daily Fishing Log -TSF01. Source: www.afma.gov.au.