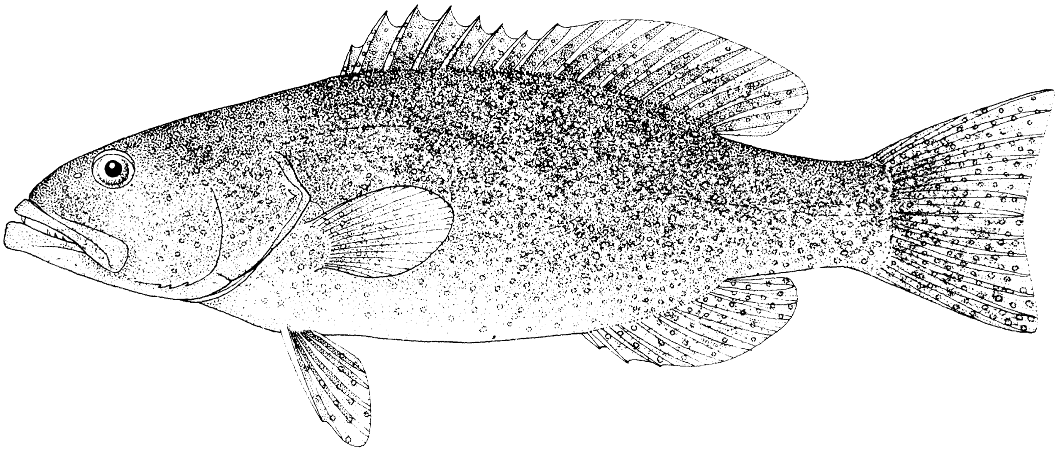

Monitoring requirements for common coral trout

March 2018

Queensland Government

This publication has been compiled by A.R. Northrop, M.F. O'Neill and G.M. Leigh of Fisheries Queensland, Department of Agriculture and Fisheries and C. Lunow of Fisheries Queensland, Department of Agriculture and Fisheries

Acknowledgements

The authors would like to thank a number of individuals who contributed their time and gave valuable advice.

Sue Helmke for her review and guidance.

Rich Little for running workshops and giving of his time freely to enable the use of ELFSim for the underwater visual survey analysis.

Tom Roberts for arranging an ELFSim workshop in Tasmania, and giving valuable advice on the coral trout fishery.

Jennifer Larkin for providing the data that was used for analysis in this report, often in short time frames.

Anthony Roelofs for his assistance in the publishing process.

Finally, Peter Kind, Kimberly Foster, Eddie Jebreen and Mal Pearce for their input and review.

Summary findings and recommendations

Some studies have suggested that in certain situations, there is a poor correlation between fishery catch rates for coral trout and the species abundance. Environmental factors, such as cyclones, can affect fishery catch rates for some time after the event and social learning results in lower catchability of fish. The actual state of the stock may be more stable than fishery catch rates indicate (Leigh et al., 2014). The uncertainty in the relationship between fishery catch rates and fish abundance means there is strong evidence, and need, to collect additional abundance data to support stock assessment, reference point (quota) management and harvest strategies.

To date, the most informative indices of coral trout abundance were those taken from underwater visual surveys, as there was no reliance on fish taking bait or the fishery temporal-spatial patterns of fishing. The underwater visual surveys also measures an index of fish abundance that is not as sensitive to change in fish behaviour due to cyclones and social learning.

A number of underwater visual surveys have been carried out in the past, the most informative was the coral trout surveys carried out by Ayling and Ayling (1986). These were conducted using transects along roughly 10% of the Great Barrier Reefs. From the Ayling and Ayling (1986) underwater visual survey data, the 2014 coral trout stock assessment model (Leigh et al., 2014) created a measure of absolute abundance (fish per hectare). This was extremely valuable for stock assessment, to measure reference points and an absolute abundance for a population of fish, which moves little between reefs.

A second underwater visual survey dataset, collected from 1992 to 2011, was also used in the coral trout stock assessment (Leigh et al., 2014). The Australian Institute of Marine Science surveyed 24 reefs every two years. These were carried out within six sectors of the Great Barrier Reef. The survey recorded counts of fish of over 100 different species. This was approximately 0.6% of the reefs in the Great Barrier Reef. The underwater visual survey was used as an index of relative abundance in the 2014 stock assessment.

To support future stock assessments and management procedures, designing a “once-off”, large-scale underwater visual survey similar to that of Ayling and Ayling (1986) is recommended. If trained staff work in an identical manner, the results would be directly comparable to the abundance estimate that came from the 1980s survey. Because roughly 10% of the reefs would be sampled, this would result in high power and an *absolute* abundance estimate would be derived. It is important that the comparison between the survey in the 1980s and this recommended survey take into account the reduction in live coral cover over that period. Failure to account for this effect (reduced habitat and productivity) may overestimate fish abundance and quota.

In addition to the above, or as a less preferable alternative, smaller underwater visual surveys carried out annually can be used as a relative index of abundance. Developing one that encompasses all sub-regions of coral trout habitat is recommended. The underwater visual surveys should sample only a few species of interest, which includes coral trout, to reduce observer error. In the medium to longer term, better use of camera technology, (e.g. robot fish (Katzschmann et al., 2018)), should be explored to reduce survey costs and increase survey coverage. Baited remote underwater videos have been used successfully in common coral trout monitoring (Mclean et al., 2011) and may be worth considering.

An understanding of the age-composition is required for coral trout to track cohort and year class strength. Mortality and general population dynamics can be derived from this information. Length data alone for coral trout should not be used, as coral trout are a slow-growing fish, and cohorts cannot be determined from length data alone.

Simulation modelling has shown there is little difference between collecting age composition data from commercial fishers and collecting it from a fishery-independent survey (Little et al., 2016). However, the sampling scheme for the collection of the age data must be random, which can be difficult to control when sampling from the fishery.

Direct ageing from a structured line survey is preferable. If cheaper fishery dependent fish age-length key sampling is used, then sampling each of the four main fishing regions (Cairns, Townsville, Mackay and the Swains) is required. Age-length keys differ significantly between regions and the different level of fishing in each region affects the age structure of the fish in that area.

The sampling of age-composition data should be carried out annually for all four regions. For each region, at least 500 random fish lengths should be sampled with approximately 270 of them aged to develop the age-length key. However, if this required quantity of otoliths cannot be aged due to financial constraints, then preference would be to have less fish aged per region per year, but still done on an annual basis; i.e. rather than collect the full sample size once every two years, collect half of the sample size every year.

It would be advantageous to begin sampling the far northern region, as this region is much more lightly fished and would provide contrast in the data for stock assessment.

Two component generalised linear models were applied to the recreational catch rates of coral trout recorded from the Department of Agriculture and Fisheries boat ramp surveys. The methodology can be used to monitor performance of recreational catch rates. The results are more demonstrative as the survey program is still in its infancy. Improved power of analysis can be obtained from ensuring improved data collection.

- *Directly asking the fishers how much time they think they spent actually fishing would improve the estimates greatly. Travel time, breaks, and sleeping over multiple days are currently unknown. The analysis used the time the boat arrived at the ramp, less the time the fisher said he went out, as a proxy for hours of effort.*
- *Asking the fisher questions to quantify skill is recommended. There is a very large variation in fisher skill, and change in abundance may be confounded by the change in the average skill level of the fishers we survey.*
- *More information on fishing power is required to standardise the index over time.*
- *Fishing location data at a finer scale should be asked at interview. Whether the fisher was inside Net Free Zones needs to be ascertained.*
- *There needs to be sufficient overlap of reefs where recreational fishers and commercial fishers fish to use the abundance index for both sectors.*

The ELFSim software is quite powerful and highly complex. It was used for testing the importance of underwater visual surveys similar to the ones carried out by the Australian Institute of Marine Science. However, it is starting to become quite dated. The operating model's historical period goes to 2011. Its reef locations were based on old information. It also currently does not simulate the social learning believed to be found within coral trout populations. If ELFSim is to be used in the future, it should be updated and optimised by an experienced code developer/programmer and a mathematician.

Table of contents

Definitions and acronyms

AIMS	Australian Institute of Marine Science
ALK	Age-length key
Boxplot	The middle horizontal line within each box is the median, with the top and bottom of the box representing first quartile and the third quartile respectively. The whiskers denote 1.5 times the interquartile range.
BRUV	Baited remote underwater video
Coral Trout	Unless specified, this refers to common coral trout –*Plectropomus leopardus*
CPUE	Catch per unit effort
CV	Coefficient of variation. The standard deviation divided by the mean.
DAF	Department of Agriculture and Fisheries
ELFSim	Effect of Line Fishing Simulator
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
HCR	Harvest control rule
MLS	Minimum legal size
MSE	Management Strategy Evaluation
Region	Based on Great Barrier Reef Bioregions as defined by GBRMPA expert taskforces as part of the preparation for the Representative Areas Program implemented in 2004 (GBRMPA, 2009)
SFS	Sustainable Fisheries Strategy
Sub-region	Because the fishing intensity increases from north to south in the northern regions of the Great Barrier Reef (defined above), the Far Northern Region is divided into three Subregions, and the Cairns-Townsville Region is divided into two Subregions (Leigh et al., 2014)
TAC	Total allowable catch
UVS	Underwater visual survey

1. Background

This project evaluated coral trout monitoring strategies to inform management procedures. It is part of the Sustainable Fisheries Strategy Program (Department of Agriculture and Fisheries, 2017) which sets out the government reform for Fisheries from 2017–2027. Common coral trout (*Plectropomus leopardus)* has been identified as a high priority species in the reform. Coral trout is economically significant and in high demand by foreign markets.

Figure 1 shows the coral trout regions. The 2014 coral trout stock assessment (Leigh et al., 2014) used Great Barrier Reef Marine Park Authority (GBRMPA) bioregions to divide the Great Barrier Reef (GBR) into six different Regions (Far Northern Region, Cairns-Townsville Region, Mackay, Swains and Capricorn Bunker).

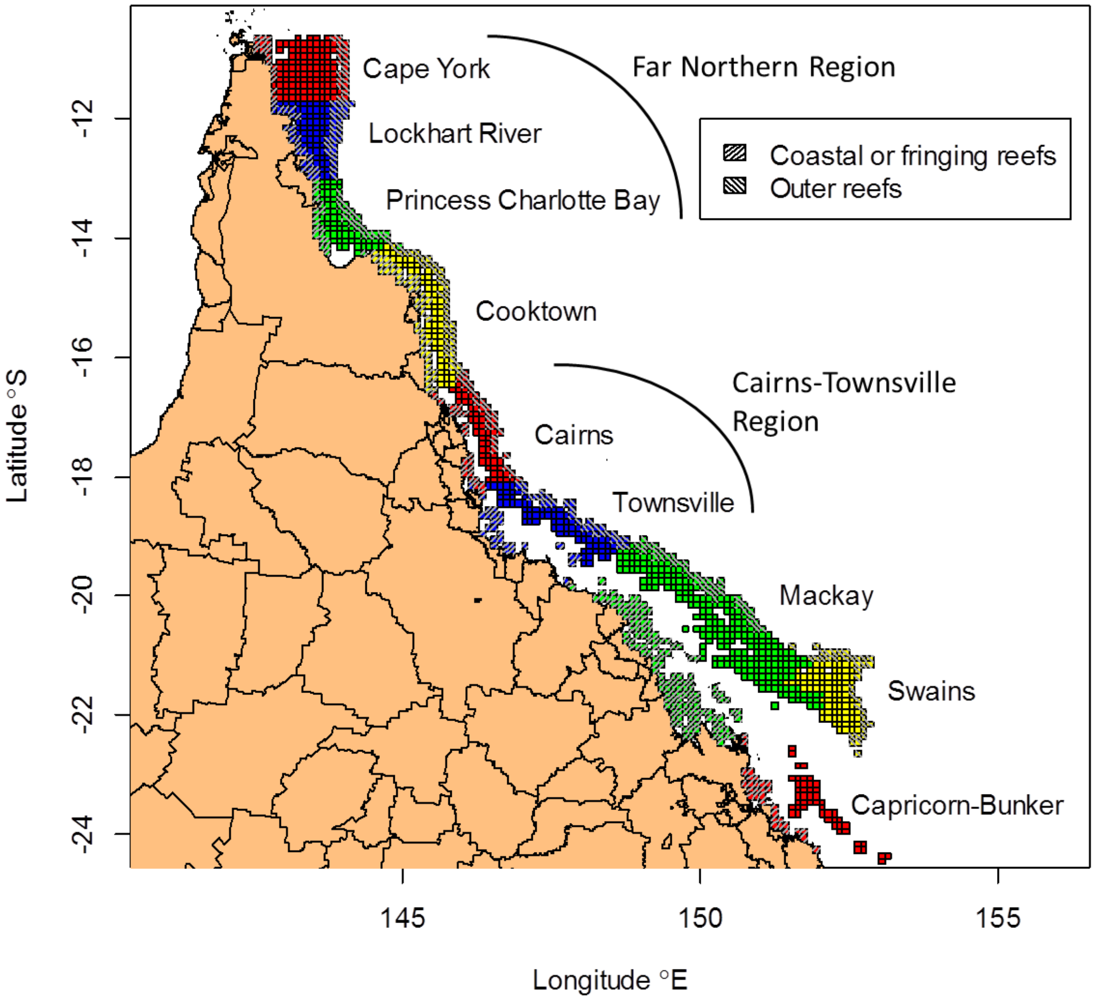

Figure 1: Regions and Subregions used in the 2014 coral trout stock assessment. The small squares on the map are the six-nautical-mile fishery logbook grid squares (Leigh et al., 2014).

Monitoring of the species is required for evidence-based management of the fishery. Hence questions arise as to what type of data to collect, how much data to collect, and what will the data cost? This work investigated different types of monitoring data and the precision in the data, that may be applied in future management procedures.

Aims

The aims of this investigation were:

1. *To determine whether there would be differences between the age-length keys of the four main regions of the common coral trout fishery – Cairns, Townsville, Mackay and the Swains. If differences between regions were found, then random sampling of harvests for age data would need to be stratified by region. If the analysis proved that region was not a significant factor in the age-length relationship, it is still vital that samples are carried out randomly across the coral trout habitat area.*
2. *To quantify if the common coral trout age-length key differed between years.*
3. *To calculate the optimal sample size of fish-lengths and otoliths to yield a reasonable level of precision in the age-length key.*
4. *To develop a statistical analysis by which boat ramp survey data could be converted into a recreational catch rate of fish. This could then be used as an index of fish abundance and/or a performance measure of fishing success for recreational anglers. The method was applied to coral trout.*
5. *To determine how informative underwater visual surveys are to common coral trout stock assessment models.*

There were three key focus areas in the report

1. *Age-length keys*
2. *Recreational boat ramp surveys as an index of abundance*
3. *Underwater visual surveys*

1.1. Age-length keys (ALKs)

Age determination is crucial for age-structured models, and error in the ageing process may have an effect on the stock assessment or harvest rule. The more fish that are aged, the more precision the model will have. However, resources are used in the ageing of fish, so there should be an optimal amount of fish aged such that the trade-off between precision and cost of ageing are apposite.

In the past, annual monitoring of coral trout age frequencies were carried out by direct ageing of all fish sampled. This was to determine the annual age-structure of the fished population of coral trout. Every fish sampled through fishery independent and fishery dependent monitoring had its otoliths removed and aged and tallied into an annual age-structure.

Most commercially caught coral trout are shipped live overseas and the market value of the fish is very high, estimated at up to $50 per kilogram in 2017. Fisheries Queensland have the ability to obtain samples of coral trout for age-length data before export. The cost of buying sufficient samples to kill for direct ageing of the fish is prohibitive. A two-staged sampling approach may be a more feasible alternative for coral trout stock assessment.

The two stages are:

1) Sample many random harvests to measure fish lengths and

2) Sub-sample fish from (1) for ageing.

Use an age-length key developed in (2) to convert the fish lengths into an age frequency.

The second stage of the sampling can be carried out in two ways. The first technique is fixed allocation. A standard number of fish are sampled in each length class. The second technique, proportional allocation, sub-samples the fish *proportionally* based on the numbers obtained for each length class in the first stage of sampling (Quinn and Deriso, 1999).

1.2. Recreational boat ramp surveys

A boat ramp (access) survey is an effective manner in which to determine catch and effort for individual recreational fishers. There is mostly low recall bias and low refusal rates to interviews for these on-site surveys (Pollock et al., 1994). The boat ramp surveys in Queensland began at the end of 2015. Surveys were conducted four to five times per month, on weekdays and weekends, resulting in over 900 hours of monitoring each month. Abundance estimates may be derived from this data.

1.3. Underwater visual surveys

A underwater visual survey (UVS) is when an observer in SCUBA gear swims along a transect and counts the number of fish (Halford and Thompson, 1996). UVS have provided indices of coral trout abundance. These were used in the 2014 coral trout stock assessment model (Leigh et al., 2014). Various UVS have been done in the past:

1. The Great Barrier Reef Marine Park (GBRMPA) sponsored a large series of UVS of over 200 reefs from 1983 to 1986 (Ayling and Ayling, 1986).
2. Various one-off surveys have been conducted after 1986 but not on the scale of the 1983–1986 series.
3. Between 1995 and 2005, the Effects of Line Fishing (ELF), a CRC Reef Research Centre and FRDC program, collected UVS data from 24 reefs each year. Both green and blue zoned reefs were sampled.
4. The Australian Institute of Marine Science (AIMS) conducted a UVS program from 1992 to 2011. They sampled roughly 22 reefs every second year from both blue and green zones. Similar to Ayling and Ayling (1986), divers swam along a 50 m x 5 m belt transect counting a number of fish, which included common coral trout.
5. Fisheries Queensland ran a UVS program from 1999 to 2002. The project was discontinued due to high costs involved in diver staff and their training.

2. Method

2.1. Age-length keys

2.1.1. Data

Age-length data from the Long Term Monitoring Program were obtained from Fisheries Queensland for analysis. The Long Term Monitoring Program ran from 2005 to 2009, with 2005 data currently unavailable. Figure 2 shows the number of fish sampled and aged during that period. This analysis used the 2006 and 2007 data, as the sample sizes in those years were large and complete.

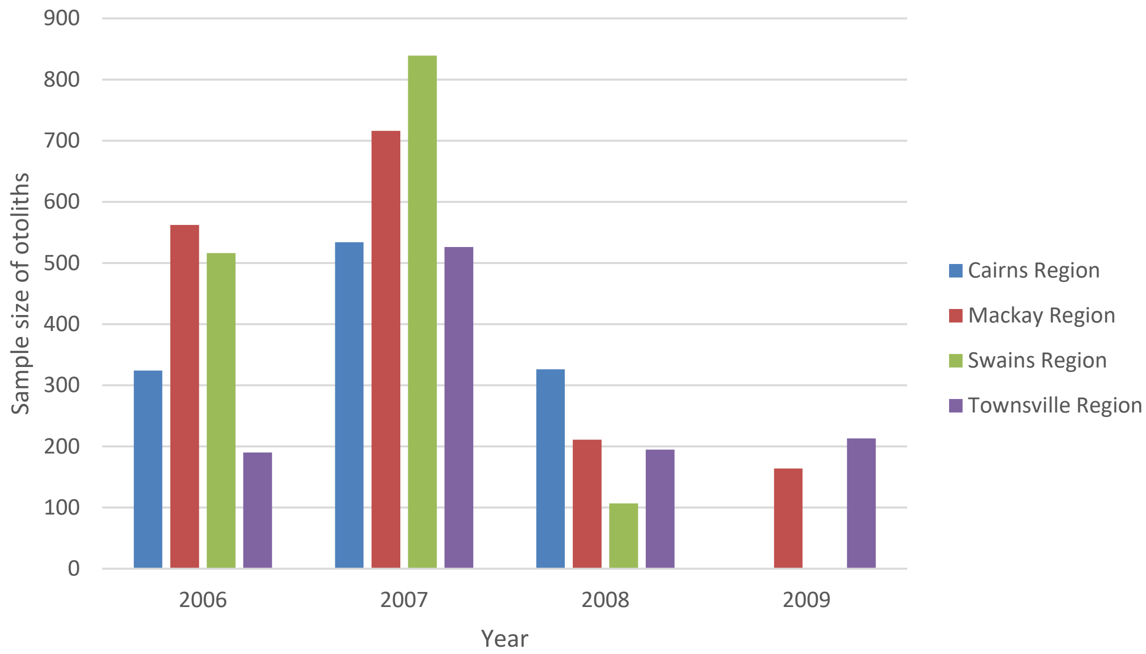

Figure 2: Number of coral trout sampled for ageing in the Long Term Monitoring Program

The fish fork lengths were categorised into 5 cm intervals. All fish that were nine years and older were lumped into a nine year old “plus group” to ensure appropriate use of older fish in analyses.

The number of increments on the otolith was converted to age using the age group allocation matrix provided by Fisheries Queensland (Table 1).

Table 1: Age group allocation matrix used in the analysis

Capture month	Edge Type		
	New	Intermediate	Wide
October	Increment	Increment	Increment + 1
November	Increment	Increment	Increment + 1
December	Increment	Increment	Increment + 1

2.1.2. Analysis

Statistical models were used to fit the observed length interval data to their corresponding ages using multinomial logistic regressions. This followed the approach set out by Gerritsen et al. (2006) and further described by Ogle (2016).

The analysis tested the influence of sampling region by comparing the multinomial regression with region, to a model that did not include region as a predictor variable. First, a model was used to predict age frequencies from each 5 cm length category alone. A second model was then used to predict the age from both the length category and the region the fish was captured. These two models were compared using a likelihood ratio test. If a statistical difference was found, it was due to the inclusion of "region" in the regression – showing that region has a significant impact on the age-length relationship.

Similarly, the effect of "Year" was quantified by first running an initial model that predicted age by length category and region alone. In the comparison model, Year was also included as a predictor. The likelihood ratio of the two models was then compared to determine whether Year had a significant effect.

Sample R Code

```
#Create a dataset with only 2006 data
subs06 = sis[which(Yr=="2006"),]
# Run the two models - one without region and one with.
mod1 = multinom(agegroup ~ lcat, data = subs06, maxit = 500)  #Up the number of default
iterations to 500
mod2 = multinom(agegroup~lcat*Region, data =subs06, maxit =500) #This is the shorthand
version for the full model
anova(mod1,mod2)  #Use the Likelihood ratio test to see if the second model is
significantly different to the first
#Create a matrix with the length categories in the first row and a Region in the second.
Have shown this below only for Cairns
lens = seq(200,550,50) # 5 cm increments from 20 cm to 55 cm
dfCairns = data.frame(lcat=lens,Region = "Cairns")
#Set up the predictions from the model for 2006
alkCairns = predict(mod2,dfCairns, type = "probs")
rownames(alkCairns) = lens

#Create the multinomial logistic models, one with, one without year
mod3 = multinom(agegroup ~ Region*lcat, maxit = 500)
mod4 = multinom(agegroup ~ Region*lcat*Yr, maxit = 500)
anova(mod3,mod4)
```

The Lai (1987) approach was used to calculate required sample sizes. The approach estimates a level of precision that incorporates all ages to determine an appropriate sample size for fish species. The D-statistic is the square root of the derived total variance. A value of about 0.05 is assumed reasonable (Quinn and Deriso, 1999). This technique is especially powerful as it shows how additional ageing, after a certain point, does not meaningfully improve precision.

The package *fishmethods* in R (Nelson, 2014) was used to carry out these calculations.

```
Sample R Code

library(fishmethods)

# Make the ALK from the data of interest.

ex1 = alk(round(towns07$ageclass,0), size = towns07$lcat, binsize = 0 )

# D statistic for a length sample size of 500, minimum age sample size of 25,

#maximum of 500, intervals of size 10, proportional allocation

alkD(ex1, lss = 500, minss = 25, maxss = 500, sampint = 10, allocate = 1)
```

2.2. Recreational boat ramp surveys

2.2.1. Data

Data rules

Boat ramp surveys were conducted in 18 different regions along the Queensland coast from the Aurukun Region to the Gold Coast. Nine of the regions were retained for analysis and were condensed into a larger scale for coral trout specific regions that are relevant to the stock assessment (Table 2).

Table 2: Correlating Long Term Monitoring Program (LTMP) Sampling Regions to Coral Trout Regions

LTMP Sampling Regions	Coral Trout Region
Bowen Region	Townsville
Cairns Region	Cairns
Cooktown Region	Cairns
Fraser Offshore	SE Qld
Karumba Region	Gulf
Lucinda Region	Townsville
Mackay Region	Mackay
Mission Beach Region	Townsville
Rockhampton Offshore	Capricorn Bunker or Rockhampton Offshore
Sunshine Coast Offshore	SE Qld
Weipa Region	Gulf

Aurukun Region and Sunshine Coast estuarine fell outside of the scope of the project and thus data relating to these areas were removed. Brisbane Offshore, Fraser Inshore, Gold Coast Offshore, Moreton Bay and Rockhampton Estuarine areas were excluded as they were determined to not be adequate habitat for the capture of coral trout. The Region “Gulf” from the Karumba and Weipa region was also removed as very little data were collected in this area.

The fish catch data for the areas analysed were collected at each ramp five times a month covering weekends and weekdays. Staff trained in the survey protocol and identifying fish interviewed recreational fishers at boat ramps during a survey shift. The information was recorded on paper and later digitised to a computer database by staff of Fisheries Queensland. The surveys aimed to collect information on effort, catch and length of retained target species, and recreational fishing value information. A shift lasted for four hours and commenced at either 8.00 am or 12.00 pm. Appendix C contains the data field descriptions.

In its raw form, the dataset contained a new row for every species captured by a boat of fishers on a trip. The data were reshaped to one single row for each boat fishing trip. A row gave information on a particular boat's fishing location, the hours away from the ramp, whether they were targeting coral trout, whether they caught coral trout and how many (kept and released), and the date of fishing.

The final dataset contained a sample of 8748 recreational boats that line-fished in regions within the scope of the project.

Table 3: Number of daily boat trips analysed by region, year and species targeted.

	Year 2016	Year 2017	Grand Total
Targeting Coral Trout	**178**	**470**	**648**
Cairns	82	100	182
Capricorn Bunker or Rockhampton	6	30	36
Mackay	20	33	53
Southeast Queensland	1	19	20
Townsville	69	288	357
Targeting Other	**2346**	**5754**	**8100**
Cairns	366	623	989
Capricorn Bunker or Rockhampton	172	592	764
Mackay	466	999	1465
Southeast Queensland	60	777	837
Townsville	1282	2763	4045
Grand Total	**2524**	**6224**	**8748**

For analyses the following data rules were applied:

1. Only data for boats that went out for one day were retained.
2. Only those boats that engaged in line fishing were retained. No other fishing methods were analysed.
3. The analysis was done on total fish caught to reduce the bag limit effect (Pollock et al., 1997) i.e. the sum of coral trout retained and coral trout released.
4. Table 2 defined the coral trout spatial regions to be broadly in line with stock assessment reporting (Leigh et al., 2014).
5. A season factor variable was created broadly in line with those defined in O'Neill (2002).
    - December to February (Summer)
    - March to May (Autumn)
    - June to August (Winter)
    - September to November (Spring)

6. The data provided is from the Net Free Zone survey data which covers November 2015 to October 2016 and the Enhanced Boat Ramp Survey data which covers from October 2016 to December 2017. The number of boat ramps surveyed over these years differed.
7. Fishers may not be able to differentiate between common coral trout and bar-cheeked trout released portion of the catch. Because of this, common coral trout catch and bar-cheeked coral trout were grouped together in the analysis.
8. Fishing boats were surveyed after they had pulled the boat from the ramp. The time of interview and the time the boat was launched was recorded. This was used to calculate the "Hours From Ramp", a proxy for boat hours fished (search time plus fishing time).

2.2.2. Analysis

Standardised catch rates and confidence intervals

The boat ramp catch data contained an extremely high proportion of zeros (i.e. no coral trout were caught by the boat). O'Neill (2002) showed that a zero-truncated model may be better for modelling recreational fish catches. It is a two-stage process whereby:

1. The probability of catching zero fish is estimated using a binomial regression with a logit link.
2. For the non-zero counts, analysis is carried out using a separate truncated discrete distribution model, sometimes referred to as the "truncated count component" of the model.

For (2) a negative binomial regression with a log link was used in this analysis using the *pscl* package in R (Jackman et al., 2007).

The number of fish caught by the boat was the dependent variable. Predictors were the hours away from the ramp, the number of fishers on board, if they were targeting coral trout, the region they were fishing in, the year they were fishing, and also the interaction of the year that they were fishing and the region they fished. Rootograms (Kleiber and Zeileis, 2016) were used to assess goodness of fit.

The catch rate for coral trout was derived using the predictions from the regression for each year, region and whether they were targeting coral trout or not, for an average number of Hours away from Ramp and an average number of fishers on board. This predicted value may be used as an index of abundance. The confidence intervals for the predictions of this model were derived by a weighted bayesian bootstrap (Rubin, 1981).

```
Sample R Code
library(MASS)
#The Zero-truncated or Hurdle model
modhurd = hurdle(TotalCaught ~ HoursAwayFromRamp + NumberOfFisher +  target + CTRegion + Year
+ Year*CTRegion, data = boatline, dist = "negbin")
# Get the predicted "response" - ie. the hurdle count, add it to the dataset
df$PredHurdCount = predict(modhurd, df, type = "response")

#Obtain confidence intervals on predictions
#Bootstrapped Confidence Intervals – obtained by altering Venables R course notes
set.seed(32867700)
Norm <- function(x) x/mean(x)
X <- replicate(500, {
               tmp <- update(modhurd, weights = Norm(rexp(nrow(boatline))))
               predict(tmp, df, type = "response")
               })
ci <- apply(X, 1, quantile, prob = c(0.05, 0.95))
v <- apply(X, 1, var)
df$lower = ci[1,]
df$upper = ci[2,]

# Obtain a rootogram
library(countreg)
rootogram(modhurd,  max = 40, main =  "Hurdle Regression")
```

2.3. Underwater visual surveys

To determine the importance of a UVS dataset on the coral trout stock assessment model a Management Strategy Evaluation (MSE) was used. ELFSim (The Effects of Line Fishing Simulator) was used to compare the stock assessment results with, and without a UVS similar to that of the Australian Institute of Marine Science. Note that this UVS was treated as a *relative* index of abundance in the coral trout stock assessment model. Other, more large-scale UVS are converted to an absolute abundance measure in the coral trout stock assessment, which is not simulated.

The ELFSim operating model is a spatially and age-structured simulation model that works in monthly time steps. It includes biology of the fish, larval dispersal, sex change, recruitment–spawning dynamics and environmental variation. It accounts for recreational and commercial fishing (Little et al., 2007). It can also simulate some predefined management procedures.

ELFSim has a historical period. This uses past information about the fishery, which includes the fish biology, commercial catch rates, survey indices of abundance and their associated age-structure. The historical period was 1965–2011. It then has a projection period where it simulated the fishery going into the future (2012–2035).

Management Strategy Evaluations (MSEs)

MSEs involve simulating a fishery using high-level programming languages. This way, management procedures can also be simulated and tested on the fishery.

MSEs are carried out using an *operating model* which generates hypothetical populations of fish in different scenarios. Realistic parameters for the stock are chosen by the programmer, and used to produce hypothetical populations of fish. Therefore, everything about the population dynamics of the fishery in the operating model is known. For example, the carrying capacity of the stock, annual recruitment, the current exploitable biomass and the total allowable catch (TAC) to keep the stock at required management targets. Data are then generated from the operating model in the same form that it is sampled via fishing and fishery independent processes. The sampled (virtual) data drawn from the operating model can be tested in different *assessment models* and management procedures. Estimated parameters can be compared between the operating (simulation) model and assessment models (Figure 3).

An extension is to then simulate the management action that would be taken, given the sampled monitoring data or estimated management quantities from the assessment model. The management action can be fed back into the operating model (e.g. annually) to see what the simulated impact would be. This way, the process becomes iterative in time.

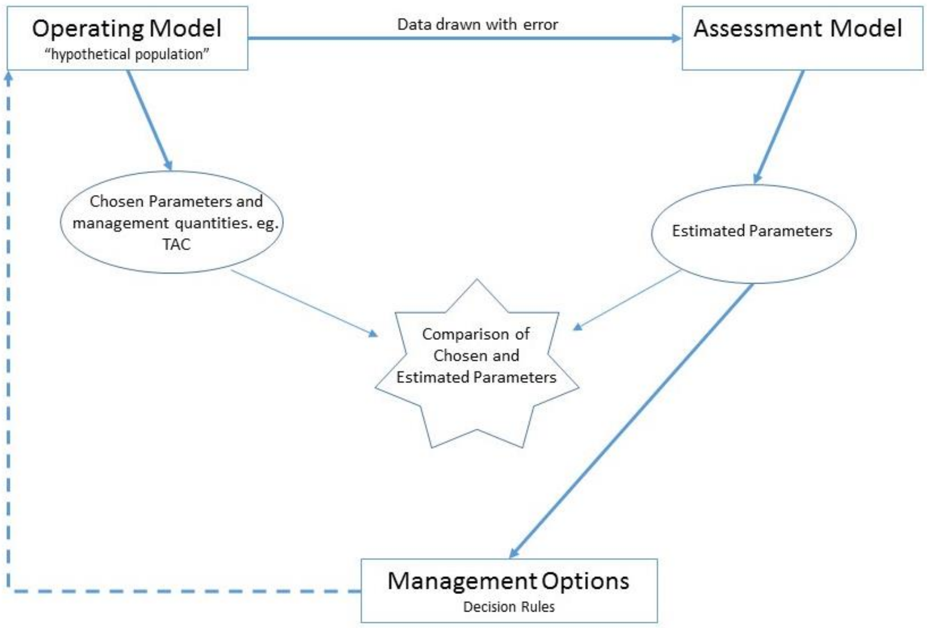

Figure 3: A general form of a Management Strategy Evaluation.

Monitoring data are drawn from the operating model with error and tested in a stock assessment model. The simulated population parameters from the operating model and the estimated population parameters from the assessment model are compared. The estimated parameters are used as an input into management procedures. The impact the management decision and action has on the operating model is then quantified (Adapted from Northrop, 2008).

This particular experiment did not evaluate any feedback control on fishery management procedures like TAC. It was designed strictly to evaluate the accuracy of the assessment model under different dataset scenarios (Figure 4).

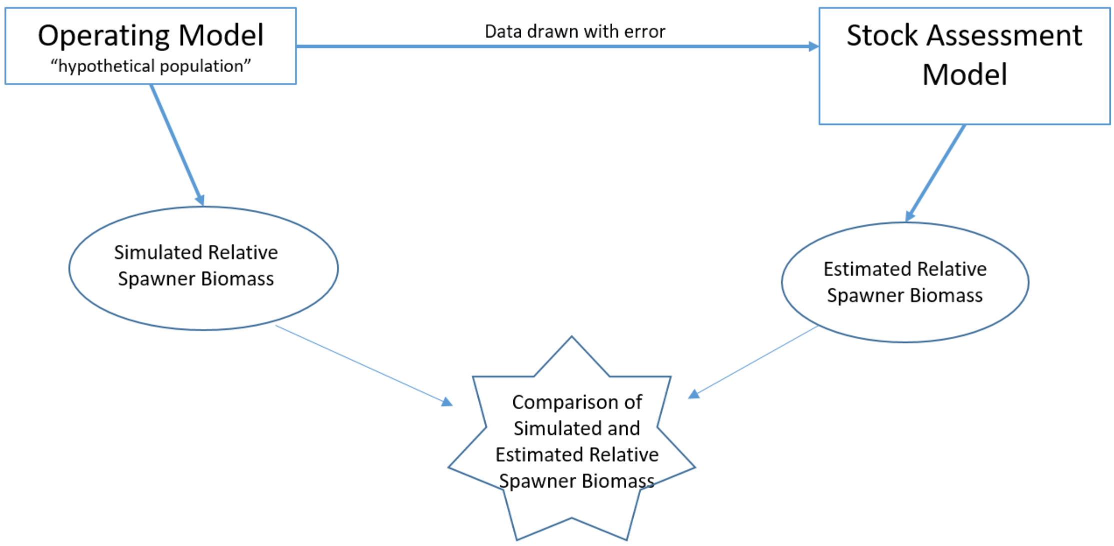

Figure 4: System used to evaluate UVS monitoring strategy

The operating model generated hypothetical populations of fish. Monitoring data were drawn from the operating model with error and used in the stock assessment model. The simulated population parameters and the estimated parameters were compared (Adapted from Northrop, 2008)

There were four different scenarios carried out. The first scenario had no UVS series. The second, third and fourth had a 15 year UVS series generated with a standard deviation equal to 0.3, 0.5 or 0.7 respectively. "The number of fish ≥20 cm from each reef was determined with a log-normal sampling error $\exp\left(N(0,x^2)-\frac{x^2}{2}\right)$. The abundance estimate was scaled to the reef perimeter and the average index calculated across reefs" (Little et al., 2016). ELFSim has used a standard deviation of 0.5 as default in the past, though these other values were tested to determine sensitivity.

For the UVS scenarios, 24 reefs were randomly chosen to be sampled for 15 years. Due to computational time, 10 runs were simulated for each scenario, resulting in a total of 40 runs. The value for the actual simulated spawner biomass relative to initial levels was recorded at the start of 2012. The corresponding value obtained from the stock assessment model was also recorded and the simulated (actual) and assessed values were compared by using an average absolute relative error metric. The relative error for a single run was calculated as:

$$Relative\ Error = \frac{Assessment\ Value - Actual\ Value}{Actual\ Value}$$

3 Results

3.1. Age-length keys

The mean length-at-age had reasonable standard deviations, with a coefficient of variation (CV) of approximately 10% of the mean for fish older than two years of age. The means and standard errors are reported in Appendix B.

Figure 5 and Figure 6 show boxplots of the age of the fish plotted against the 5 cm length categories. Appendix A show the actual probabilities vs the predicted probabilities of age-at length.

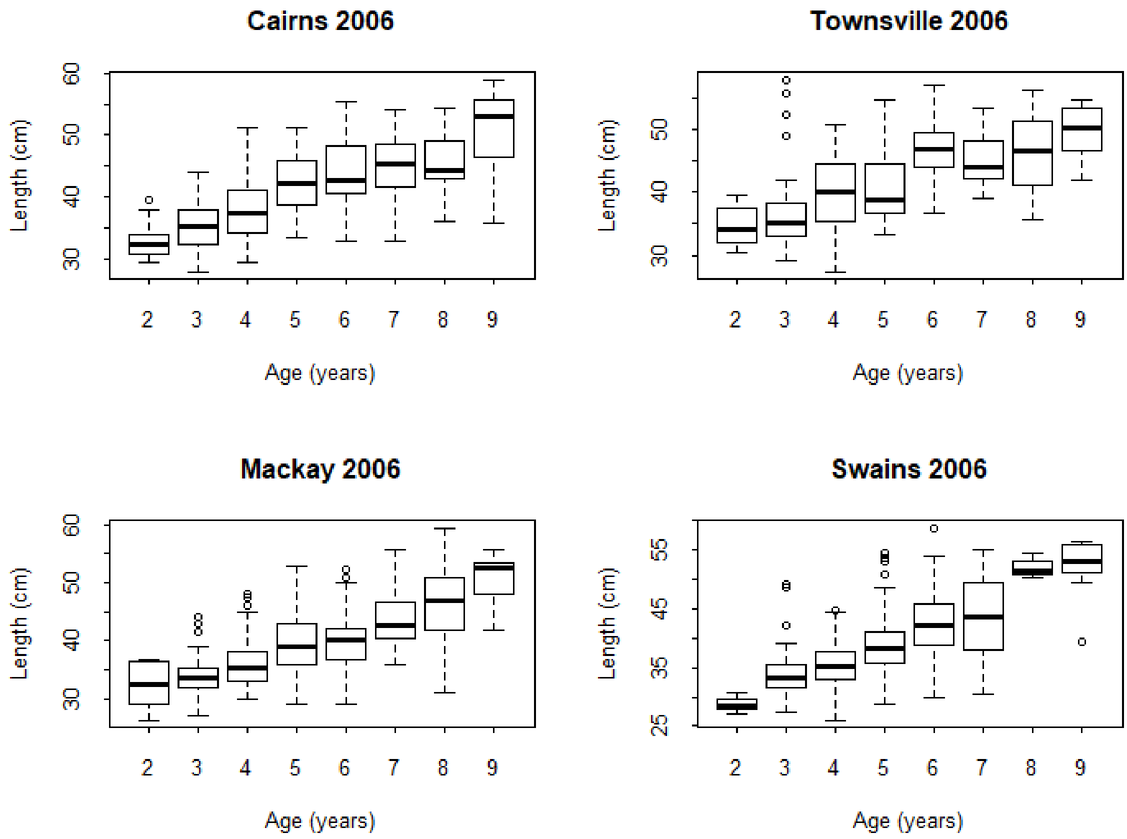

Figure 5: Boxplots of fish lengths at age for coral trout across the four regions in 2006.

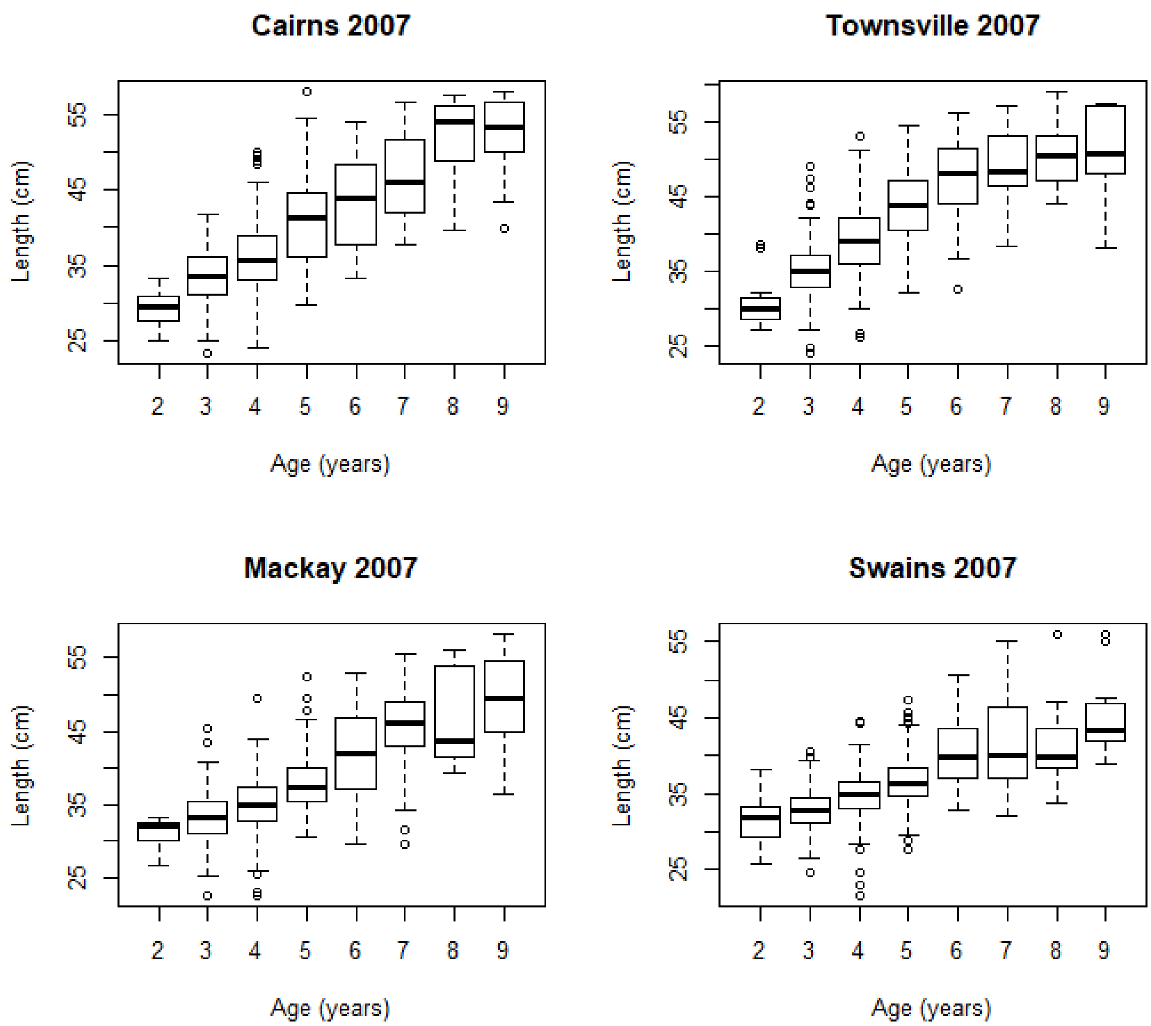

Figure 6: Boxplot of fish lengths at age for coral trout across the four regions in 2007

Region analysis

Region was found to have a significant effect on coral trout age-length keys (ALKs). In 2006, a significant difference was found when including region in the multinomial model (Likelihood ratio statistic = 187.5398, Df = 42, p< 0.0001). Similarly, in 2007, the inclusion of region resulted in a significant difference between the models (Likelihood ratio statistic = 238.5925, Df = 42, p< 0.0001).

Townsville in general appeared to have faster growing fish in both 2006 and 2007 than that of Cairns. Mackay and the Swains had more variation in age in certain length categories than that of Cairns and Townsville.

Pairwise comparisons of region were carried out in line with the Gerritsen et al. (2006) method. The ALK amongst regions were significantly different from each other, apart from that of the Swains and Mackay in 2007, where there was no evidence to show a statistical difference. Note also that Townsville and Cairns comparison in 2006 yielded a *p-value* = 0.0505, which is very close to the arbitrary cut-off of 0.05 (Goodman, 1999).

Spline graphs for the ALKs were generated to show the proportion of age at length in the various regions, within a particular year in Figure 7 and Figure 8, showing the smoothed probabilities of age at length.

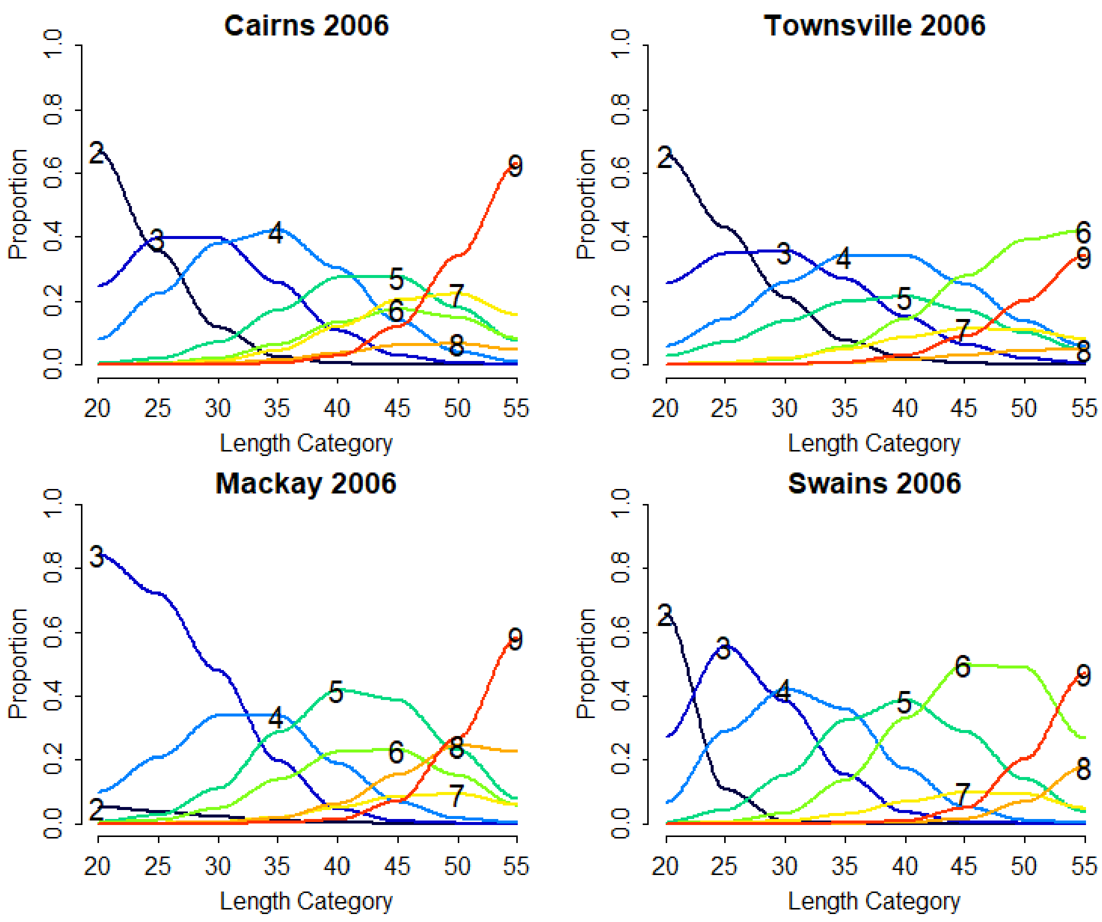

Figure 7: Spline plots of the predicted proportions of length-at-age for the four regions in 2006. Length categories are in centimetres

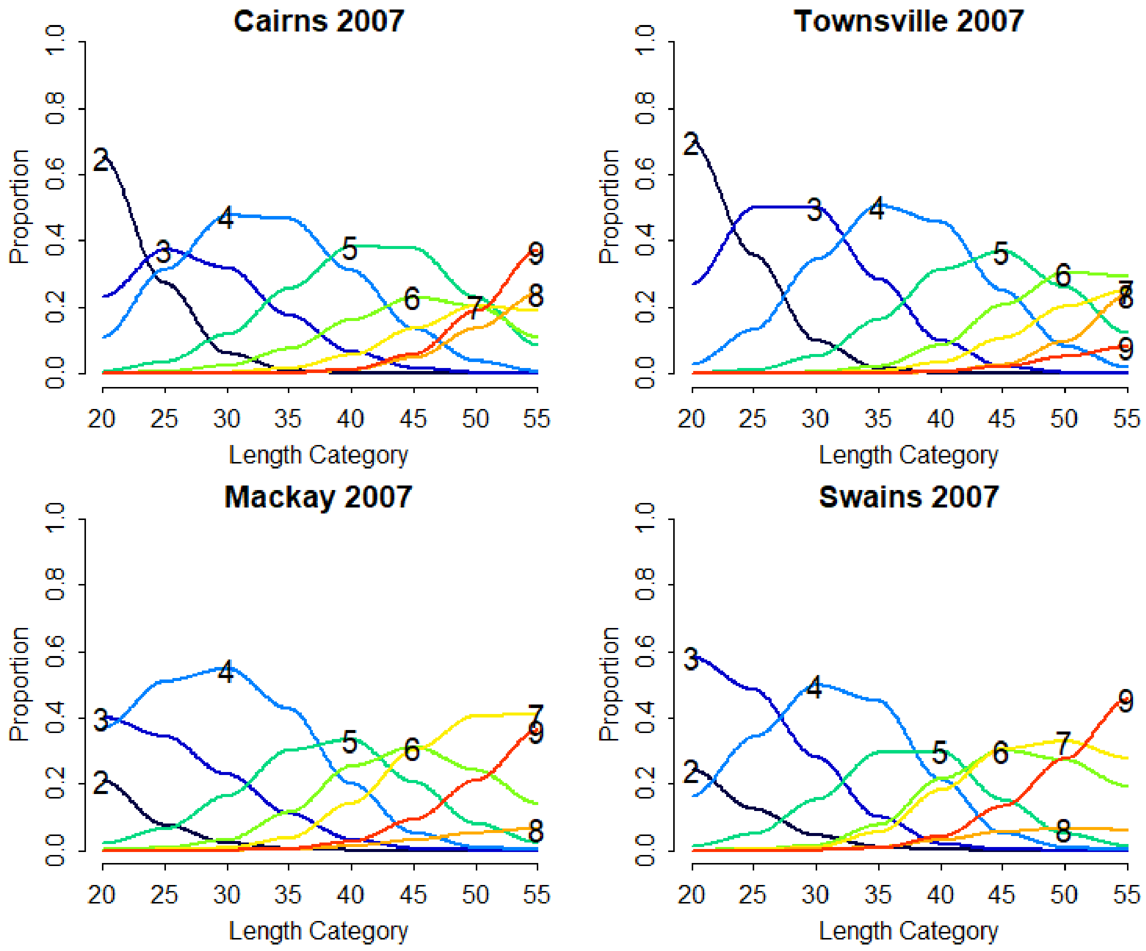

Figure 8: Spline plots for the predicted proportions of age at length for the four regions in 2007. Length categories are in centimetres

An actual versus predicted plot was generated to check how the model had smoothed the probabilities, and to assess goodness of fit (Appendix A, Figure 13 and Figure 14).

Analysis by year

An additional model was run including "Year" as an effect to evaluate whether the age-length key differed between years and region. A significant difference was found between the two years (Likelihood ratio statistic = 229.9 Df = 56, $p < 0.0001$).

Sample size analysis

The number of fish otoliths that need to be sub-sampled from a length sample of size L is presented in Table 4. The table shows how many otoliths would need to be sampled based on a particular region, and also shows how the estimate differed between the two sampling years. Sample sizes for age ranged from N =240 to N =285 per region.

There are four important points to note from this analysis.

1. Increases in the aged samples, after a certain point, do not improve accuracy significantly. See Figure 9.
2. The different regions require similar aged sample sizes.
3. The number of fish lengths sampled, over L = 500, only improve estimates very marginally.
4. Random sampling is vital. The sampling of fish needs to be independent.

Table 4: The number of aged samples required to obtain a variance estimate of 0.05. "All data" is how much will be needed for a single age-length key if the highly significant differences between growth in regions is ignored.

	Number of fish sampled for length (L)		
	L = 500	**L = 1000**	**L = 2500**
All Data 2006	*275*	*265*	*260*
Cairns 2006	280	270	265
Townsville 2006	285	275	260
Mackay 2006	265	255	250
Swains 2006	260	250	245
All Data 2007	*260*	*255*	*250*
Cairns 2007	265	255	250
Townsville 2007	260	250	240
Mackay 2007	255	245	240
Swains 2007	250	245	240

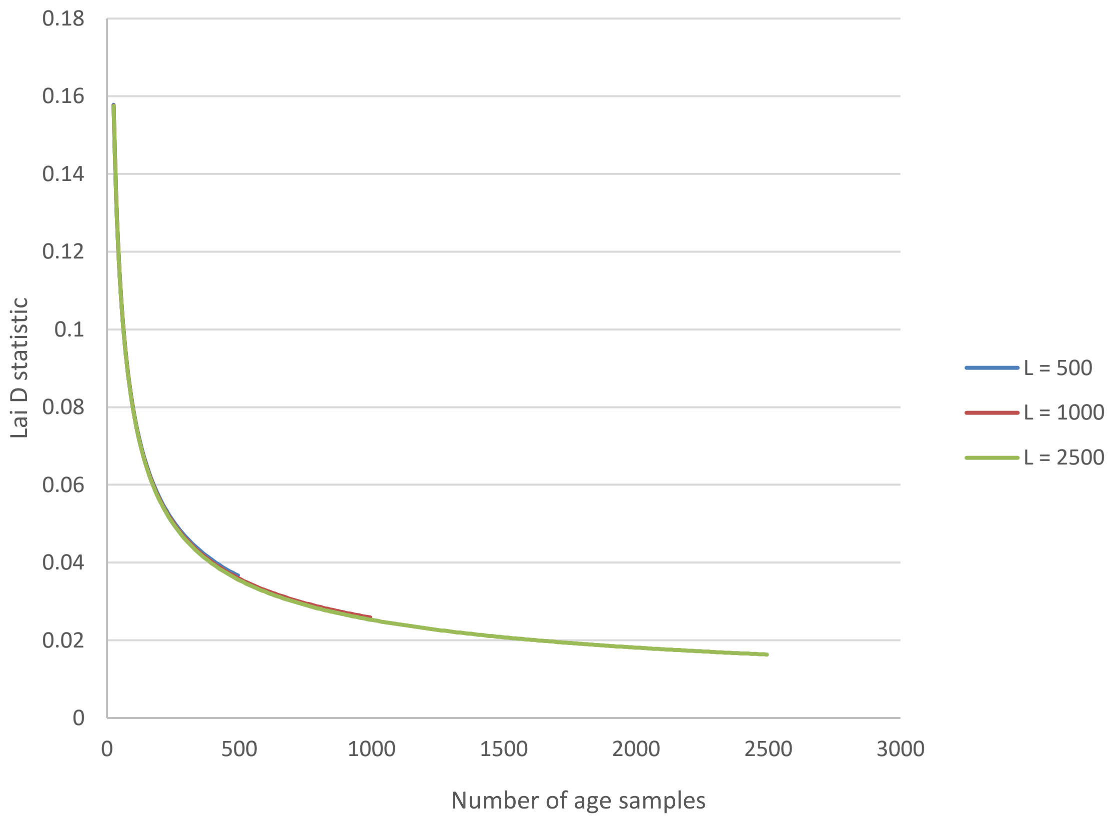

Figure 9: Level of precision measured by the statistic D for common coral trout as a function of age sample size and three different values of length sample sizes (500, 1000, 2500) for Townsville in 2007

3.2 Recreational boat ramp survey

There were 8748 boat trips in the final dataset. There were 3935 coral trout captures recorded in total over the study period by 880 boats, of which 44% were retained. Ten per cent of boats caught at least one coral trout.

Eight per cent (648) of the boats were targeting coral trout as a primary or secondary species. Those boats that targeted coral trout were far more likely to capture the trout. Sixty-five per cent of those that targeted coral trout, caught it. Six per cent of those that were not targeting coral trout caught the fish. Those boats targeting the fish caught two-thirds of the total catch, even though they represented a small proportion of fishers.

Table 5: Number of boats interviewed, whether they targeted coral trout, and how many coral trout they retained and released

		No of Boats	Total Coral Trout	Total Retained	Total Released
Target Coral Trout		**648**	**2545**	**1148**	**1397**
	None Caught	224	0	0	0
	Caught	424	2545	1148	1339
Target Other		**8100**	**1390**	**577**	**813**
	None Caught	7644	0	0	0
	Caught	456	1390	577	813
Grand Total		**8748**	**3935**	**1725**	**2210**

The truncated negative binomial model output is shown below. The hours away from rmp, the number of fishers on the boat, whether the boat was targeting coral trout and the region the boat fished all had a significant effect on coral trout captured.

```
Call:
hurdle(formula = TotalCaught ~ HoursAwayFromRamp + NumberOfFisher + target + CTRegion + Year
+ Year * CTRegion, data = boatline, dist = "negbin")

Pearson residuals:
    Min      1Q  Median      3Q     Max
-0.8930 -0.2018 -0.1629 -0.1339 23.4531

Count model coefficients (truncated negbin with log link):
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                        -0.19488    0.26280  -0.742 0.458348
HoursAwayFromRamp                   0.09965    0.01849   5.391 7.02e-08 ***
NumberOfFisher                      0.15572    0.04592   3.391 0.000696 ***
targetOther                        -0.96770    0.10082  -9.598  < 2e-16 ***
CTRegionCapBunker.or.RockOff        0.36414    0.34574   1.053 0.292243
CTRegionMackay                      0.55601    0.32260   1.724 0.084791 .
CTRegionSE.Qld                     -1.03861    1.55980  -0.666 0.505499
CTRegionTownsville                  0.42819    0.20749   2.064 0.039055 *
Year2                               0.30501    0.21063   1.448 0.147598
CTRegionCapBunker.or.RockOff:Year2 -1.00269    0.40644  -2.467 0.013624 *
CTRegionMackay:Year2               -0.54440    0.38670  -1.408 0.159190
CTRegionSE.Qld:Year2               -1.22502    1.63430  -0.750 0.453514
CTRegionTownsville:Year2           -0.16888    0.25719  -0.657 0.511428
Log(theta)                         -0.49859    0.16083  -3.100 0.001934 **


Zero hurdle model coefficients (binomial with logit link):
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                        -1.63092    0.23044  -7.077 1.47e-12 ***
HoursAwayFromRamp                   0.18540    0.01249  14.840  < 2e-16 ***
NumberOfFisher                      0.33750    0.04255   7.931 2.17e-15 ***
targetOther                        -3.23304    0.10306 -31.370  < 2e-16 ***
CTRegionCapBunker.or.RockOff        0.39752    0.31017   1.282   0.2000
CTRegionMackay                     -0.64413    0.29816  -2.160   0.0307 *
CTRegionSE.Qld                     -1.67314    1.06167  -1.576   0.1150
CTRegionTownsville                 -0.02801    0.21356  -0.131   0.8957
Year2                               0.13361    0.22713   0.588   0.5564
CTRegionCapBunker.or.RockOff:Year2 -0.24198    0.36701  -0.659   0.5097
CTRegionMackay:Year2                0.56569    0.35622   1.588   0.1123
CTRegionSE.Qld:Year2                0.95140    1.08843   0.874   0.3821
CTRegionTownsville:Year2            0.22476    0.26440   0.850   0.3953
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta: count = 0.6074
Number of iterations in BFGS optimization: 27
Log-likelihood: -3892 on 27 Df
```

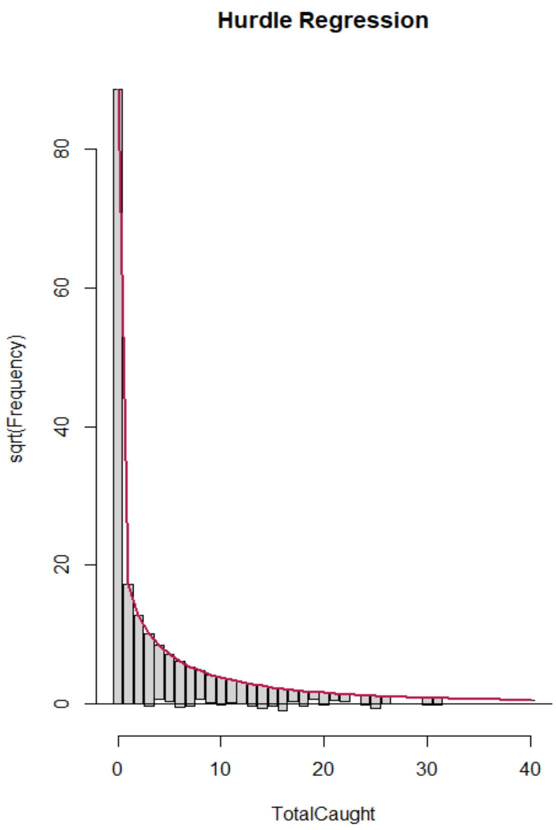

Figure 10: Goodness of fit – rootogram for the truncated negative binomial regression for the boat ramp survey data

Figure 10 shows the hanging rootogram, which yields a suitable level of accuracy for counts.

The predictions from the model showed the expected catch rate. Year 1 had larger confidence intervals than Year 2, as there were less data obtained in Year 1 (Figure 11 and Figure 12).

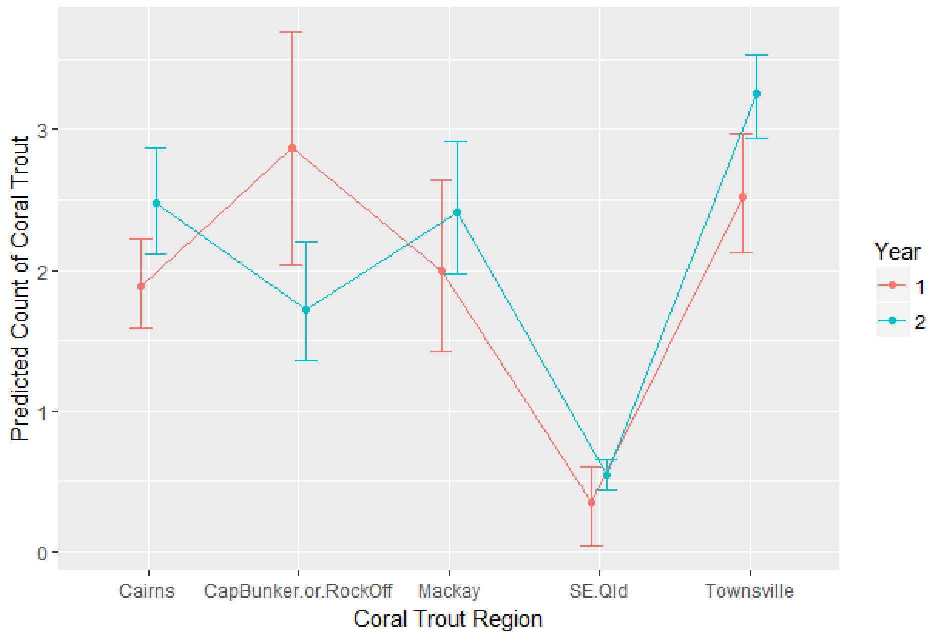

Figure 11: Predicted catch by region of an average recreational boat targeting coral trout using the truncated negative binomial model

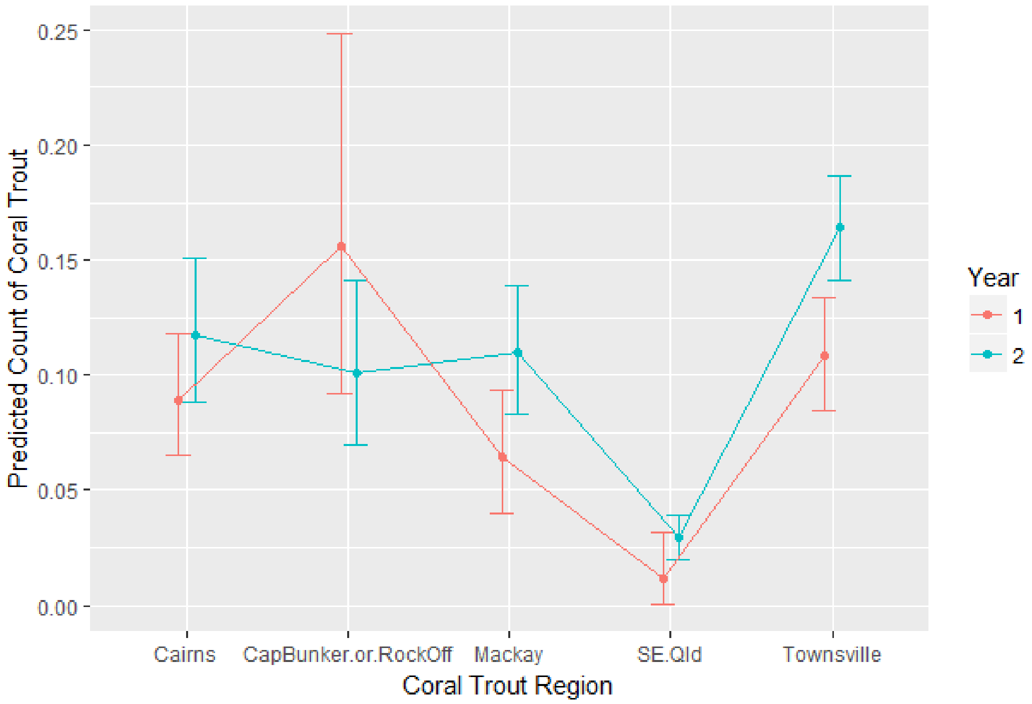

Figure 12: Predicted catch by region of an average recreational boat not targeting coral trout using truncated negative binomial model

3.3 Underwater visual surveys

The average absolute relative error for the “no UVS data” scenario was 5.19%. For the scenario which contained the default sampling error of 0.5, the average absolute relative error dropped to 1.72%. It is important to note that the assessment model had a variety of other datasets available to it, so interpretation must be done in relative terms. We would expect if less data were available, that the “gap” between the two models would increase quite meaningfully.

In this case, the accuracy level improved by three times with the UVS data.

A log-normal sampling error of 0.3 resulted in an average relative error of 1.68%, and a log normal sampling error of 0.7 resulted in an average relative error of 1.77%. This difference is not viewed as meaningful, and in this range it appears that the model is not sensitive to the choice of sampling error.

4 Discussion and recommendations

4.1. Age-length key

Age composition data is critical for coral trout to track the cohorts and year-class strength. From this, mortality and general population dynamics can be derived. Using length data alone for coral trout is not feasible, as they are a slow-growing fish (Mclean et al., 2011).

Collecting otoliths from a structured line survey for direct ageing is the best and most robust sampling strategy. One of the main benefits of a structured line survey over sampling from fishers, is fish smaller than the minimum legal size (MLS) can be sampled. According to this analysis, coral trout reach the MLS of 38 cm roughly between three and four years old. Structured line sampling would have the following benefits over sampling from commercial fishers:

1. Give an indication of younger cohort strength and mortality.
2. Would not select for the more “plate-sized” fish which are sought by the Asian market. Commercial selectivity can distort recorded length distributions (Morton and Bravington, 2008). Younger and older fish are less likely to be captured commercially.
3. If the Structured Line Survey utilised Department of Agriculture and Fisheries (DAF) staff, there would be less variability in sampling.

Direct ageing from fishers will also be sufficient, and has been found by one simulation study to give similar levels of accuracy in stock assessment models (Little et al., 2016). The lack of randomness from sampling the commercial catch, may result in a non-representative sample. The sampling must be random, therefore compliance from fishers is of paramount importance.

An ALK is a feasible alternative to determine the age-structure of coral trout. If this is the case, it is important to create an ALK for each of the four fishing regions (Cairns, Townsville, Mackay and the Swains). The ALK should be developed in accordance with the way regions are divided in the 2014 stock assessment (Leigh et al., 2014). These were based on the bioregions defined by a committee of experts assembled by the Great Barrier Reef Marine Park Authority (GBRMPA, 2009).

It was clear from the analysis that regional differences in the ALKs were significant. For example, in the period sampled, six year old coral trout off Townsville were very fast growing compared to the other regions. The level of fishing varies substantially between regions, so it is highly desirable for analysis to be done at the regional level.

The far northern region is currently not sampled and is lightly fished. Data from this region would provide contrast and improve model estimates.

Significant differences in the ALK were found between the two years analysed. This is typical and demonstrates proof of point that an ALK from previous years cannot be applied to current year’s length data (Gulland and Rosenberg, 1992)

If there were no funding for obtaining age composition data, the coral trout stock assessment could still be carried out, but confidence limits would become wider and stock assessors and fisheries managers may miss important signals relating to fishing and fishery performance. For example, the proportion of old fish in the population may increase or decrease in response to fishing, but there would be no way of knowing this. Also recruitment may be inaccurate- for example, there may be a strong year class in one year but we may not know about it.

Using the Lai D-statistic, which is a precision measure, between 240 and 285 aged samples per region are required, with 500 fish length samples collected.

If Fisheries Queensland does not have the funding for the full samples annually, it would be better to have less samples *every* year, than to have the full aged sample only on alternate years. This would have the following advantages:

1. Strong signals would become apparent earlier (e.g., an exceptionally strong year class).
2. The ability to trace the year-class strength from one year to the next (albeit with less accuracy than at full sample size), which would provide more confidence in the ageing techniques.
3. Confidence that samples collected in different years are genuinely independent. If a large sample is collected in one year there is always a risk that the fish may not be truly independent, so the effective sample size may be much less than the actual sample size.

4.2 Recreational boat ramp surveys

An abundance index was derived for coral trout using the boat ramp survey data. More years of data are required, as such the results are more demonstrative of the methodology that can be used. Season was found not to have a significant effect on recreational catch, so it was removed from the model. However, in the future, season could be taken into account so the catch rates can be standardised to a particular season within a particular region like in O'Neill et al. (2018). Recommendations are:

1. *Directly asking the fishers how much time they think they spent actually fishing would improve the estimates greatly. Travel time, breaks, and sleeping over multiple days are currently unknown. The analysis used the time the boat arrived at the ramp, less the time the fisher said he went out, as a proxy for hours of effort.*
2. *Develop a measure of fisher skill. Ask the fisher more questions at interview, such as whether they are a keen angler or how often they fish a month. There is a very large variation in fisher skill, and change in abundance may be confounded by the change in the average skill level of the fishers we survey. Collection of individual boat license number is advisable, as particular fishers could be tracked over time.*
3. Information on fishing power, e.g. the use of fish finders etc. would also greatly improve the abundance index.
4. Improved understanding of where the angler has fished will greatly improve estimates. Whether they fished within the Net Free Zone is important, and better understanding of particular reefs that are targeted would help account for the highly spatial nature of coral trout.
5. Ensure there is sufficient overlap of reefs where recreational fishers and commercial fisher's fish if the intention is use the abundance index for both sectors.

Diary surveys kept for many years by more skilled fishers are also useful, and are an alternative as an index of abundance. The improvement in an individual fisher's skill over time would need to be accounted for.

4.3 Underwater visual surveys

The 2014 coral trout stock assessment model (Leigh et al., 2014) used the Cabezon model as a base. It then added a number of refinements – one of which was to include a measure of absolute abundance (fish per hectare) derived from the extensive UVS carried out by Ayling and Ayling (1986). The opportunity to include a measure of absolute abundance for a population of fish that is so spatially distributed, with little movement between reefs, is extremely valuable.

Ayling and Ayling carried out transects along roughly 10% of the Great Barrier Reefs. In comparison, AIMS UVS was carried out along 24 reefs (0.6% of the reefs). AIMS also needed to identify over 100 fish species, and the surveys are not designed specifically for coral trout. This being said, the analysis above shows that the AIMS data are still valuable to the stock assessment, and will continue to be used going into the future.

Catch rates for coral trout can be variable. There are two reasons for this:

1. Social learning – commercial fishers believe that common coral trout "learn" not to take the bait on highly targeted reefs (Leigh et al., 2014)
2. Catch rates may decrease following a major tropical cyclone, for up to two years, though it is unknown why.

UVS is not reliant on fish taking the bait, which bypasses the social learning issue. UVS also provides a measure of recruitment of fish one year and older "the young of the year". Information on fish smaller than the MLS can be obtained, as the minimum legal size for coral trout is 38 cm which is – at minimum – a three year old fish.

The effect of major cyclones and their impact on coral trout populations is challenging to quantify. Cyclones (and coral bleaching) cause severe structural damage to the coral reef. This may make it *easier* for coral trout to be sighted in a UVS, as they have less coral to hide in. Some also believe that the prey fish have less habitat to hide in, resulting in coral trout gorging themselves on these fish. They are then less likely to take the bait from commercial fishers, which could explain the decrease in catch rate. This may potentially explain the marginal *increase* in coral trout numbers seen after Cyclone Hamish during UVS, combined with 66% coral cover damage, while the catch rates decreased significantly (Tobin et al., 2010). However, others believe that coral trout go "off the bite", and the UVS is the most accurate source of information.

In the short term, a new three year large-scale UVS study similar to the Ayling and Ayling study is highly recommended. If the methods were replicated, it should be directly comparable to the one carried out in the 1980s. Another "once off" set of absolute abundance would calibrate the stock assessment model after many years with limited data and greatly improve the accuracy of management reference points.

UVS that covers all the sub-regions of the coral trout are recommended. More focused UVS on only key fishery species should be carried out to reduce observer error.

ELFSim is powerful but highly complex. It is written in C++ and is difficult to use. If DAF continues to use it for coral trout, the following is recommended:

1. A programmer/developer with a strong background in mathematics, and years of experience in C++, should be enlisted to debug and optimise the code. Porting the code to other platforms, such as MATLAB, should be explored.
2. Currently, the historical period of the operating model ends at 2011. Data from the previous seven years needs to be coded into the model. This includes commercial catch rates, underwater visual surveys, age and length frequencies etc.
3. The most recent knowledge of reef locations should be coded into the model.

References

Ayling, A., and A. Ayling. 1986. Coral trout survey data. Unpublished report to GBRMPA. 212pp

Department of Agriculture and Fisheries. 2017. What is the sustainable fisheries strategy? https://www.publications.qld.gov.au/dataset/155ccffb-3a30-48c1-8144-7892e8a57339/resource/319c7e02-f07b-4b2e-8fd5-a435d2c2f3c9/fs_download/qld-sustainable-fisheries-strategy.pdf Fisheries Queensland. 2017. General Metadata.

GBRMPA. 2009. Great Barrier Reef Outlook Report 2009, Great Barrier Reef Marine Park Authority, Townsville.

Gerritsen, H. D., D. McGrath, and C. Lordan. 2006. A simple method for comparing age–length keys reveals significant regional differences within a single stock of haddock (Melanogrammus aeglefinus). ICES Journal of Marine Science 63(6):1096-1100.

Goodman, S. N. 1999. Toward evidence-based medical statistics. 1: The P value fallacy. Annals of internal medicine 130(12):995-1004.

Gulland, J. A., and A. A. Rosenberg. 1992. A review of length-based approaches to assessing fish stocks. Food & Agriculture Org.

Halford, A. A., and A. A. Thompson. 1996. Visual census surveys of reef fish. Long term monitoring of the Great Barrier Reef. Standard operational procedure No. 3.

Jackman, S., C. Kleiber, and A. Zeileis. 2007. Regression Models for Count Data in R.

Katzschmann, R. K., J. DelPreto, R. MacCurdy, and D. Rus. 2018. Exploration of underwater life with an acoustically controlled soft robotic fish. Science Robotics 3(16)doi: 10.1126/scirobotics.aar3449

Kleiber, C., and A. Zeileis. 2016. Visualizing count data regressions using rootograms. The American Statistician 70(3):296-303.

Lai, H.-L. 1987. Optimum allocation for estimating age composition using age-length key. Fishery Bulletin 85(2):179-186.

Leigh, G., A. Campbell, C. Lunow, and M. O'Neill. 2014. Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery. Brisbane, Australia: Queensland Government

Little, L., B. Kerrigan, O. Thébaud, A. Campbell, J. Innes, D. Cameron, B. Mapstone, A. Norman-Lopez, A. Punt, J. Kung, S. Slade, G. Leigh, M. O’Neill, and A. Tobin. 2016. Evaluating candidate monitoring strategies, assessment procedures and harvest control rules in the spatially complex Queensland Coral Reef Fin-fish Fishery. 2011/030, CSIRO and Queensland Government, Brisbane.

Little, L., A. Punt, B. Mapstone, F. Pantus, A. Smith, C. Davies, and A. McDonald. 2007. ELFSim—a model for evaluating management options for spatially structured reef fish populations: an illustration of the “larval subsidy” effect. Ecological Modelling 205(3):381-396.

Mclean, D. L., E. S. Harvey, and J. J. Meeuwig. 2011. Declines in the abundance of coral trout (Plectropomus leopardus) in areas closed to fishing at the Houtman Abrolhos Islands, Western Australia. Journal of Experimental Marine Biology and Ecology 406(1-2):71-78.

Morton, R., and M. Bravington. 2008. Comparison of methods for estimating age composition with application to Southern Bluefin Tuna (Thunnus maccoyii). Fisheries Research 93(1):22-28.

Nelson, G. 2014. fishmethods: Fishery science methods and models in R. R package version:1.6-0.

Northrop, A. R. 2008. Importance of various data sources in deterministic stock assessment models, Rhodes University.

O'Neill, M. F. 2002. Use of binary and truncated regression models in the analysis of recreational fish catches.

O’Neill, M., J. Langstreth, and S. Buckley. 2018. Stock assessment of Australian east coast Spanish Mackerel. Agriculture and Fisheries. p 107. Queensland Government.

Ogle, D. H. 2016. Introductory fisheries analyses with R. CRC Press.

Pollock, K. H., J. M. Hoenig, C. M. Jones, D. S. Robson, and C. J. Greene. 1997. Catch rate estimation for roving and access point surveys. North American Journal of Fisheries Management 17(1):11-19.

Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press.

Rubin, D. B. 1981. The bayesian bootstrap. The annals of statistics 9(1):130-134.

Tobin, A., A. Schlaff, R. Tobin, A. Penny, A. Ayling, B. Krause, D. Welch, S. Sutton, B. Sawynok, and N. Marshall. 2010. Adapting to change: minimising uncertainty about the effects of rapidly-changing environmental conditions on the Queensland Coral Reef Fin Fish Fishery.

Appendix A: Age-length key figures

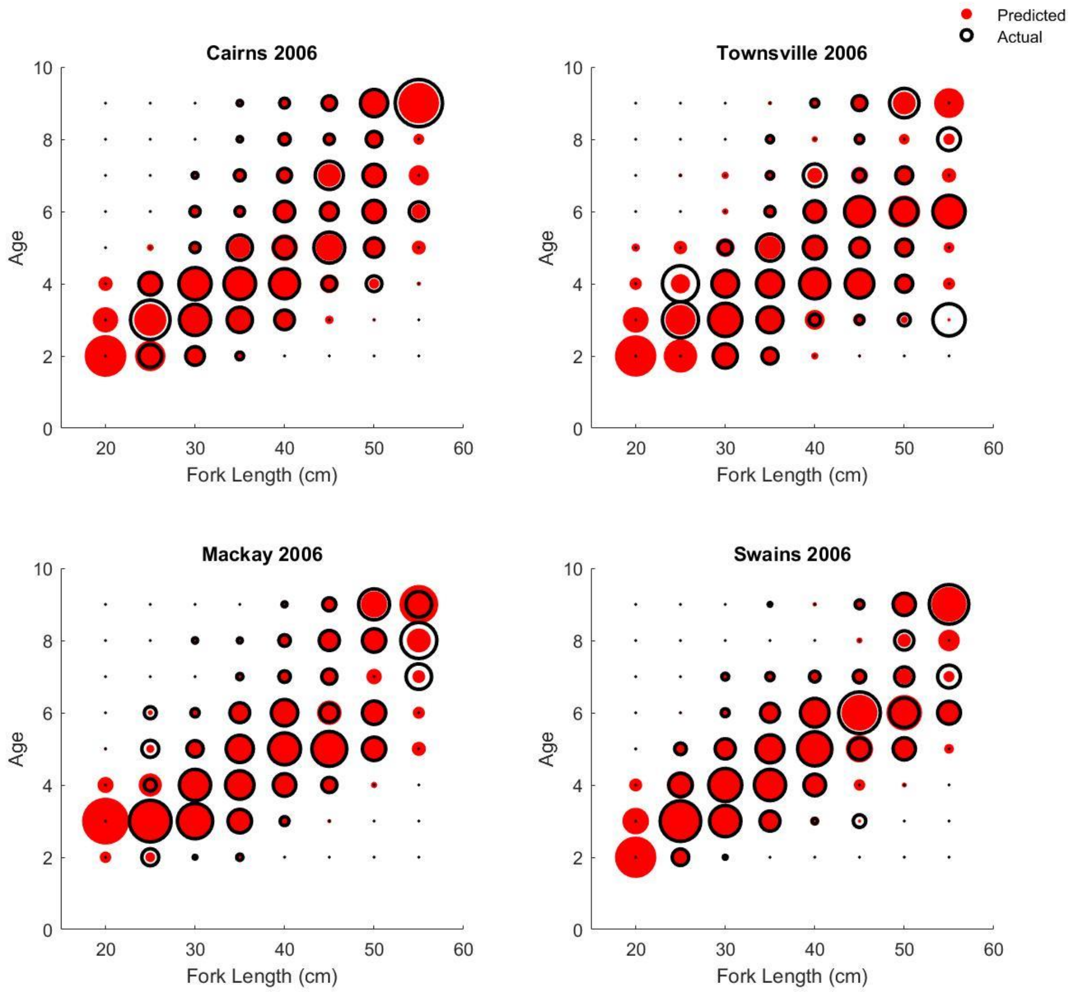

Figure 13: Goodness of fit graphs by region for the proportions of age at length in 2006. The sum over all ages for a particular length category equals 1

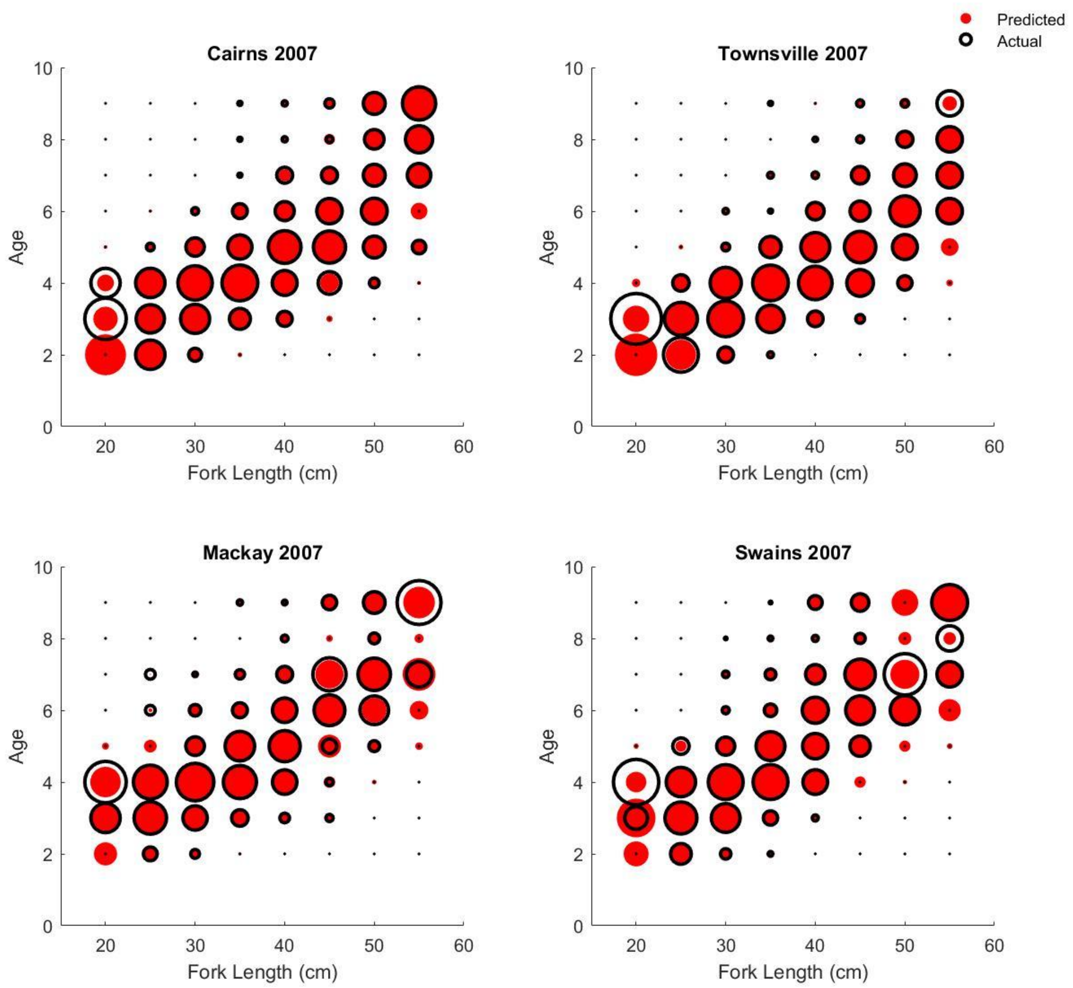

Figure 14: Goodness of fit graphs by region for the proportions of age at length in 2007. The sum over all ages for a particular length category equals 1

Appendix B: Mean length at age for coral trout sampled in the four different regions, with their corresponding standard deviation.

	2006 Mean (cm)	2006 SD	2007 Mean (cm)	2007 SD
Age 2				
Cairns	32.9	2.7	29.2	1.7
Townsville	34.6	2.8	30.5	3.1
Mackay	32.3	4.2	31.0	1.9
Swains	28.7	1.6	31.7	2.5
Age 3				
Cairns	35.5	3.8	33.7	3.6
Townsville	36.9	6.6	35.1	4.1
Mackay	33.7	2.7	33.5	3.7
Swains	33.6	3.3	32.7	2.2
Age 4				
Cairns	38.0	4.4	36.1	4.6
Townsville	40.1	5.3	39.3	4.7
Mackay	36.0	3.4	35.0	3.3
Swains	35.5	3.1	34.8	2.7
Age 5				
Cairns	42.0	4.5	40.9	5.6
Townsville	41.1	5.4	43.6	4.6
Mackay	39.8	4.9	37.9	3.3
Swains	38.8	4.4	36.6	3.1
Age 6				
Cairns	43.7	5.6	43.5	5.7
Townsville	46.8	4.7	47.6	4.6
Mackay	40.0	4.5	41.7	5.6
Swains	42.6	5.2	40.5	4.4
Age 7				
Cairns	45.2	4.8	46.8	5.4
Townsville	44.9	4.2	48.8	4.4
Mackay	43.2	5.2	45.3	5.6
Swains	43.1	7.2	41.3	5.7
Age 8				
Cairns	46.2	5.7	51.7	5.9
Townsville	46.1	10.3	50.8	4.1
Mackay	46.0	7.1	46.3	6.5
Swains	52.1	0.0	41.9	7.3
Age 9+				
Cairns	50.8	6.2	52.2	5.4
Townsville	50.0	3.8	50.2	7.1
Mackay	50.8	4.1	48.3	7.1
Swains	51.9	5.2	45.5	5.5

Appendix C: Data descriptions for boat ramp survey data (Fisheries Queensland, 2017, unpublished report)

Data Field Descriptions

Survey Table Details		
Field	**Description of Field**	**Data Recorded**
SurveyID	Identifying record	Generated number (key)
BatchID	Identifying record	Generated number
CheckedDateTime	Stamped date and time at which the survey data was checked	Date and Time
TemplateCode	Datasheet version	Version BRI01 or BRI02

Boat Ramp Survey Table Details		
Field	**Description of Field**	**Data Recorded**
SessionID	Identifying record	Generated number (key)
Session	Interviewers three initials and DDMMYY	i.e. JXL141117
SurveyDate	Date that survey shift is conducted	Date
RampAbrev	An abbreviation of the boat ramp name	Ramp abbreviation from list
StartTime	The time at which the survey shift started	Time (24 hour)
StartTimeSecond	As above	Time (seconds)
TrailerCount	The number of trailers parked in the boat ramps carpark at the start of the survey shift.	Number
FinishTime	The time at which the survey shift finished	Time (24 hour)
FinishTimeSecond	As above	Time (seconds)
SamplingActivityCode	Identifies whether the interviewer was core (QG) staff or casual staff	Two digit code (from sampling activity table)
NonFishingBoats	Sum of the number of non-fishing boats retrieved during the survey	Number
CommercialFishingVessel Retreived	Sum of the number of commercial fishing vessels retrieved during the survey shift	Number
FullRefusal	A count of the number of fishers that refused to partake in the survey	Number

Interview Table Details		
Field	**Description of Field**	**Data Recorded**
SiteID	Identifying record	Generated number (key)
Interview#	Consecutive interview number for a survey shift	Number
RetrieveTime	Time that fisher retrieved boat from ramp	Time (24 hour)
RetrieveTimeSecond	As above	Time (seconds)
LaunchDate	Date that fisher launched boat at ramp	Date
LaunchTime	Time that fisher launched boat at ramp	Time (24 hour)
LaunchTimeSecond	As above	Time (seconds)
NumberOfFisher	Number of persons fishing on board the vessel	Number
PrimaryCAAB	Species being targeted by fisher (no order of preference)	Species name
SecondaryCAAB	Species being targeted by fisher (no order of preference)	Species name
Fishing (NFZ)	Were the people in the interviewed vessel fishing? (obsolete field no longer used)	Y/N

Town & Postcode Table Details		
Field	**Description of Field**	**Data Recorded**
AbioticID	Identifying record	Generated number (key)
Town	Name of fishers' residential town	Town name
Postcode	Postcode of fishers' residential town	Postcode
ValidTownID	Identifying record for a particular combination of town and postcode	Number (from town/postcode table)
FishingMainPurpose	Was the main reason for leaving their residence to come here and go fishing?	Y/N

Location & Methods Table Details		
Field	**Description of Field**	**Data Recorded**
SampleID	Identifying record	Generated number (key)
Activity#	Each different fishing activity is numbered separately and consecutively starting at 1. This number is carried through the Total Kept plus Released Details and the Kept Details so that we can match catches to activities	Number
Location	General area/location that the fishing occurred for that activity	Three digit code (from Valid Locations table)
FishingMethodCode	Fishing method types used for that activity	Two digit code related to a certain method
DaysFished	Number of days fished for this activity	Number

Total Kept plus Total Released Table Details		
Field	**Description of Field**	**Data Recorded**
CatchID	Identifying record	Generated number (key)
CAABSpeciesID	Identifying eight digit code for the species	Eight digit code
SpeciesName	Common name of species that was caught (restricted survey species only)	Species common name
TotalKept	The total number of fish/crustaceans kept for that species and fishing activity	Number
TotalReleased	The total number of fish/crustaceans released for that species and fishing activity	Number
Counted (Y/N)	Whether or not the interviewer counted the fish kept	

Kept Table Details		
Field	**Description of Field**	**Data Recorded**
CatchID	Identifying record	Generated number (key)
CAABSpeciesID	Identifying eight digit code for the species	Eight digit code
SpeciesName	Common name of the species that was caught (restricted survey species only)	Species common name
Length	Fish length measurement in millimetres and rounded to the nearest 10mm.	Number (mm)
LengthType	The measurement type used for the length measurement of the fish.	Two digit code related to a certain length measurement type

Ramp Locations/Regions

Region	Town	Ramp Name	Ramp Abrev	NFZ RAMPS
BRISBANE	Brisbane	Jacobs Well Ramp	JACOBS	
BRISBANE	Brisbane	Victoria Point Ramp	VIC POINT	
BRISBANE	Brisbane	Raby Bay Ramp	RABY	
BRISBANE	Brisbane	Wellington Point Ramp	WELLO	
BRISBANE	Brisbane	Whyte Island Ramp	WHYTE	
BRISBANE	Brisbane	Scarborough Harbour Ramp	SCARB	
BRISBANE	Brisbane	Spinnaker Sound Ramp	SPIN	

BRISBANE	Brisbane	Donnybrook Ramp	DONNY	
BRISBANE	Brisbane	Toorbul Ramp	TOORBUL	
CAIRNS	Cooktown	Cooktown Ramp	COOKTOWN	
CAIRNS	Port Douglas	Port Douglas Ramp	PORTDOUG	
CAIRNS	Innisfail	Mourilyan Ramp	MOUR	
CAIRNS	Cairns	Tingira Street Ramp	TINGIRA	NFZ
CAIRNS	Cairns	Daves Boat Yard Ramp	DAVES	NFZ
CAIRNS	Cairns	Yorkeys Knob Ramp	YORKEYS	
FRASER	Hervey Bay	River Heads Ramp	RHEADS	NFZ REF
FRASER	Hervey Bay	Urangan Boat Harbour Ramp	URANGAN	NFZ REF
FRASER	Tin Can Bay	Tin Can Bay Ramp	TINCAN	
FRASER	Bundaberg	Burnett Heads Ramp	BURNETT	
FRASER	Bundaberg	Bundaberg City Ramp	BUNCR	
FRASER	Agnes Water	1770 Ramp	1770	
GLADSTONE	Gladstone	Gladstone Power Station Ramp	GLADPOWER	
GLADSTONE	Gladstone	Gladstone Marina Ramp	GLADMAR	
GOLD COAST	Southport	Grand Hotel Ramp	GRAND	
GOLD COAST	Southport	Broadwater Parklands Ramp	BROADWATER	
HINCHINBROOK	Cardwell	Cardwell Ramp	CARDWELL	NFZ REF
HINCHINBROOK	Lucinda	Lucinda Ramp	LUCINDA	NFZ REF
KARUMBA	Karumba	Karumba Town ramp	KTOWN	
KARUMBA	Karumba	Karumba Point Ramp	KPOINT	
MACKAY	Sarina	Rocky Dam Creek Ramp	RDC	
MACKAY	Mackay	Mackay Harbour Ramp	MACKAY	
MACKAY	Seaforth St Helens	Seaforth Ramp	SEAFORTH	NFZ
MACKAY	Seaforth St Helens	St Helens Ramp	HELENS	NFZ
MACKAY	Airlie Beach	Airlie Beach Marina Ramp	AIRLIE	
MACKAY	Airlie Beach	Whisper Bay Ramp	WHISPER	
ROCKHAMPTON	Rockhampton	Nerimbera Ramp	NERIM	NZF
ROCKHAMPTON	Rockhampton	Quay Street Ramp	QUAY	NFZ
ROCKHAMPTON	Yeppoon	Coorooman Creek Ramp	COOROO	NFZ
ROCKHAMPTON	Yeppoon	Rosslyn Bay Ramp	ROSSLYN	NFZ
SUNSHINE COAST	Caloundra	Caloundra Powerboat Club Ramp	CPBC	
SUNSHINE COAST	Mooloolaba	Mooloolaba Coast Guard Ramp	MCG	
SUNSHINE COAST	Maroochydore	Fishermans Road Ramp	FISHERMANS	
SUNSHINE COAST	Noosa	Noosa Sailing Club Ramp	NOOSASC	
SUNSHINE COAST	Kawana	Kawana Ramp	KAWANA	
TOWNSVILLE	Townsville	Morriseys Ramp	MORRIS	
TOWNSVILLE	Bowen	Bowen Boat Harbour Ramp	BOWEN	
TOWNSVILLE	Townsville	Townsville Recreational Boating Park Ramp	TCG	NFZ REF
TOWNSVILLE	Townsville	Bohle River Ramp	BOHLE	NFZ REF
WEIPA	Weipa	Rocky Point Ramp	ROCKYPT	
WEIPA	Weipa	Evans Landing Ramp	EVANS	

NFZ – Net Free Zone Site; NFZ REF – Net Free Zone Reference Site