Developing a fish recruitment indicator for the Gladstone Harbour Report Card using data derived from castnet sampling

Gladstone Healthy Harbour Partnership

infofish AUSTRALIA

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SUMMARY

The objectives of this project were to:

1. Design an optimal, quantitative cast-net sampling program to collect fish recruits from Gladstone Harbour and its inlets and estuaries, from The Narrows to Rodds Bay.
2. Conduct a cast-net sampling program based on the approved sampling design over the 2015-16 recruitment season.
3. Undertake a statistical assessment of the new dataset in conjunction with existing datasets held by Infofish Australia to pilot preliminary recruitment indicators for Yellowfin bream (*Acanthopagrus australis*) and Pikey bream (*A. berda*) in Gladstone Harbour.

The report is present in 2 parts. Part 1 addresses the first 2 objectives. Part II addresses the third objective. This summary relates to Part 1 while there is a separate non-technical summary for part II.

The Gladstone Harbour is subdivided into 13 sub-regions and each sub-region was assessed for suitable sites where Bream recruits were likely to be found and where castnet surveys could be undertaken. The Outer Harbour (sub-region 11) was not considered to have any suitable habitat that Bream recruits were likely to use other than for transit to more suitable locations. No sites were proposed in this sub-region.

For the remaining 13 regions, based on the criteria for site selection, there were a total of 26 sites selected where castnet surveys were undertaken. There was at least 1 site in each sub-region. Where appropriate existing sites were selected to provide some continuity with data previously collected. There were 14 existing sites and 12 new sites selected.

Standardised castnet surveys were undertaken monthly at sites from Dec 2015-Mar 2016. A castnet survey involved 20 or 10 casts at a site with the number of casts being determined by the size and characteristics of the site. Surveys were repeated monthly from Nov 2014-Dec 2015 at most sites.

There were 103 surveys at 26 sites with a total of 2,020 casts resulting in a catch of 8,653 individuals. A total of 561 (27.8%) resulted in a nil catch. Catch rates varied considerably between sites. The highest catch rate was at Ramsay Crossing at 12.3 individuals/cast followed by Mud Island at 11.8 individuals/cast and then South Trees at 9.6 individuals/cast. Lowest catch rates were recorded at Wappentake Creek at 1.0 individuals/cast and Barney Point Pond and Gatcombe Anchorage at 1.3 individuals/cast.

Yellowfin Bream were recorded at 22 (84.6%) of the 26 sites and in 11 of the 12 sub-regions surveyed. There were no sites surveyed in sub-region 11 (Outer Harbour) as there was no habitat suitable for juvenile Bream in that sub-region. Pikey Bream were recorded at 19 (73.1%) sites and in 11 of the 12 sub-regions surveyed. Sub-region 3 (Western Basin) was the only sub-region where neither species of Bream was recorded.

There were a total of 325 Yellowfin Bream and 179 Pikey Bream recorded. Over the whole survey period from Dec-Mar the overall catch rate for Yellowfin Bream was 0.16 fish/cast which was double that for Pikey Bream at 0.08 fish/cast.

INTRODUCTION

Building on the Pilot Report Card 2014, the Gladstone Harbour Report Card 2015 has been informed by 78 measures of the four components of harbour health: environmental, social, cultural and economic.

The 2015 report card is based on data collected during the period from July 2014 to June 2015. As GHHP continues to expand and refine its monitoring programs, additional measures will become available. *Figure 1* shows the results of the 2015 Report Card and *figure 2* shows the Environmental Grades of Harbour Zones.[1]

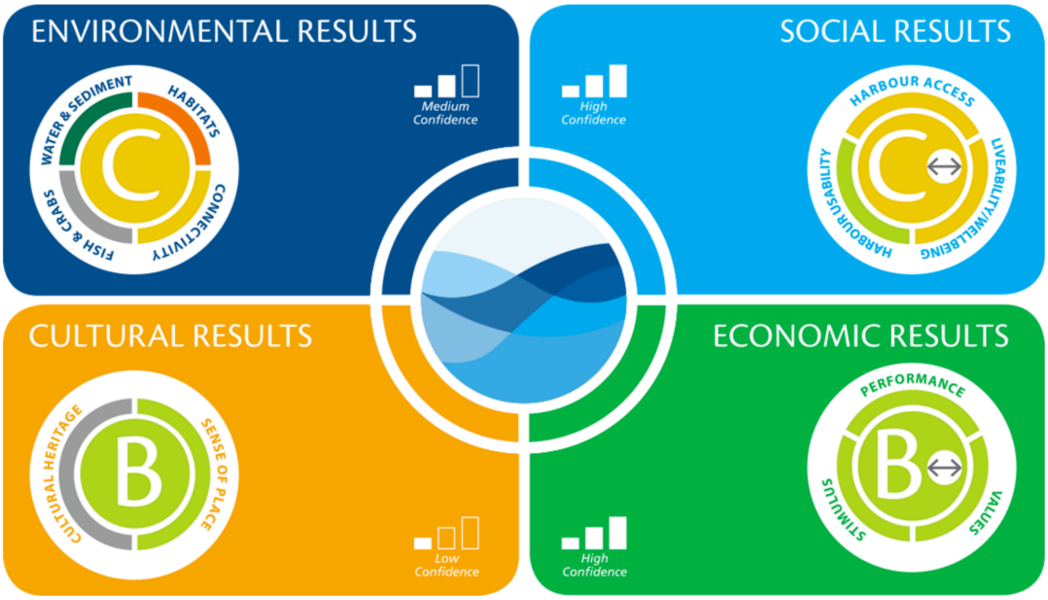

Figure 1: Indicators used in the Gladstone Harbour Health Report Card

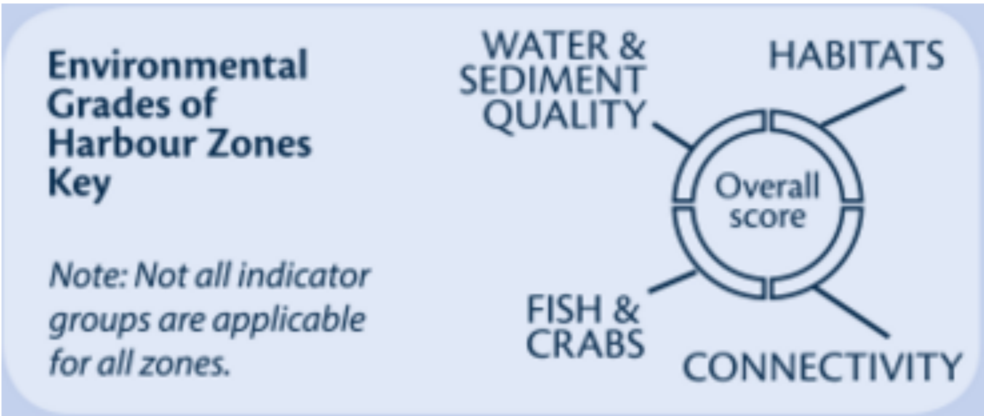

Figure 2: Environmental Grades of Harbour Zones

[1] From http://ghhp.org.au/report-cards/2015

The environmental grades of Harbour Zones are based on 4 components:

- Water and sediment quality
- Habitats
- Fish and crabs
- Connectivity

The environmental indicators include fish and crabs. GHHP determined that recruitment of key fish species be an appropriate fish indicator. To assist with the development of a fish recruitment indicator in 2015 it was decided to undertake an assessment of fish recruitment in the Gladstone area with a focus on Barramundi and 2 Bream species.

The results of that assessment were in the report "Developing a fish recruitment indicator for the pilot Gladstone Healthy Harbour Report Card in 2015" (Sawynok et al 2015). Based on that assessment it was decided that recruitment of Yellowfin and Pikey Bream be used for the development of the fish indicator.

OBJECTIVES

The requirements of this project were to:

1. Design an optimal, quantitative cast-net sampling program to collect fish recruits from Gladstone Harbour and its inlets and estuaries, from The Narrows to Rodds Bay.
2. Conduct a cast-net sampling program based on the approved sampling design over the 2015-16 recruitment season.
3. Undertake a statistical assessment of the new dataset in conjunction with existing datasets held by Infofish Australia to pilot preliminary recruitment indicators for Yellowfin bream (*Acanthopagrus australis*) and Pikey bream (*A. berda*) in Gladstone Harbour.

GLADSTONE HARBOUR SUB-REGIONS

The Gladstone Harbour has been divided into 13 sub-regions for the GHHP Report Card are shown in *figure 3*. The area includes Gladstone Harbour, Calliope River, Boyne River, the Narrows, Outer Harbour and Rodds Bay.

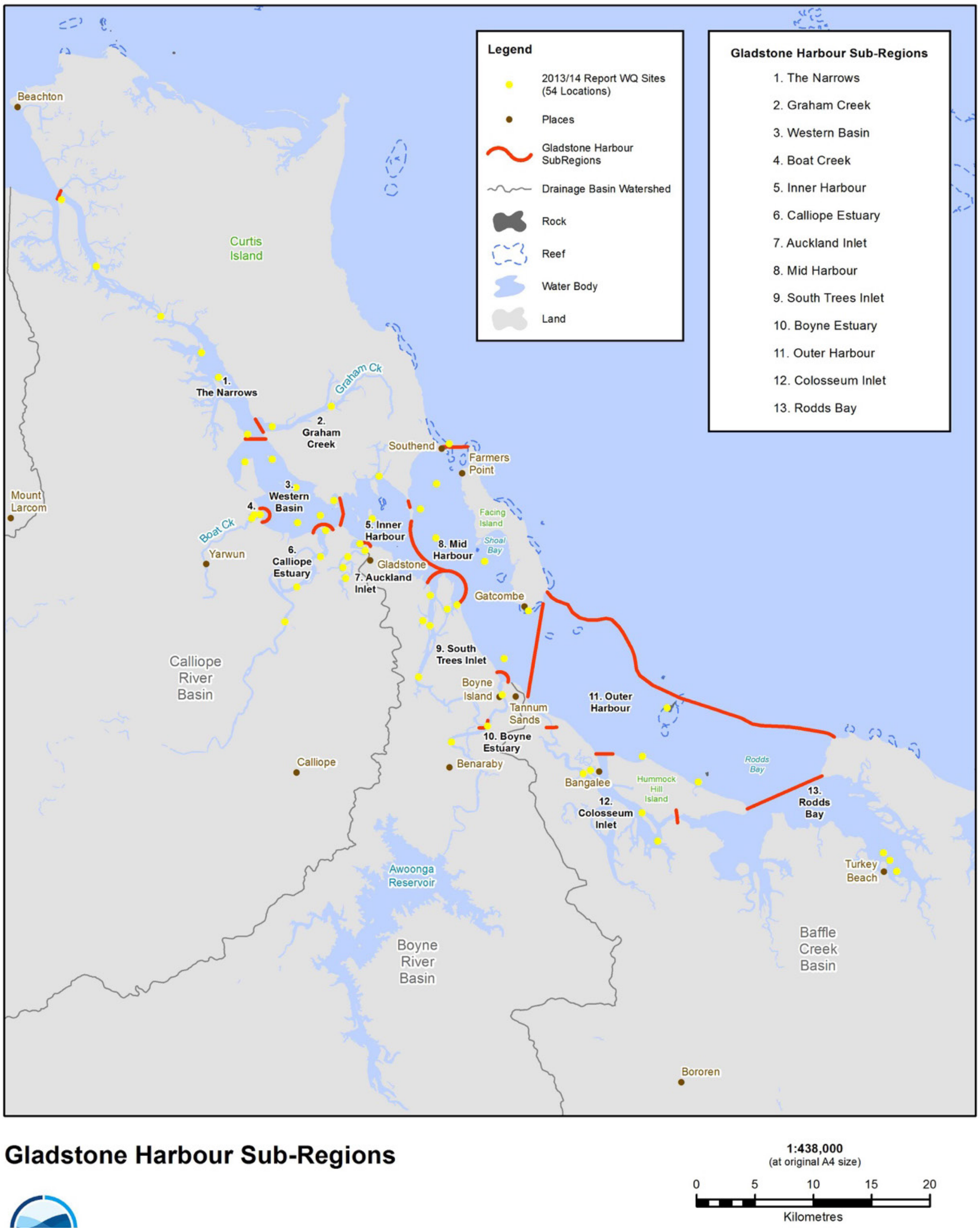

Figure 3: Gladstone sub-regions for the GHHP Report Card

The 13 Gladstone Harbour sub-regions are:

1. The Narrows
2. Graham Creek
3. Western Basin
4. Boat Creek

5. Inner Harbour
6. Calliope Estuary
7. Auckland Creek
8. Mid Harbour
9. South Trees Inlet
10. Boyne Estuary
11. Outer Harbour
12. Colosseum Inlet
13. Rodds Bay

METHODS

SPECIES SELECTION

1. Based on the recruitment surveys in 2015 Yellowfin Bream and Pikey Bream were selected as the key species.

SITE SELECTION

2. Bream recruits generally use all parts of the estuary to the top end of the tidal limit and into the freshwater reaches on occasions when conditions allow.
3. At least one site selected in each sub-region.
4. In each sub-region where possible one site selected towards the upper tidal limit and another within the area of daily tidal influence.
5. Existing sites to be used where possible to allow for comparison with historically collected data.
6. Sites to be located to cover all key areas of the sub-regions.
7. Details of sites are stored in the Infofish 2016 database. Details include site ID, Suntag map and grid, latitude, longitude, text description, type of sub-strata, vegetation, site photographs and Google Earth image of site. Site details are in Appendix 1.

TIMING OF SURVEYS

8. Bream spawn during the winter months however the location of spawning sites is uncertain in Gladstone Harbour. By Oct recruits are generally in the size range 30-40mm and able to by caught in a castnet.
9. During Nov additional sites were identified and a trial survey was undertaken to check that the location was used by juvenile Bream.
10. Standardised surveys were undertaken at selected sites each month from Dec 2015-Mar 2016.
11. Timing of surveys was generally after the largest spring tides as that was mostly when recruits access nursery habitat, particularly at the upper tidal reaches. Surveys were generally completed over a 2 week timeframe.

DEFINING BREAM RECRUITS

12. Both Yellowfin and Pikey Bream spawn at the mouths of rivers and nearshore locations (Pollock 1982a) from May-Aug (Pollock 1982b) and then recruits make their way to all parts of the estuary.
13. Yellowfin Bream reach from 130-150mm after 1 year (Brown 2007, Pollock 2011, Cowden 1995). No data are available for Pikey Bream however is it expected that growth rates are similar to those of Yellowfin Bream and reaching a similar size after 1 year. Recruits during the survey period were fish from 0-100mm.

SURVEY METHODS

14. Survey apparatus used was a castnet. This is the same apparatus as used in other Infofish recruitment surveys and ensured a standardised approach so that the results were comparable with other surveys. A standard castnet was a monofilament net with a drop of 2.4m, a mesh size of 20mm and a spread of 3.6m+. Photographs of the survey equipment in use were taken (*figure 4*).
15. Infofish has a current permit to undertake surveys using a wide range of equipment. Permit number is 147717 and is current to 20/6/2016.
16. At each site a number of casts were determined depending on site size and characteristics. The number of casts were 10 or 20 based on the site. The number of casts was recorded so that results could be used if the survey could not be completed for any reason (eg incoming tide). Casts were valid if the spread covered over 75% of the maximum area that can be covered by a cast.
17. Details of the number of casts and all fish including species, date, location and length (key species only) were recorded in a waterproof field record book for later transfers to a standard excel spreadsheet (Infofish 2015 trip sheet). The length of the fish was recorded to the nearest mm. For fork tailed fish the fork length was measured. For round tailed fish the total length was recorded.

Figure 4: Castnet method used for the recruitment surveys

MAXIMISING SURVIVAL OF FISH CAUGHT

18. To maximise the survival of fish on released, for casts where a small number of fish were caught these were removed quickly from the net, measured and then released. For casts where a large number of fish were caught the net was left in the water while the fish were removed.
19. Some species are hardier than others so fish that were more susceptible to mortality were removed first (eg Bony Bream). These steps maximised the survival of released fish however some mortality did occur.
20. Surveys were not undertaken when the water temperature was above 32°C as survival decreases rapidly when this temperature is exceeded.

TAGGING OF FISH

21. Bream and other key species over 150mm were tagged using standard 30mm or 45mm Hallprint gun tags (*figure 5*).

Figure 5: Pikey Bream tagged in Hobble Gully

DATA MANAGEMENT

22. Data on the recruitment sites and from the recruitment surveys are stored in the Infofish 2015 online database located at http://qld.info-fish.net/infofish/. Access to the database is managed by secure login and the level of access is limited based on the users need eg taggers can login and view their own data (read only).
23. Data from the standard excel spreadsheet was validated by visual examination and cross checking prior to being uploaded to the database.

DATA ANALYSIS

24. This report provides a summary of the data collected. For each site the number of surveys, number of casts, total individuals in the catch and the number of Yellowfin and Pikey Bream were recorded.
25. Catch rate at each site were calculated for each site and for each month of surveys and for fish and prawn. Data were standardised on individuals/cast.
26. Percentage of fish and prawn in the monthly surveys was calculated.
27. The number of Yellowfin and Pikey Bream surveyed in each sub-region was calculated.

STATISTICAL ANALYSIS

28. Statistical analysis was carried out by Dr Bill Venables and is appended to this report.

FISH HEALTH

29. Fish health issues were recorded during recruitment surveys.

SITE LOCATIONS

The Gladstone Harbour is subdivided into 13 sub-regions and each sub-region was assessed for suitable sites where Bream recruits were likely to be found and where castnet surveys could be undertaken. The Outer Harbour (sub-region 11) was not considered to have any suitable habitat that Bream recruits were likely to use other than for transit to more suitable locations. No sites were proposed in this sub-region.

For the remaining 12 regions, based on the criteria for site selection there were a total of 26 sites selected where castnet surveys were undertaken. There was at least 1 site in each sub-region. Where appropriate existing sites were selected to provide some continuity with data previously collected. There were 14 existing sites and 12 new sites selected.

Figure 6 shows the locations of sites with details of the sites contained in Appendix 1. Where locations are in sub-regions are shown in *table 1*.

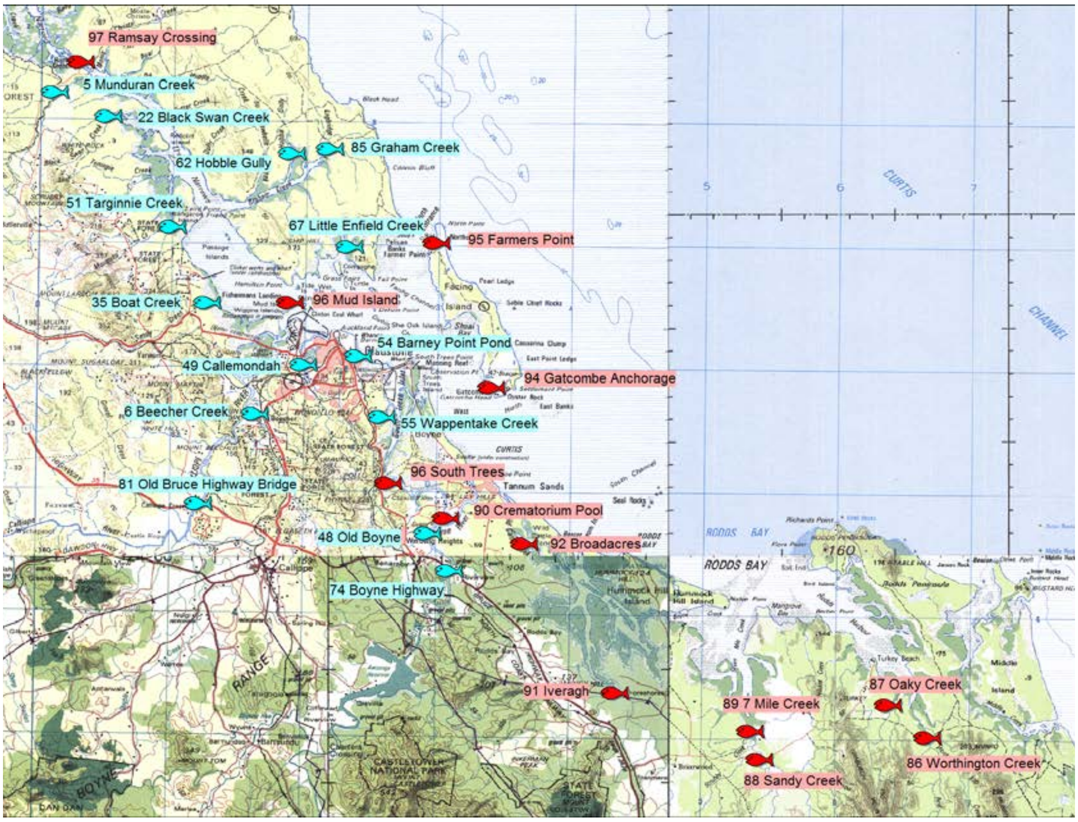

Figure 6: Site locations in the Gladstone area (existing sites shown in blue and new sites shown in red)

RESULTS
SUMMARY OF SURVEYS

Table 1: Sites and surveys

SUB-REGION	SITE ID	SITE	SURVEYS	CASTS	CATCH	Y BREAM	P BREAM
1	97	RAMSAY CROSSING	4	40	493	2	54
1	5	MUNDURAN CREEK	4	80	128	14	0
1	22	BLACK SWAN	4	80	197	0	1
1	51	TARGINNIE CREEK	4	80	117	5	0
2	62	HOBBLE GULLY	4	80	436	2	30
2	85	GRAHAM CREEK	3	60	175	5	2
3	96	MUD ISLAND	4	80	941	0	0
4	35	BOAT CREEK	4	80	238	1	2
5	67	LITTLE ENFIELD CREEK	4	80	363	1	13
5	54	BARNEY POINT POND	4	80	104	0	0
6	6	BEECHER CREEK	4	80	261	9	1
6	81	OLD BRUCE HWY BRIDGE	4	80	438	11	10
7	49	CALLEMONDAH	4	80	408	16	15
8	95	FARMERS POINT	4	80	224	0	0
8	94	GATCOMBE ANCHORAGE	4	80	107	2	2
9	55	WAPPENTAKE CREEK	4	80	83	2	1
9	76	SOUTH TREES	4	80	769	7	11
9	90	CREMATORIUM POOL	4	80	261	49	0
10	48	OLD BOYNE	4	80	308	34	1
10	74	BOYNE HIGHWAY	4	80	244	42	1
11		NO SITES					
12	92	BROADACRES	4	80	294	15	2
12	91	IVERAGH	4	80	393	18	2
13	89	7 MILE CREEK	4	80	333	14	19
13	88	SANDY BRIDGE	4	80	424	44	0
13	87	OAKY CREEK	4	80	627	22	11
13	86	WORTHINGTON CREEK	4	80	287	10	1
		TOTAL	103	2020	8653	325	179

Table 1 provides a summary of surveys at all sites from Dec 2015-Mar 2016. There were 103 surveys with 2,020 casts resulting in a catch of 8,653 individuals. A total of 561 casts (27.8%) resulted in a nil catch.

Catch rates varied considerably between sites. The highest catch rate was at Ramsay Crossing at 12.3 individuals/cast followed by Mud Island at 11.8 individuals/cast and then South Trees at 9.6 individuals/cast. Lowest catch rates were recorded at Wappentake Creek at 1.0 individuals/cast and Barney Point Pond and Gatcombe Anchorage at 1.3 individuals/cast.

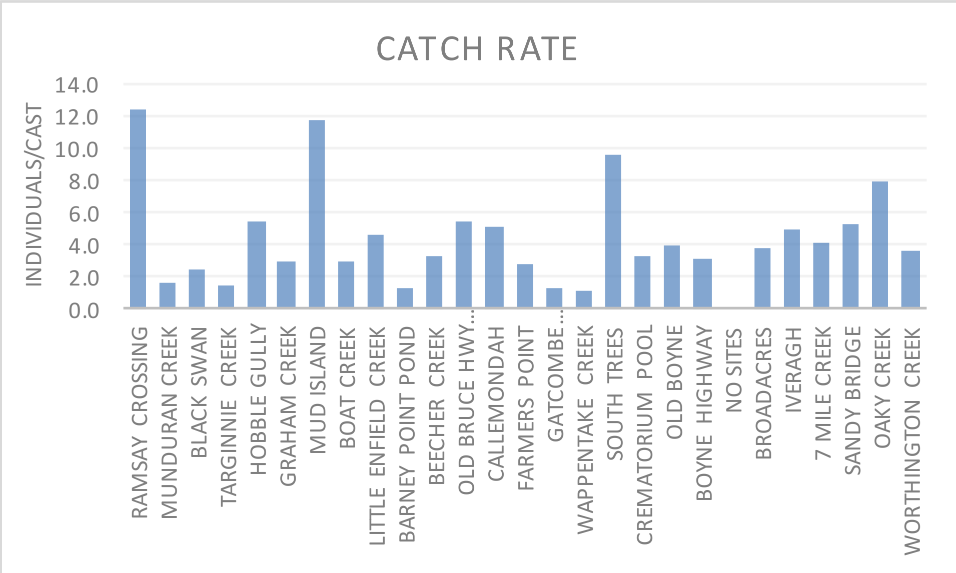

Figure 7: Catch rate at each site

Flattail Mullet (24.8%), Banana Prawn (21.6%) and Estuary Glassfish (8.4%) were the most caught species. Yellowfin Bream were the 8th most caught (3.8%) and Pikey Bream were the 11th most caught (2.1%).

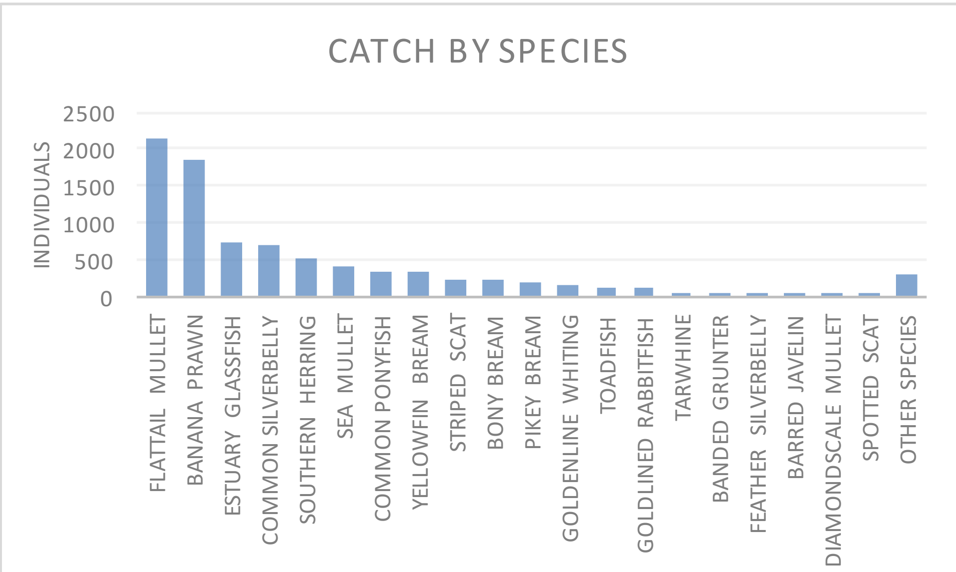

Figure 8: Number of individuals (fish and prawn) recorded across all sites from Dec 2015-Mar 2016

Surveys were undertaken over a 4 month period so that comparisons could be made over time. The mean catch/cast (fish and prawn) ranged from a low of 2.9 in Dec to a high of 5.1 in Mar. From Jan-Mar there was little change in the catch rate. *Figure 9* shows the mean catch rate with bars representing the 95% confidence interval from each month's surveys. A list of all species including scientific names is shown in Appendix 2.

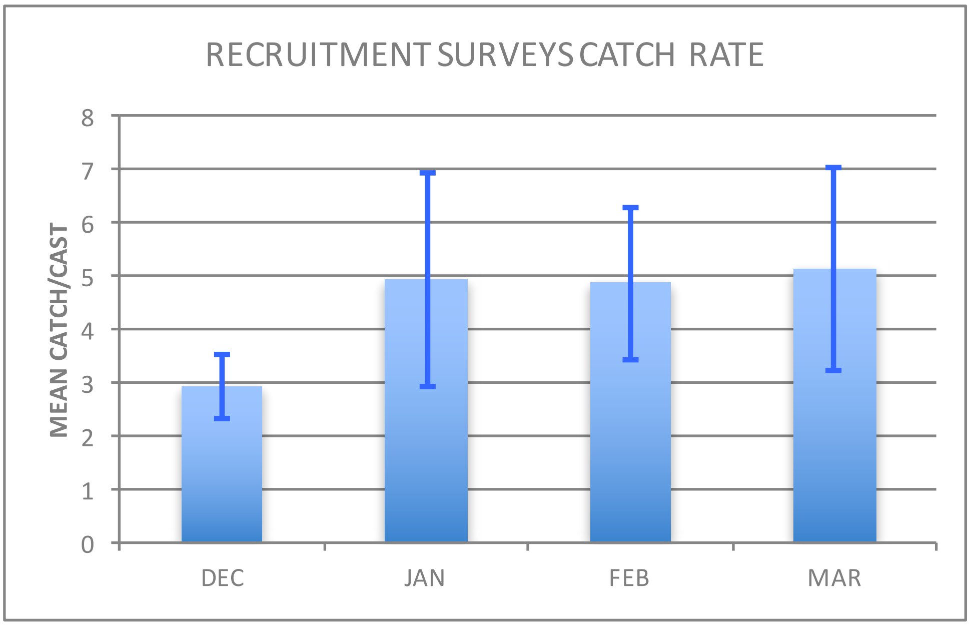

Figure 9: Mean catch rate all sites on monthly surveys from Dec 2015-Mar 2016 (mean with bars showing 95% confidence interval)

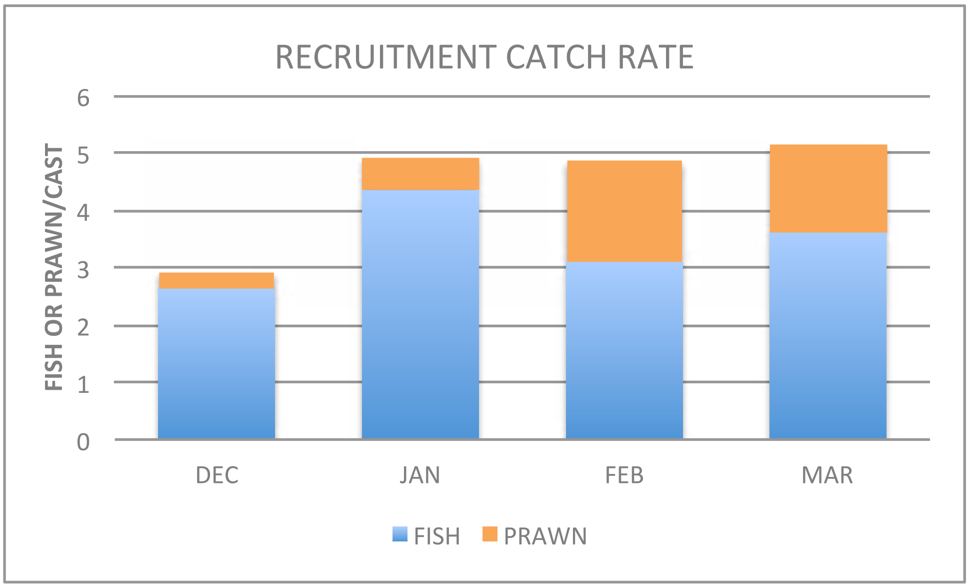

Figure 10: Catch rate for fish and prawn all sites on monthly surveys from Dec 2015-Mar 2016

Figure 10 shows the catch rate for fish and prawn each month while *figure 11* shows the percentage of fish and prawn in the catch each month. Prawn catch rate was highest in Feb as was the percentage of prawn in the catch.

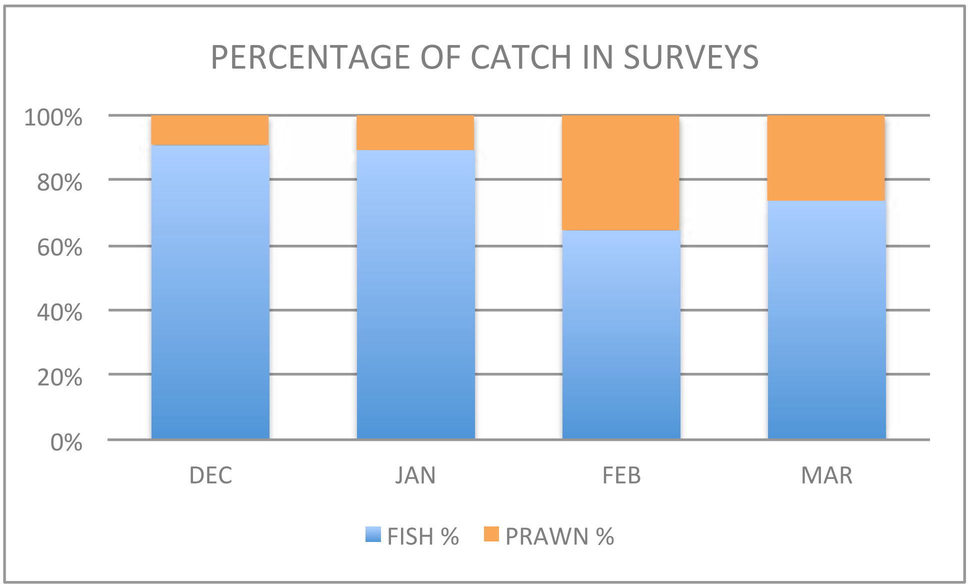

Figure 11: Percentage of fish and prawn in the catch all sites on monthly surveys from Dec 2015-Mar 2016

BREAM

Bream (Yellowfin and Pikey) are the most caught species by recreational fishers in the Gladstone area comprising 20.7% of the catch and 20.3% of the kept catch from 2006-2014 (Sawynok et al 2015) Therefore Bream recruitment is important for maintaining fish stocks.

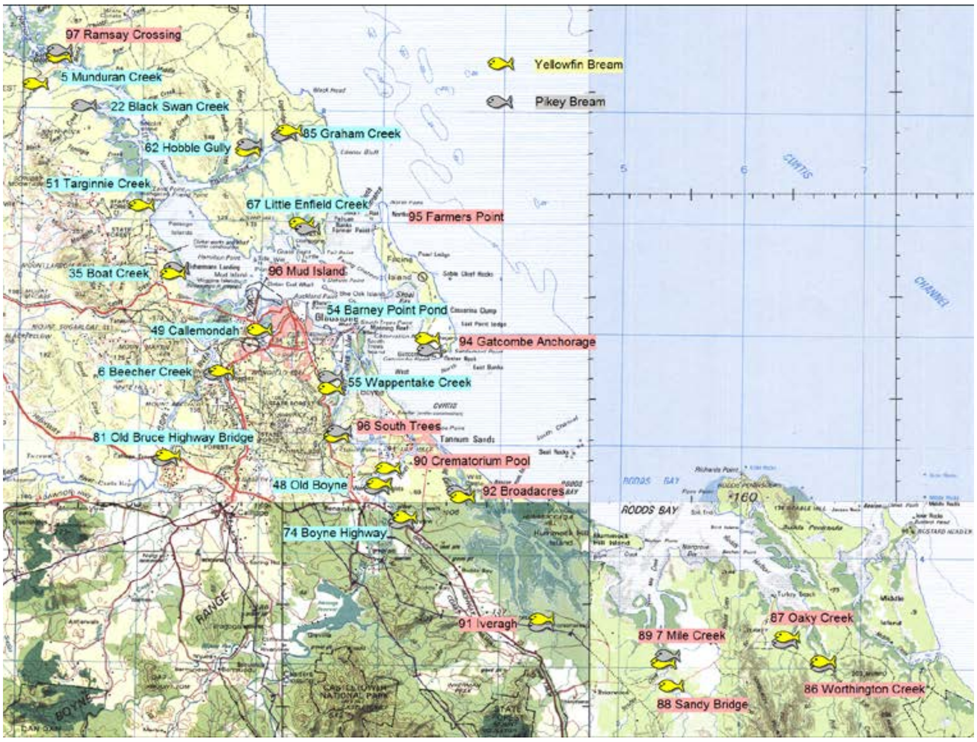

Figure 12: Sites where Yellowfin Bream (yellow) and Pikey Bream (grey) were recorded

Figure 12 shows the sites where Bream were recorded. Yellowfin Bream were recorded at 22 (84.6%) of the 26 sites and in 11 of the 12 sub-regions surveyed as shown in *figure 13*. There were no sites surveyed in sub-region 11 (Outer Harbour) as there was no habitat suitable for juvenile Bream in that sub-region. Pikey Bream were recorded at 19 (73.1%) sites and in 11 of the 12 sub-regions surveyed as shown in *figure 14*. Sub-region 3 (Western Basin) was the only sub-region where neither species of Bream was recorded.

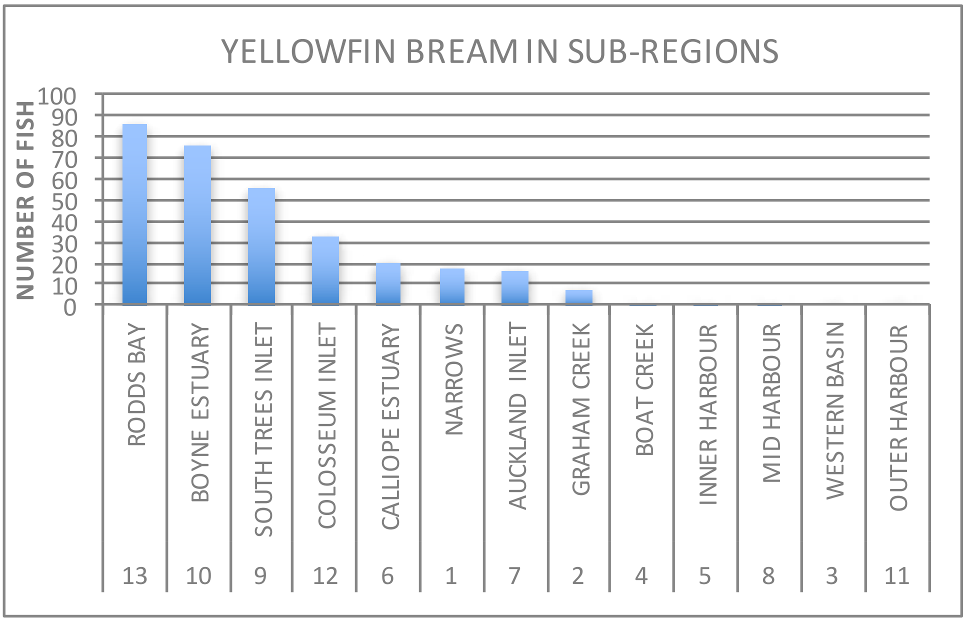

Figure 13: Sub-regions (name and number) where Yellowfin Bream were recorded (Outer Harbour not surveyed)

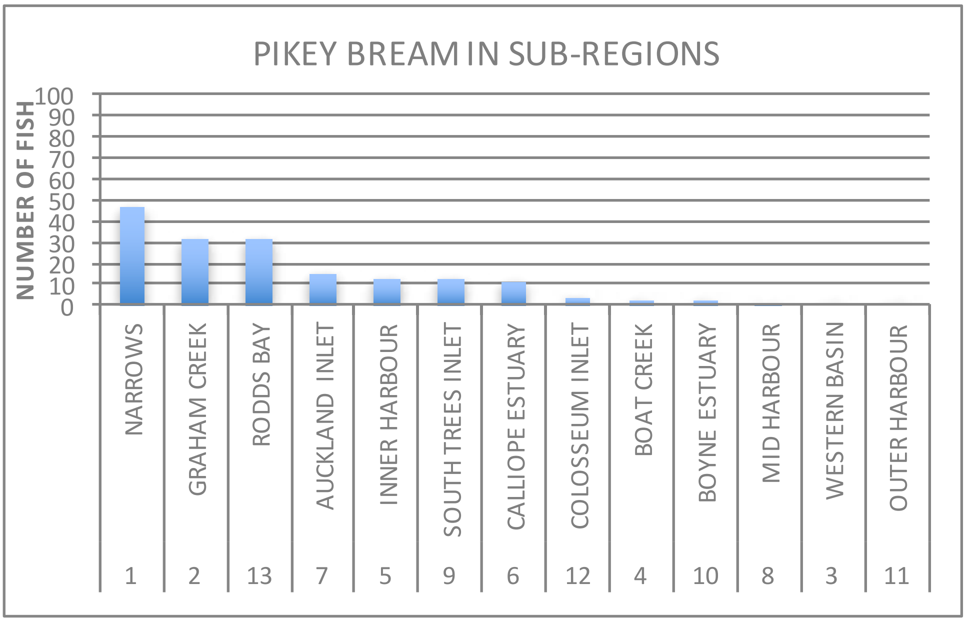

Figure 14: Sub-regions (name and number) where Pikey Bream were recorded (Outer Harbour not surveyed)

There were a total of 325 Yellowfin Bream and 179 Pikey Bream recorded. Over the whole survey period from Dec-Mar the overall catch rate for Yellowfin Bream was 0.16 fish/cast which was double that for Pikey Bream at 0.08 fish/cast as shown in *figure 15*.

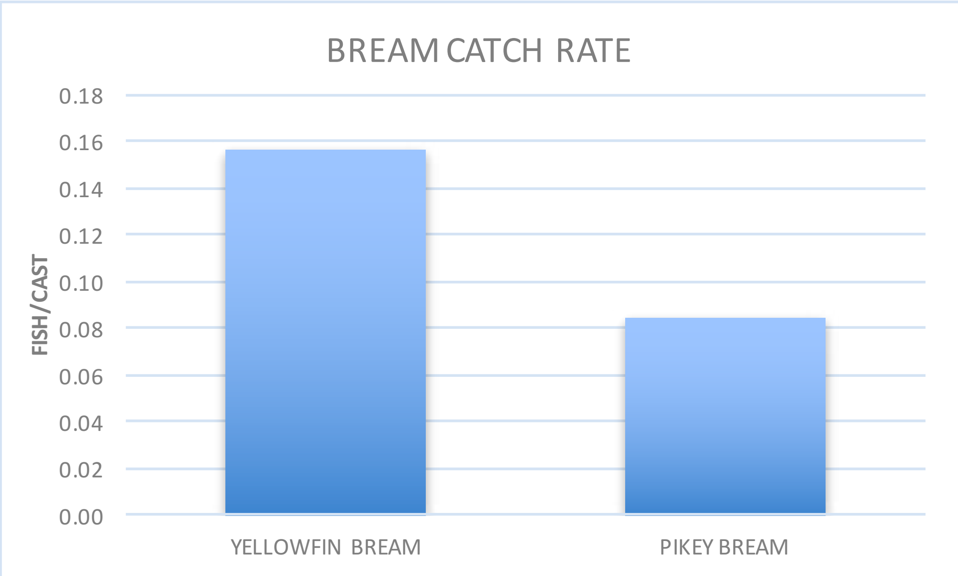

Figure 15: Overall Bream catch rates of Bream from monthly surveys

Figure 16 shows the catch rate, mean +/- 95% confidence interval, for Bream for each of the monthly surveys. Apart from Dec the catch rates for the 2 species were similar.

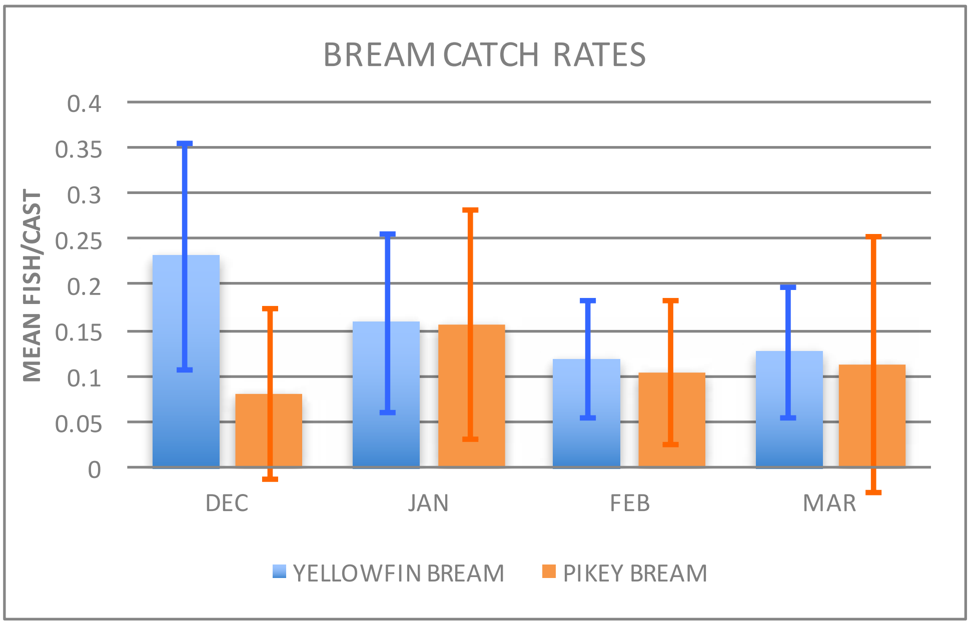

Figure 16: Mean catch rates for Bream from monthly surveys
(mean with bars showing 95% confidence interval)

Figure 17 shows the timeline of the surveys with boxes showing Bream recorded during the monthly surveys. Bream prior to that were recorded during surveys undertaken to identify suitable sites. Surveys were undertaken after full moon and new moon tides as these provided the maximum opportunity for Bream recruits to move to all areas of subject to tidal influence.

Surveys were generally undertaken over a 2 week period to minimise the effect of changes over time. Dates for surveys were:

- 12-24 Dec with one survey delayed to 3/1/2016 due to access difficulties
- 23-28 Jan with 2 surveys delayed to 5/2/2016 due to access difficulties
- 18-28 Feb with 1 survey delayed to 2/3/2016 due to access difficulties
- 13-25 Mar with 1 survey unable to be completed due to access difficulties

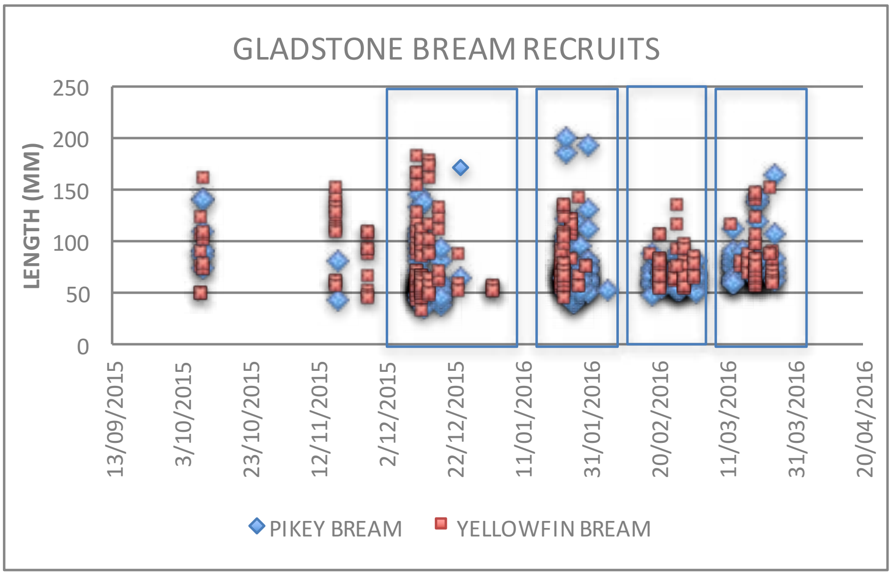

Figure 17: Timelines of Bream recorded during surveys

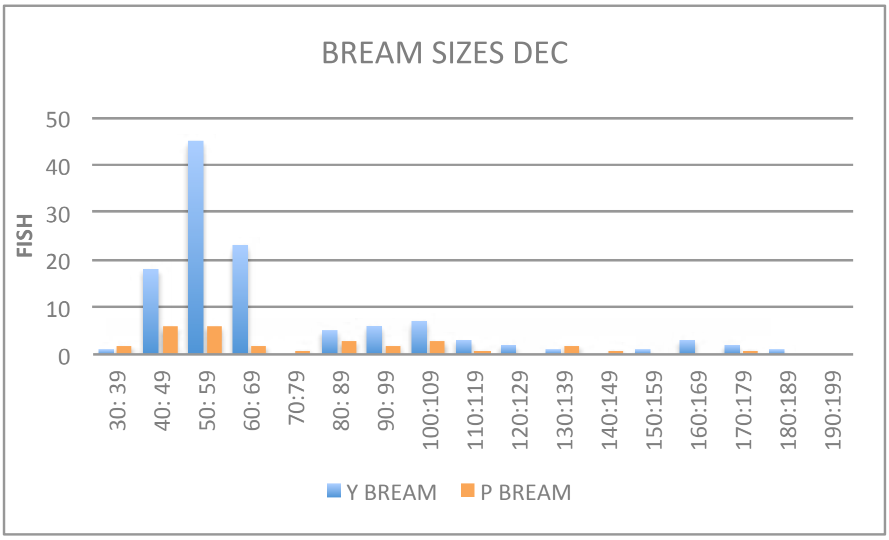

Figure 18: Bream sizes (mm) from Dec 2015 surveys

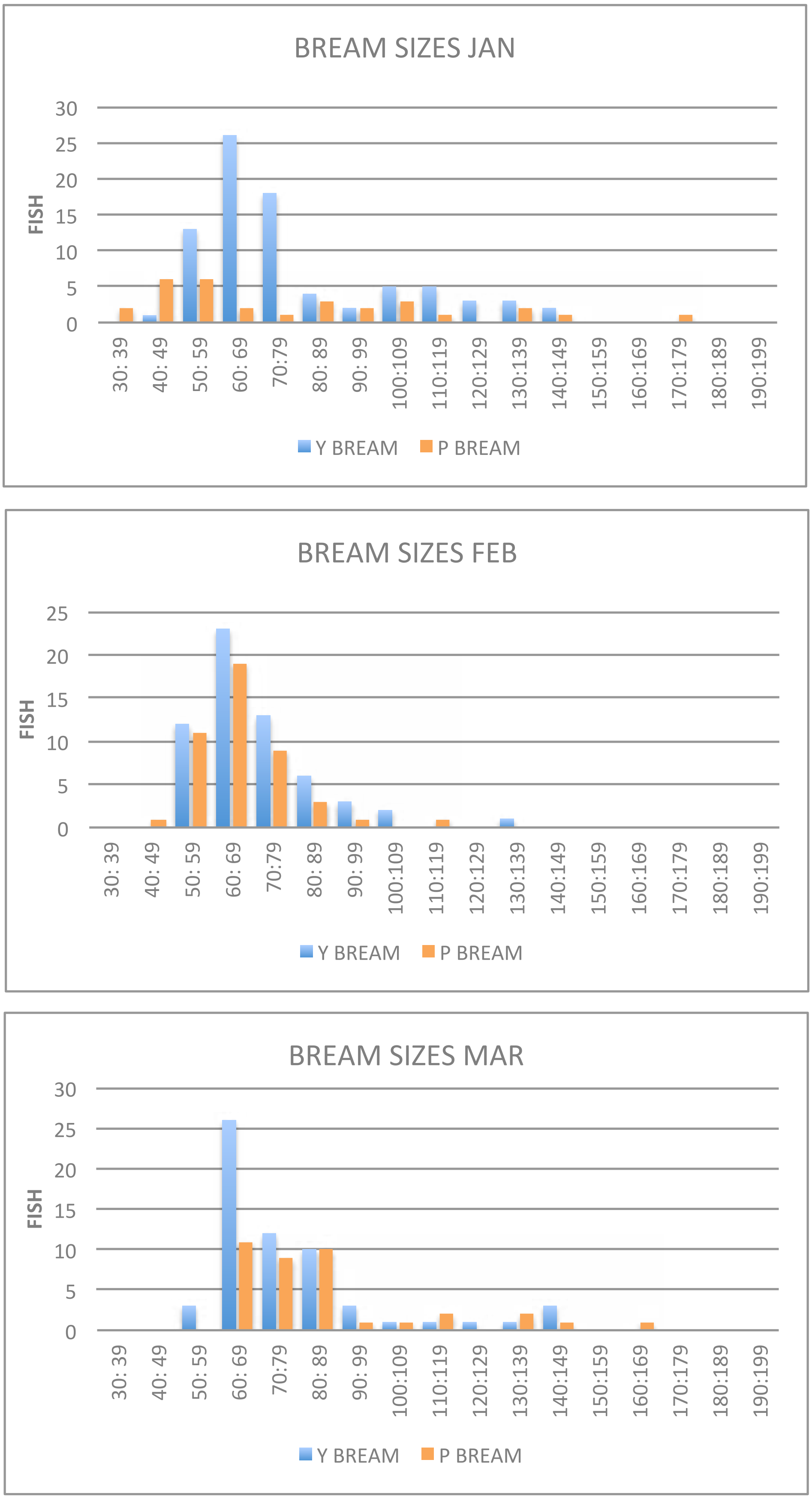

Figure 19: Bream sizes (mm) from Jan-Mar 2016 surveys

Figures 18 and 19 show the sizes of Bream recorded in each of the monthly surveys. The smallest Yellowfin Bream recorded was a fish of 30mm (fork length) on 13/12/2016 at the Crematorium Pool. The smallest Pikey Bream recorded were fish of 35mm on 13/12/2015 at South Trees and 38mm on 18/12/2015 at Ramsay Crossing.

Bream recruits of both species were recorded in the earlier surveys in Oct-Nov in the 40-50mm size range indicating that recruits were already found at survey sites. There were 5 Yellowfin Bream from 40-50mm recorded at 3 locations being South Trees (2 fish), Sandy Bridge (2 fish) and Crematorium Pool (1 fish). There was also 1 Pikey Bream from 40-50mm recorded at Ramsay Crossing.

OTHER SPECIES

There were 11 other species of recreational, commercial, indigenous or conservation importance that were recorded during recruitment surveys as shown in *table 2*. Of those species Flattail Mullet were recorded at all 26 sites, Sea Mullet at 23 sites and Banana Prawn at 18 sites. Flattail Mullet (2,150) and Banana Prawn (1,867) were the most recorded of those species. A complete list of all species is contained in Appendix 2.

Table 2: Other species on recreational, commercial, indigenous or conservation importance

SPECIES	SITES	NUMBER
FLATHEAD - DUSKY	6	10
GROPER - QUEENSLAND	2	3
JAVELIN - BARRED	10	42
JAVELIN - SPECKLED	1	22
MANGROVE JACK	5	8
MULLET – FLATTAIL	26	2150
MULLET – SEA	23	401
PRAWN - BANANA	18	1867
ROCKCOD – GOLDSPOTTED	3	4
WHITING - SAND	1	3
WHITING – GOLDENLINE	13	168

FISH HEALTH

During recruitment surveys fish with any form of health issues were recorded. There were no fish recorded with health issues over the survey period. Also there were no other reports received of dead or sick fish. This is the first year since monitoring of fish health issues in 2011 that no issues were recorded.

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APPENDIX 1 – SURVEY SITES

A summary of sites and site details, as stored in the Infofish 2015 database, along with a more detailed description of the habitat. Details of each site as stored in the database are included in this appendix.

Sub-Region	Site ID	Site Name	Latitude	Longitude	Map	Grid
1	97	RAMSAY CROSSING	-23.641	151.066	CIS	S31
1	5	MUNDURAN CREEK	-23.658	151.048	CISG	Q33
1	22	BLACK SWAN	-23.679	151.089	CISG	V35
1	51	TARGINNIE CREEK	-23.762	151.13	GLD	HZ1
2	62	HOBBLE GULLY	-23.71	151.222	GLD	NZ10
2	85	GRAHAM CREEK	-23.702	151.255	GLD	NZ14
3	96	MUD ISLAND	-23.815	151.22	GLD	BZ10
4	35	BOAT CREEK	-23.814	151.162	GLD	BZ4
5	67	LITTLE ENFIELD CREEK	-23.775	151.266	GLD	FZ15
5	54	BARNEY POINT POND	-23.86	151.275	GLD	D16
6	6	BEECHER CREEK	-23.923	151.207	CR02	I8
6	81	OLD BRUCE HIGHWAY BRIDGE	-23.964	151.154	CR02	P4
7	49	CALLEMONDAH	-23.862	151.232	GLD	D11
8	95	FARMERS POINT	-23.774	151.33	GLD	FZ21
8	94	GATCOMBE ANCHORAGE	-23.876	151.365	GLD	F25
9	55	WAPPENTAKE CREEK	-23.89	151.282	BRG	H16
9	76	SOUTH TREES	-23.951	151.291	BRG	N17
9	90	CREMATORIUM POOL	-23.972	151.334	BRG	Q22
10	48	OLD BOYNE	-23.981	151.33	BRG	R21
10	74	BOYNE HIGHWAY	-24.01	151.338	BRG	U22
11		NO SITES				
12	92	BROADACRES	-23.991	151.392	BRG	S28
12	91	IVERAGH	-24.103	151.46	RBT	H18
13	89	7 MILE CREEK	-24.131	151.561	RBT	R21
13	88	SANDY BRIDGE	-24.15	151.567	RBT	R23
13	87	OAKY CREEK	-24.11	151.663	RBT	AB18
13	86	WORTHINGTON CREEK	-24.135	151.689	RBT	AD21

SITE DETAILS – RAMSAY CROSSING

Site Id:	97
Site Name:	RAMSAY CROSSING
Waterway:	NARROWS
Sub-Region:	1
Map:	CIS
Grid:	S31
Lat:	-23.641
Long:	151.066
Tidal Influence:	Tidal
Depth:	1
Access:	Land
Distance to Mouth:	11
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☑ Rock
Description	ADJACENT TO NORTHERN RAMSAY CROSSING BOAT RAMP/SURVEY AROUND LOW TIDE
Vegetation	MANGROVES
Image:	 Image
Second Image:	 Image

SITE DETAILS – MUNDURAN CREEK

Site Id:	5
Site Name:	MUNDURAN CREEK
Waterway:	MUNDURAN CREEK
Sub-Region:	1
Map:	CISG
Grid:	Q33
Lat:	-23.658
Long:	151.048
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	16
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	POOL AT TOP END OF TIDAL LIMIT OF MUNDURAN CREEK/ACCESS BY NARROWS ROAD
Vegetation	SMALL SCATTERED MANGROVES WITH MIXED FOREST ON BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – BLACK SWAN

Site Id:	22
Site Name:	BLACK SWAN
Waterway:	BLACK SWAN CREEK
Sub-Region:	1
Map:	CISG
Grid:	V35
Lat:	-23.679
Long:	151.089
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Water
Distance to Mouth:	14
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	TIDAL POOL AT TOP END OF BLACK SWAN CREEK
Vegetation	MANGROVES ALONG BANKS AND ON TIDAL FLAT

Image:

Image

Second Image:

Image

SITE DETAILS – TARGINNIE CREEK

Site Id:	51
Site Name:	TARGINNIE CREEK
Waterway:	TARGINNIE CREEK
Sub-Region:	3
Map:	GLD
Grid:	HZ1
Lat:	-23.762
Long:	151.13
Tidal Influence:	Tidal
Depth:	1
Access:	Water
Distance to Mouth:	9
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☐ Rock
Description	TIDAL LIMIT AT TOP END OF TARGINNIE CREEK
Vegetation	LOW MANGROVES WITH EUCALPYT FOREST ON BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – HOBBLE GULLY

Site Id:	62
Site Name:	HOBBLE GULLY
Waterway:	GRAHAM CREEK
Sub-Region:	2
Map:	GLD
Grid:	NZ10
Lat:	-23.71
Long:	151.222
Tidal Influence:	Tidal
Depth:	1
Access:	Water
Distance to Mouth:	8
Substrate:	☐ Sand ☑ Mud ☐ Gravel ☑ Rock
Description	TIDAL REACH OF HOBBLE GULLY BELOW ROCK HOLE
Vegetation	MANGROVES ALONG BANK

Image:

Image

Second Image:

Image

SITE DETAILS – GRAHAM CREEK

Site Id:	85
Site Name:	GRAHAM CREEK
Waterway:	GRAHAM CREEK
Sub-Region:	2
Map:	GLD
Grid:	NZ14
Lat:	-23.702
Long:	151.255
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	10
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☐ Rock
Description	TOP END OF GRAHAM CREEK AT TIDAL LIMIT
Vegetation	SCATTERED MANGROVES WITH EUCALYPT FOREST ON BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – MUD ISLAND

Site Id:	96
Site Name:	MUD ISLAND
Waterway:	GLADSTONE HARBOUR
Sub-Region:	3
Map:	GLD
Grid:	BZ10
Lat:	-23.815
Long:	151.22
Tidal Influence:	Tidal
Depth:	2
Access:	Water
Distance to Mouth:	0
Substrate:	☑ Sand ☑ Mud ☑ Gravel ☐ Rock
Description	TIDAL GUTTERS ON WESTERN SIDE OF MUD ISLAND
Vegetation	NIL
Image:	 Image
Second Image:	 Image

SITE DETAILS – BOAT CREEK

Site Id:	35
Site Name:	BOAT CREEK
Waterway:	BOAT CREEK
Sub-Region:	4
Map:	GLD
Grid:	BZ4
Lat:	-23.814
Long:	151.162
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	4
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	Top end of tidal limit in Boat Creek above railway line and near overhead conveyor
Vegetation	SPARSE MANGROVE WITH EUCALYPTS BACK FROM CREEK
Image:	 Image
Second Image:	 Image

SITE DETAILS – LITTLE ENFIELD CREEK

Site Id:	67
Site Name:	LITTLE ENFIELD CREEK
Waterway:	ENFIELD CREEK
Sub-Region:	5
Map:	GLD
Grid:	FZ15
Lat:	-23.775
Long:	151.266
Tidal Influence:	Tidal
Depth:	1
Access:	Water
Distance to Mouth:	1
Substrate:	☐ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	DRAINS IN LITTLE ENFIELD CREEK/SURVEY AT LOW TIDE
Vegetation	DENSE MANGROVES ALONG BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – BARNEY POINT POND

Site Id:	54
Site Name:	BARNEY POINT
Waterway:	GLADSTONE HARBOUR
Sub-Region:	6
Map:	GLD
Grid:	D16
Lat:	-23.86
Long:	151.275
Tidal Influence:	Intermittent Tidal
Depth:	2
Access:	Land
Distance to Mouth:	1
Substrate:	☐ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	TIDAL POOL AT THE END OF TIDAL FLAT AT BARNEY POINT
Vegetation	SPARSE LOW SCATTERED MANGROVES

Image:

Image

Second Image:

Image

SITE DETAILS – BEECHER CREEK

Site Id:	6
Site Name:	BEECHER CREEK
Waterway:	CALLIOPE RIVER
Sub-Region:	6
Map:	CR02
Grid:	I8
Lat:	-23.923
Long:	151.207
Tidal Influence:	Intermittent Tidal
Depth:	2
Access:	Land
Distance to Mouth:	15
Substrate:	☑ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	POOLS AT TIDAL LIMIT OF BEECHER CREEK ABOVE AND BELOW CAUSEWAY/ACCESS BY JEFFERIS ROAD OFF DAWSON HIGHWAY
Vegetation	SPARSE MANGROVES AND EUCALYPT FOREST ALONG BANKS

Image:

Image

Second Image:

Image

SITE DETAILS – OLD BRUCE HIGHWAY BRIDGE

Site Id:	81
Site Name:	OLD BRUCE HIGHWAY BRIDGE
Waterway:	CALLIOPE RIVER
Sub-Region:	6
Map:	CR02
Grid:	P4
Lat:	-23.964
Long:	151.154
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	22
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	Below old Bruce Highway bridge on Calliope River
Vegetation	
Image:	 Image
Second Image:	 Image

SITE DETAILS – CALLEMONDAH

Site Id:	49
Site Name:	CALLEMONDAH
Waterway:	AUCKLAND INLET
Sub-Region:	7
Map:	GLD
Grid:	D11
Lat:	-23.862
Long:	151.232
Tidal Influence:	Tidal
Depth:	2
Access:	Land
Distance to Mouth:	5
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☑ Rock
Description	TIDAL POOL BELOW CALLEMONDAH DAM WALL/ACCESS FROM BLAIN DRIVE
Vegetation	SPARSE MANGROVES
Image:	 Image
Second Image:	 Image

SITE DETAILS – FARMERS POINT

Site Id:	95
Site Name:	FARMERS POINT
Waterway:	FACING ISLAND
Sub-Region:	8
Map:	GLD
Grid:	FZ21
Lat:	-23.774
Long:	151.33
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Water
Distance to Mouth:	0
Substrate:	☑ Sand ☐ Mud ☐ Gravel ☐ Rock
Description	SMALL TIDAL CREEK POOLS NORTH OF FARMERS POINT ON FACING ISLAND
Vegetation	SPARSE MANGROVES WITH CASUARINAS ON SAND DUNES

Image:

Image

Second Image:

Image

SITE DETAILS – GATCOMBE ANCHORAGE

Site Id:	94
Site Name:	GATCOMBE ANCHORAGE
Waterway:	FACING ISLAND
Sub-Region:	8
Map:	GLD
Grid:	F25
Lat:	-23.876
Long:	151.365
Tidal Influence:	Tidal
Depth:	2
Access:	Water
Distance to Mouth:	0
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☑ Rock
Description	SMALL ANCHORAGE AT GATCOMBE HEAD ON FACING ISLAND
Vegetation	SPARSE SMALL MANGROVES

Image:

Image

Second Image:

Image

SITE DETAILS – WAPPENTAKE CREEK

Site Id:	55
Site Name:	WAPPENTAKE CREEK
Waterway:	SOUTH TREES INLET
Sub-Region:	9
Map:	BRG
Grid:	H16
Lat:	-23.89
Long:	151.282
Tidal Influence:	Intermittent Tidal
Depth:	2
Access:	Land
Distance to Mouth:	6
Substrate:	☑ Sand ☑ Mud ☑ Gravel ☐ Rock
Description	POOLS AT TIDAL LIMIT AT TOP END OF WAPPENTAKE CREEK
Vegetation	SPARSE MANGROVE WITH EUCALYPT FOREST ALONG BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – SOUTH TREES

Site Id:	98
Site Name:	SOUTH TREES
Waterway:	SOUTH TREES INLET
Sub-Region:	9
Map:	BRG
Grid:	N17
Lat:	-23.951
Long:	151.291
Tidal Influence:	Tidal
Depth:	1
Access:	Land
Distance to Mouth:	11
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☑ Rock
Description	ROCKY SECTION OF SIDE ARM OF SOUTH TREES INLET TO EAST OF GLADSTONE - BENARABY ROAD
Vegetation	LIGHT MANGROVES WITH EUCALYPT FOREST BACK FROM BANKS
Image:	 Image
Second Image:	 Image

SITE DETAILS – CREMATORIUM POOL

Site Id:	90
Site Name:	CREMATORIUM POOL
Waterway:	SOUTH TREES INLET
Sub-Region:	9
Map:	BRG
Grid:	Q22
Lat:	-23.972
Long:	151.334
Tidal Influence:	Tidal
Depth:	1
Access:	Land
Distance to Mouth:	7
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	TIDAL POOL NEAR BOYNE ISLAND CREMATORIUM/ACCESS VIA PIONEER DRIVE OFF BOYNE ISLAND ROAD
Vegetation	MANGROVES BELOW TRACK CROSSING WITH SPARSE MANGROVES AROUND POOL
Image:	 Image
Second Image:	 Image

SITE DETAILS – OLD BOYNE

Site Id:	48
Site Name:	OLD BOYNE
Waterway:	BOYNE RIVER
Sub-Region:	10
Map:	BRG
Grid:	R21
Lat:	-23.981
Long:	151.33
Tidal Influence:	Intermittent Tidal
Depth:	2
Access:	Water
Distance to Mouth:	7
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	TIDAL POOLS AT LOWER END ON OLD BOYNE RIVER CHANNEL
Vegetation	LIMITED VEGETATION WITH MOSTLY SPARSE MANGROVES
Image:	 Image
Second Image:	 Image

SITE DETAILS – BOYNE HIGHWAY

Site Id:	74
Site Name:	BOYNE HIGHWAY
Waterway:	BOYNE RIVER
Sub-Region:	10
Map:	BRG
Grid:	U22
Lat:	-24.01
Long:	151.338
Tidal Influence:	Tidal
Depth:	1
Access:	Land
Distance to Mouth:	13
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☐ Rock
Description	BOYNE RIVER AT BRUCE HIGHWAY BRIDGE AT BENARABY/SURVEY AT LOW TIDE
Vegetation	SPARSE MANGROVES WITH EUCALPYT FOREST ALONG BANKS
Image:	 Image
Second Image:	 Image

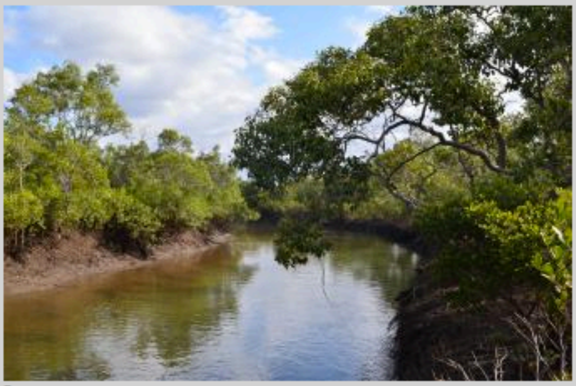
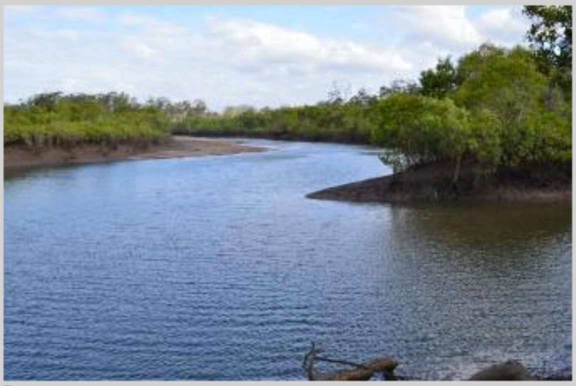
SITE DETAILS – BROADACRES

Site Id:	92
Site Name:	BROADACRES
Waterway:	WILD CATTLE CREEK
Sub-Region:	12
Map:	BRG
Grid:	S28
Lat:	-23.991
Long:	151.392
Tidal Influence:	Tidal
Depth:	2
Access:	Land
Distance to Mouth:	6
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☑ Rock
Description	AT BROADACRES LAUNCH SITE/ACCESSED FROM YACHT ROAD OFF BROADACRES ROAD/SURVEY AROUND LOW TIDE
Vegetation	MANGROVES ALONG BANKS BUT CLEARED AREA AROUND LAUNCH SITE
Image:	 Image
Second Image:	 Image

SITE DETAILS – IVERAGH

Site Id:	91
Site Name:	IVERAGH
Waterway:	12 MILE CREEK
Sub-Region:	12
Map:	RBT
Grid:	H18
Lat:	-24.103
Long:	151.46
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	14
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	SIDE ARM OF 12 MILE CREEK UNDER POWER LINE/ACCESSED THROUGH CHRISTIE'S PRIVATE PROPERTY
Vegetation	LOW MANGROVES ALONG BANKS AND SALT FLATS
Image:	 Image
Second Image:	 Image

SITE DETAILS – 7 MILE CREEK

Site Id:	89
Site Name:	7 MILE
Waterway:	7 MILE CREEK
Sub-Region:	13
Map:	RBT
Grid:	R21
Lat:	-24.131
Long:	151.561
Tidal Influence:	Tidal
Depth:	2
Access:	Land
Distance to Mouth:	6
Substrate:	☑ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	SCRUBBY CREEK AT JUNCTION WITH SANDY CREEK NEAR 7 MILE BOAT RAMP/ACCESSED BY DYCKHOFFS ROAD OFF TURKEY BEACH ROAD/SURVEY AT LOW TIDE
Vegetation	MANGROVES ALONG BANK AND MUD FLATS WITH ADJACENT EUCALYPT FOREST
Image:	 Image
Second Image:	 Image

SITE DETAILS – SANDY BRIDGE

Site Id:	88
Site Name:	SANDY BRIDGE
Waterway:	SANDY CREEK
Sub-Region:	13
Map:	RBT
Grid:	R23
Lat:	-24.15
Long:	151.567
Tidal Influence:	Intermittent Tidal
Depth:	1
Access:	Land
Distance to Mouth:	9
Substrate:	☑ Sand ☐ Mud ☑ Gravel ☐ Rock
Description	POOLS ABOVE AND BELOW ROAD BRIDGE ON TURKEY BEACH ROAD/THIS IS THE SAME LOCATION AS SITE 7 BUT WITH THE REMOVAL OF CAUSEWAY HAS BEEN SIGNIFICANTLY
Vegetation	EUCALYPT FOREST ALONG BOTH BANKS WITH VERY FEW MANGROVES
Image:	 Image
Second Image:	 Image

SITE DETAILS – OAKY CREEK

Site Id:	87
Site Name:	OAKY
Waterway:	OAKY CREEK
Sub-Region:	13
Map:	RBT
Grid:	AB18
Lat:	-24.11
Long:	151.663
Tidal Influence:	Intermittent Tidal
Depth:	2
Access:	Land
Distance to Mouth:	3
Substrate:	☐ Sand ☑ Mud ☑ Gravel ☐ Rock
Description	Pools below upper junction on Oaky Creek
Vegetation	EUCALYPT AND WATTLE ALONG BANKS WITH VERY FEW MANGROVES
Image:	 Image
Second Image:	 Image

SITE DETAILS – OAKY CREEK

Site Id:	86
Site Name:	WORTHINGTON
Waterway:	WORTHINGTON CREEK
Sub-Region:	13
Map:	RBT
Grid:	AD21
Lat:	-24.135
Long:	151.689
Tidal Influence:	Tidal
Depth:	1
Access:	Land
Distance to Mouth:	1
Substrate:	☐ Sand ☐ Mud ☑ Gravel ☑ Rock
Description	Pools below and above road crossing on Worthington Creek
Vegetation	EUCALYPT FOREST ALONG BOTH BANKS WITH FEW MANGROVES
Image:	 Image
Second Image:	 Image

APPENDIX 2 - SPECIES

List of species recorded using standard name, scientific name, number of sites, and number of fish recorded in surveys from Dec-Mar. Species with a question mark are those where the identification was uncertain.

STANDARD NAME	SCIENTIFIC NAME	SITES	NUMBER
ANCHOVY - AUSTRALIAN	*Engraulis australis*	4	21
BARRAMUNDI	*Lates calcarifer*	2	4
BARRACUDA – PICKHANDLE	*Sphyraena jello*	1	1
BARRACUDA – STRIPED	*Sphyraena obtusata*	2	2
BREAM - BONY	*Nematalosa erebi*	17	221
BREAM - PIKEY	*Acanthopagrus berda*	19	179
BREAM - YELLOWFIN	*Acanthopagrus australis*	22	325
BULLROUT	*Notesthes robusta*	1	1
CATFISH – BLUE	*Arius graffei*	2	8
CRAB – MUD	*Scylla serrata*	4	6
CRAB – SAND	*Portunus pelagicus*	3	3
DIAMONDFISH	*Monodactylus argenteus*	11	27
EEL – LONGFIN	*Anguilla reinhardti*	1	1
FLATHEAD - DUSKY	*Platycephalus fuscus*	6	9
FLATHEAD – BARTAIL	*Platycephalus indicus*	1	2
FLOUNDER – LARGETOOTH	*Pseudorhombus arsius*	1	1
GARFISH - SNUBNOSE	*Arrhamphus sclerolepis*	5	17
GARFISH – RIVER	*Hyporhamphus regularis*	2	5
GLASSFISH -ESTUARY	*Ambassis marianus*	21	723
GOBY – GREENSPOTTED	*Acentrogobius viridipunctatus*	2	2
GROPER – QUEENSLAND	*Epinephelus lanceolatus*	2	3
GRUNTER - BARRED	*Amniataba percoides*	5	20
GRUNTER - CRESCENT	*Therapon jarbua*	11	78
GUDGEON – SPANGLED	*Ophiocara porocephala*	1	1
GUDGEON SPP (?)	*Hypseleotris spp*	1	1
HERRING - SOUTHERN	*Herklotsichthys castelnaui*	16	517
HERRING – GIANT	*Elops machnata*	2	2
JAVELIN - BARRED	*Pomadasys kaakan*	10	42
JAVELIN - SPECKLED	*Pomadasys argenteus*	1	22
MACKEREL – GREY	*Scomberomorus semifasciatus*	1	1
MANGROVE JACK	*Lutjanus argentimaculatus*	5	8
MILKFISH	*Chanos chanos*	3	4
MULLET – DIAMONDSCALE	*Liza vaigiensis*	2	36
MULLET - FLATTAIL	*Liza dussumieri*	26	2150
MULLET – GOLDSPOT	*Liza argentea*	3	18
MULLET - SEA	*Mugil cephalus*	23	401

MULLET – SAND	*Valamugil seheli*	3	13
MULLET SPP (?)		2	19
PERCH - SPANGLED	*Leiopotherapon unicolor*	4	5
PONYFISH - COMMON	*Leiognathus equulus*	19	350
PRAWN - BANANA	*Fenneropenaeus indicus*	18	1867
PRAWN – GREASYBACK (?)	*Metapenaeus bennettae*	1	2
PRAWN SPP (?)		1	1
PRAWN – TIGER (?)		2	3
QUEENFISH - GIANT	*Scomberoides commersonnianus*	1	1
RABBITFISH - GOLDLINED	*Siganus lineatus*	15	121
RAINBOWFISH - EASTERN	*Melanotoenia splendida*	1	1
ROCKCOD – BLACKSPOTTED	*Epinephalus malabaricus*	3	3
ROCKCOD – GOLDSPOTTED	*Epinephalus coioides*	3	4
SCAT - SPOTTED	*Scatophagus argus*	4	36
SCAT - STRIPED	*Selenotoca multifasciata*	10	222
SHRIMP – FRESHWATER (?)	*Macrobrachium spp*	2	4
SILVERBIDDY - COMMON	*Gerres subfasciatus*	23	683
SILVERBIDDY - THREADFIN	*Gerres filamentosus*	5	45
SNAPPER - MOSES	*Lutjanus russellii*	11	29
SOLE SPP (?)		1	1
STEELBACK	*Leptobrama mulleri*	1	1
TARWHINE	*Rhabdosargus sarba*	6	65
TOADFISH - COMMON	*Tetractenos hamiltoni*	12	139
TREVALLY – GIANT	*Caranx ignobilis*	1	1
TREVALLY – BIGEYE	*Caranx sexfasciatus*	1	3
TREVALLY SPP (?)		1	2
TUSKFISH – BLACKSPOT	*Choerodon schoenleinii*	1	1
WHITING – GOLDENLINE	*Sillago analis*	13	168
WHITING – NORTHERN	*Sillago sihama*	7	13
WHITING - SAND	*Sillago ciliata*	1	3
WHITING SPP (?)	*Sillago spp*	1	1
ZEBRAFISH (?)		1	4

Part II:
A Fish Health Index Based on Bream Species Recruitment

Non-technical summary

This second part of the report describes in detail the process by which the data from the cast net survey is used to construct a Bream Recruitment Index. The term "recruitment" in this context means the annual production of juvenile fish entering the mature fish population. The resulting index is intended to be used to monitor a key aspect of the fish health of Gladstone Harbour, namely the reproductive vigour and spatial extent of the two principal Bream species, namely Pikey Bream, (*Acanthopagrus berda*) and Yellowfin Bream (*A. australis*).

The data used for the index comes from the systematic cast net surveys of the region described in detail in Part I. In addition, we use some previously collected data from some of the same sites for the years 2011–2015. This is necessary to provide a context in which to view any one season.

The strategy for constructing an index is to build a statistical model that explains variations in the catch per trip to a site, typically 20 casts, and to use it to assess *proportional* changes in catch rate between seasons, relative to a notional baseline.

We justify a somewhat formal statistical modelling approach on a number of grounds. These include the sporadic and unbalanced nature of the sampling prior to current season and the character of the response itself, which is a count variable concentrated on low values, very often zero. To allow properly for these features and produce a level playing field on which to make robust and justifiable comparisons, a careful modelling approach is necessary. Simplistic computations in this case are likely to be misleading, or at least very inefficient.

The modelling approach not only provides estimates for the scores appropriate for the assessment, but it also provides a data-based suggestion for how they may be objectively rated on the required $(0, 1)$ scale.

At this stage, a summary score for the whole of the harbour looks to be reasonably possible, and the report provides the details. Extending this to reports at the Zone level is, at this stage, much more problematical. However the report does offer an extension of the modelling approach that nominally covers this case, though the results at this stage are much more tentative at the Zone level. With the acquisition of more data in future seasons this issue should eventually resolve itself.

The report concludes with a discussion of the results, recommendations for further work and an explanation of the logic and praxis of the modelling approach in simple and intuitive terms.

Contents

1 Introduction

1.1 Background

The final report for the project,

- *Developing a Fish Recruitment Indicator for the Gladstone Harbour Report Card using Data Derived from Castnet Sampling* by Bill Sawynok and Bill Venables, July, 2016, has detailed the conduct and results of the project in considerable detail. This is the definitive document and the reader is referred to it for all points of detail.

The present document is an addendum to the final report outlining a proposal for an explicit Fish Recruitment Index based on these survey results and similar annual partial surveys beginning in late 2011.

Prior to the current document the present author has distributed for comment three working papers, namely

- *Initial Notes on the Bream Recruitment Survey Data*, 6 June, 2016,
- *Supplementary Notes on the Extended Bream Recruitment Survey Data*, 15 July 2016 and
- *Possibilities for the Development of Bream Recruitment Fish Health Indices*, 19 July, 2016

The latter in particular attracted some useful comments and queries from he ISP, and the author responded to the issues raised in a further short document entitled:

- *Fish Indicator Project: Responses to the ISP comments*, 6 August, 2016

All these documents are now part of the ISP record and any confidentiality restricted tentatively placed on them are no longer in force.

The present document will be written on the assumption that these previous papers are available for reference. Their content will largely be assumed.

1.2 Scope

The structure of this document is as follows:

- The next section discusses the modelling approach we advocate in context,
- The section following will present the results if the proposed approach is adopted.
- A final section will offer a reasonably non-technical rationale for why a modelling approach is needed and what are the costs and benefits.

2 Surveys, data and model

The main features of the ultimate model adopted were detailed in the second working paper cited above. A synopsis is as follows:

2.1 Response, predictors and sampling

- The purpose-designed survey for the 2015-16 season consisted of four visits to each of 26 sampling sites, covering the four months December 2015 to March 2016. The sites were located in 12 of the 13 sub-regions of the GHHP study, with one region not having any suitable sampling sites available.

In addition, historical data, covering the years 2011 to 2015 but not specifically designed for the present purpose, were also used. These data are much more sporadic than the systematic coverage achieved in the present season.

A key map of the sampling sites is given in Appendix A on page 17.

- The response forming the focus of the model is chosen to be the *Total Bream Catch Count per Visit*, that is, Pikey Bream plus Yellowfin Bream. A careful initial analysis of the data showed that the two individual species were only partially overlapping in their distribution, and the total bream count was therefore simpler to capture in a model, while still providing a viable basis for building a recruitment health index.

- **Sizes**. For both species the size of animals was measured in the standard way by *fork length*. For both species an indicative range for year 0 recruits was **0–100 mm**, but this range was *not* strictly enforced when choosing data for the analysis.

  The study was confined to times and locations, and used gear that would focus the bream catch on juveniles. The majority of the catch did conform to the notional 0–100 mm indicative range, but some were longer than this, possibly indicating year 1 recruits rather than year 0, but were certainly still sub-adult fish. We made a decision not to exclude any data as we considered it better to include the few larger juveniles rather than to exclude them as if no bream had been caught at all. The purpose of the study was not to produce a recruitment index such as might be needed for a stock assessment but rather to produce a fish health index for inclusion in the report card.

  A summary of the fork length profiles of fish included in the study is given in Appendix B on page 18.

- We define a *Season* to be a 12 month time interval beginning at the start of the month October. The season is divided into *Period*s of calendar months, except that October-November are combined into one, which we label *Pre*, and May-September into another single category which we term *Post*.

  Season will be modelled as a random effect and *Period* as a fixed temporal effect.

- In addition there are environmental variables that will be considered as fixed effect predictors, partially explaining site differences. These are the sediment variables *Sand*, *Mud*, *Gravel* and *Rock*, the position variable *TidalInfluence* and the descriptor, *Depth*. *Note that all of these environmental variables are **binary** and hence most are inevitably measured rather imprecisely.*

- The fixed effect spatial predictors are not sufficient to explain differences between sampling sites. Hence we use a random effect term, *Location*, to allow for otherwise unexplained site differences.

- We also use a variable *SubRegion* which is a super-category of location, grouping sites within each of the reporting zones. Since reporting is needed on a zonal basis, the model will also include a random spatio-temporal interaction term between *Season* and *SubRegaion*. (Note that one of the reporting zones, *Outer Harbour*, has no suitable monitoring sites for Bream recruits and hence must remain outside the assessment.)

- The sampling effort in a standard visit to a site was 20 casts, carefully spaced and consistently conducted. Over 90% of visits did use the standard 20 casts, though some could only manage 10.

  The number of *Casts* is not a direct predictor, but will be used as an offset term in the analysis (as it happens, in the log scale) to accommodate the few site visits where the number of casts differed from the standard 20.

2.2 The model

The model we use is a Negative Binomial model, with log link, which will include both fixed and random effects. This is a standard model family for discrete response variables over-dispersed with respect to the Poisson model. An initial investigation established conclusively that the simpler Poisson model is not adequate for the present response.

2.2.1 Estimation with fixed θ parameter

This model has a parameter, θ, controlling effectively the degree to which the parent distribution diverges from Poisson behaviour. Exploration of the data shows that for any reasonable model the estimate of this parameter is close to $\hat{\theta} \approx 2$. Moreover if θ deviates from this value by small amounts in either direction, the effect on the outputs of interest is negligible. For this reason we have decided to hold the value of the parameter fixed at $\theta = 2$ and remove it from the estimation process. This does not effect the material outputs, but greatly reduces the time needed to fit the models, as well as enhancing the numerical stability of the iterative computations needed.

These were fitted using the `lme4` package in ***R***. The initial explorations were done using the `glmm.nb` function which allows for the estimation of θ. For fixed $\theta = 2$ the `glmer` function was used with the `negative.binomial` family function.

The initial results were confirmed using the `glmmADMB` package, which fits generalized linear mixed models using a different computational approach.

2.2.2 Model fitting and refinement

Several variant models were considered. The complete model was fitted initially, and a simple backward elimination with minimizing AIC as the criterion was used to reduce the fixed effect terms of the model to as few as could be justified.

Standard errors for the random effects were computed using the `arm` package in ***R***.

2.3 Inference strategy

The key terms in the model are the random main effect terms for *Season*, and the random interaction term, *Season* × *SubRegion*.

- The predictions, or BLUPs, for the main effects for the five seasons in the data record to date offer a simple and direct overall comparison, season to season.
- The BLUP for the random interaction term indicates the extent to which each Zone deviates from the main effect BLUP for that season, so adding the main effect to the interaction will be used to provide a per Zone indicator of change, season to season.

As the model has a log-link the BLUPs represent additive changes on the log scale from year to year. Hence the exponential of the BLUPs, which takes the result back to the natural scale of mean catch rate, will represent *proportional* changes from year to year. We present the result on this natural scale for ease of interpretation.

We will call these exponentials of the BLUPs the seasonal *multipliers*. Thus a seasonal multiplier of 1 represents *the baseline level* against which all relative seasonal changes are reckoned. Multipliers greater than 1 represent seasons with a greater-than-baseline overall catch rate, and conversely those with values less than 1 seasons with lower-than-baseline catch rates.

Advantages of random effects

- One advantage of using a random effect term to estimate seasonal variations is that the estimation process leading to the BLUPs is somewhat protected against the extremes. The years are viewed as coming from a single, possibly hypothetical population of potential BLUP values and in this way each seasonal estimate is able to "borrow strength" from its neighbours.
- A second advantage of this approach is that it allows the data to indicate what the potential population of BLUPs might look like. Thus not only do we get a relative ranking of the seasons, but we get some indication of where each season may sit relative to the whole potential population.

This second advantage is for our purposes the most crucial. It uses the estimate of *variance components* associated with each random effect, which in turn determine the population distribution. In turn, this allows us to assign a *score* on a $(0, 1)$ scale to the season in a fully natural way, that fulfills the requirements of a health index. The score is the probability level for which the BLUP is a quantile: that is, it is the estimated probability of a season receiving a value less than or equal to that for the season in question.

3 Results

3.1 The primary working model

The primary model is as described above, with spatial fixed effects for the depth and sediment type variables, a fixed temporal effect for the period of the season, and additive random effects for *Location* and *Season*, as well as a random *Season* × *SubRegion* interaction.

Fitting the model showed that capacity of the spatial and temporal fixed effects to explain differences is weak. This may be due to the fact that the spatial predictors are inevitably rather crude measures of their related properties and are given only as a binary variable. It may also be due to the circumstance that prior to the current season, 15-16, site visits were sporadic and nowhere near as thorough and comprehensive as for the 15-16 season, resulting in a realized design that is very unbalanced.

Nevertheless if the indicators we suggest here are adopted, the prior seasons are crucial to the process. They will remain so in future years, although with more data and more comprehensive coverage of the sites the imbalance of the realized design will become less, and hence less of an issue.

The working model after refinement contained just three fixed effect terms, namely[1]

- The term for *Period* (with 6 d.f.) and
- The terms for *Depth* and *Rock* (each with 1 d.f.).

While the inclusion of these terms could be justified by AIC, the case on a purely significance basis could be challenged. Including *Period* could be justified on intuitive grounds as well, as reflecting the seasonality of recruitment itself.

3.2 Variance components

By contrast to the fixed effect terms, the random effect term for *Location* was relatively large and its inclusion confidently supported. This recognizes that there are large *and consistent* differences between sites that cannot be explained by the spatial predictors as measured. The consistency is both from visit to visit within a season, and between seasons.

The key random effect term, that for *Season* itself, is smaller, but its inclusion is still confidently supported.

Finally, the random interaction *Season* × *SubRegion* is very weak and its inclusion in the model is not fully justifiable. As it provides the only basis we have so far for providing an index at the Zone level, though, it has to be included in the model. At this stage the capacity of the data to detect differences between Zones should be regarded as tentative, a situation

[1]Note that this result differs from that given in the second working paper cited above, which resulted in only *Period* and *Sand* being retained. This is due to the re-analysis including *Depth* in the list of candidate predictors and not in the previous analysis. There is a high degree of confounding between spatial predictors and the choice in models is inevitably volatile.

that should change as more data from comprehensive designed surveys are added to the record.[2]

Table 1 presents the variance component estimates.

Effect	Variance component
Location	0.8005
Season	0.1106
SubRegion:Season	0.0451

Table 1: Variance component estimates under the working model

3.3 The *Season* main effect

The main effect BLUPs and their standard errors, and the resulting Multipliers are shown in the initial columns of Table 2.

The resulting *scores* on the $(0,1)$ range for the current and four previous seasons are shown in Table 2. The grades shown are in accordance with the cut-offs on this scale as adopted by the Independent Science Panel, namely 0–0.25 E, 0.25–0.50 D, 0.50–0.65 C, 0.65–0.85 B, 0.85–1 A.

	BLUP	SE	Multiplier	Score	Lower	Upper	Grade
11-12	0.327	0.228	1.387	0.837	0.618	0.952	B
12-13	-0.379	0.227	0.685	0.127	0.034	0.324	E
13-14	-0.092	0.215	0.912	0.391	0.178	0.644	D
14-15	0.274	0.174	1.315	0.795	0.618	0.911	B
15-16	-0.079	0.157	0.924	0.406	0.238	0.593	D

Table 2: BLUPs, standard errors, scores and grades for whole of harbour for the past five seasons, with uncertainty estimates

The multipliers may be displayed graphically by showing their position within the hypothetical population probability density function. These are shown in Figure 1 on the next page.

The Score corresponding to a Multiplier is merely the area under the density curve to its left. That is, the score is the estimated probability of getting a Multiplier no higher. This can be illustrated using the cumulative probability function of the distribution, as shown in Figure 2 on the following page.

[2] A possible reason for this is the presence of large and identifiable differences between monitoring sites within Zones, that is at the *Location* level, that overshadow potential Zone differences. We return to this point in the Discussion section.

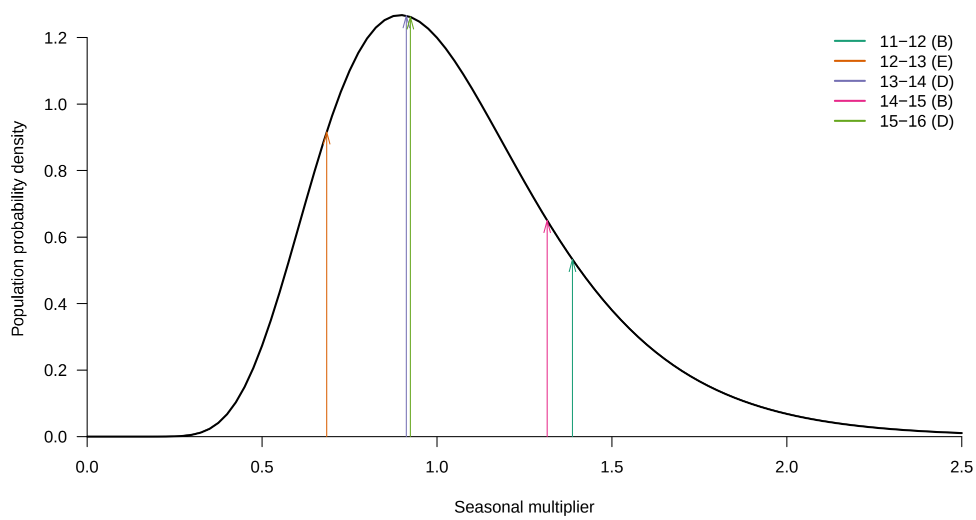


Figure 1: Season multipliers, within the estimated hypothetical multiplier population

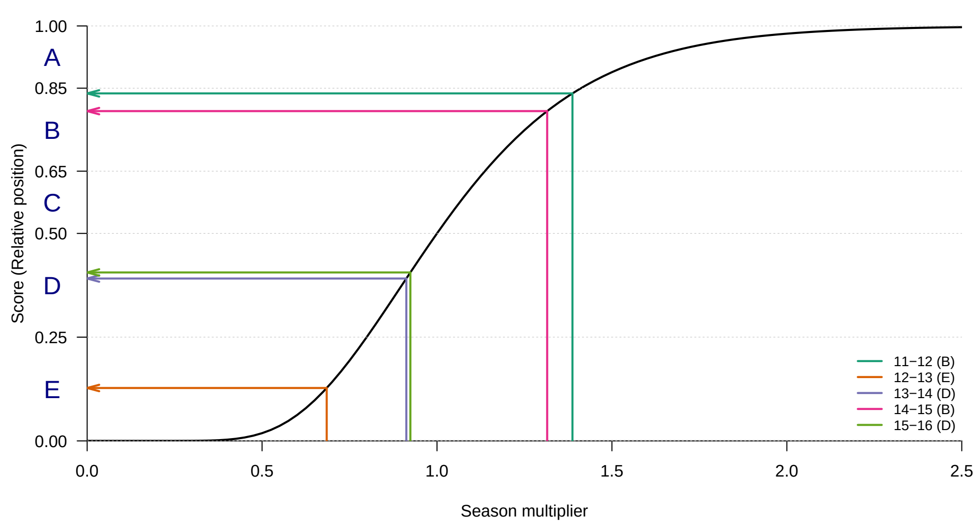


Figure 2: Translation of season multipliers into scores on the $(0, 1)$ range.

3.4 The Zone level

The random main effect for *Season* will still provide an overall score and grade for the region as a whole. The components for individual zones, or sub-regions, are found by adding together the main effect for the season to the interaction terms on the log scale and adding the two variance components. The multipliers is found again by exponentiating the score on the log scale.

In proceeding from Multipliers to Scores the seasonal main effect will be referred to the population as defined by its main effect variance component, and the individual sub-region Scores will be referred to a population defined by the sum of the two variance components.

The resulting scores are shown in Table 3 and the grades, (again on the arbitrary equal ranges cut-offs), are shown in Table 4 on the following page. In both cases the main effect results are shown in the last line of the table, labelled 'All of Gladstone Harbour'.

The result shows that there is either a high degree of consistency between sub-regions within season, or that the data has little capacity to identify such differences.

Further exploration of the data shows that a model that abandons sub-regions and includes a *Season*×*Location* interaction instead captures more of the spatial variation between seasons but again the case for extending the model further in this direction is at best weak.

	11-12	12-13	13-14	14-15	15-16
The Narrows	0.842	0.175	0.362	0.860	0.297
Graham Creek				0.727	0.443
Western Basin					0.353
Boat Creek		0.161	0.385	0.800	0.360
Inner Harbour		0.167	0.408	0.801	0.328
Calliope Estuary	0.864	0.123	0.396	0.704	0.435
Auckland Inlet	0.769	0.105	0.419	0.798	0.532
Mid Harbour					0.292
South Trees Inlet		0.168	0.444	0.724	0.428
Boyne Estuary	0.793	0.201		0.690	0.548
Colosseum Inlet					0.452
Rodds Bay					0.570
All of Gladstone Harbour	0.837	0.127	0.391	0.795	0.406

Table 3: Season scores for reporting zones for the past five seasons

3.5 Bootstrap simulations

The process of assessing uncertainty and its transmission through the health card process requires not only scores on the $(0, 1)$ scale, but bootstrap simulations to represent the uncertainty of the scores. The process for generating these in the present case is as follows. This

	11-12	12-13	13-14	14-15	15-16
The Narrows	B	E	D	A	D
Graham Creek				B	D
Western Basin					D
Boat Creek		E	D	B	D
Inner Harbour		E	D	B	D
Calliope Estuary	A	E	D	B	D
Auckland Inlet	B	E	D	B	C
Mid Harbour					D
South Trees Inlet		E	D	B	D
Boyne Estuary	B	E		B	C
Colosseum Inlet					D
Rodds Bay					C
All of Gladstone Harbour	B	E	D	B	D

Table 4: Season grades for reporting zones for the past five years

process has been incorporated into the *R* scripts provided to implement this component of the report card system.

- Parametric bootstrap samples are first generated on the log scale using the BLUP as mean and its standard error as the standard deviation of the Gaussian uncertainty distribution.
- These are then transformed onto the $(0,1)$ scale using the same process as that which transformed the BLUPs into Scores.
- As this transformation is non-linear, a bias correction is appropriate on the $(0,1)$ scale. This is achieved using a simple power transformation of the bootstrap scores

  $$S_{\text{adj.}} = S_{\text{orig.}}^{\alpha}$$

  where the power α is chosen so that after the adjustment the mean of the bootstrap simulated scores, $\overline{S}_{\text{adj.}}$, agrees with the original score, that is, with the transformed BLUP.

In practice the bias correction is very mild, with $\alpha \approx 1$, but the adjustment ensures tight consistency between scores and the uncertainty assessment process. Note also that the adjusted bootstrap simulations, $S_{\text{adj.}}$, are guaranteed to remain within the $(0,1)$ limits.

3.6 The full process

For reference, an outline synopsis of the sequence of steps needed to perform these computations is presented in Appendix C on page 20. The entire computational process is definitively encapsulated and implemented in the *R* script submitted as a key output from the project.

4 Discussion

4.1 The analysis results

Only in the current season, 15-16, has the sampling of the sites been sufficiently systematic and thorough for the result to be fully useful in constructing a reliable health index. Nevertheless the sampling done in the past few seasons, though somewhat fragmentary, is essential for the interpretation of the situation. It allows a perspective and provides a context in which the seasons can be assessed.

At present, though, there are only five seasons of data, essentially five points, from which the extent of the parent population can be estimated, and in turn the relative scores. While this is a small sample, there is some evidence from expert opinion that the result may not be completely unrealistic. Further sampling should either confirm this or rapidly shore up the information base to allow a realistic perspective to emerge. In any case, it will remain essential in future years to consider the entire record of accumulated data when assessing the results for the current season, as the context may take some time to settle fully.

The strongest random effect is that due to *Location*, or sampling site. These differences between sites are surprisingly consistent both between and within seasons, and more importantly cannot be explained to any great extent by the spatial predictors available. In a sense, the sites are the primary spatial units on which variation within seasons should be judged. The Zones, (or sub-regions), used by the GHHP as reporting regions typically contain a number of sites which may be heterogeneous. (For reference, a map is provided in Appendix A on page 17.) Seeking an index on a zonal level looks to be rather artificial in this case. Hence the assessments offered here at the zone level, to comply with GHHP reporting requirements, should be seen as tentative, at least until the data record is more comprehensive over several seasons.

4.2 Interpretation of multipliers, scores and grades

For some parameters, such as for water quality contaminants for example, it may be possible to set a *baseline level* with reference to known environmental impacts or human health hazards. In this simple situation the construction of scores and grades can be set with respect to these given externally established criteria.

From the discussion to this point, it will be clear that *no external criteria are available* to set baseline levels for fish health, so the scores need to be constructed with respect to internal criteria, derived objectively from the data itself. This also determines how the scores, and grades, should be interpreted, and for reference we recapitulate the interpretation here.

The random effect, or BLUP, for *Season* reflects the assessed degree to which the average catch rate, measured in animals per 20 casts, deviates from a median year. As the BLUP is on the log scale, the base level (as opposed to a baseline) is zero. Transferring this to the natural scale the deviation becomes a *proportional* measure, or multiplier, and the base level is 1.

Not only does the model supply the BLUP as the assessment of this deviation from the norm, but is also supplies a *variance component*, which provides a measure of scale or variability, and in turn a reference distribution, relative to which the BLUP may be gauged.

As detailed above, and illustrated in Figure 1 on page 9, scores are derived from multipliers by finding the left tail area in the reference distribution. This guarantees, in particular, that all scores will lie in the required $(0,1)$ range. The process is exactly analogous to the concept of a "$P-$value" used in statistical hypothesis testing, with the "null", (or reference), distribution, also established by the data itself.

Hence a score of precisely 0.5, for example, would indicate a season at the *median reference level*, indicating no increase or decrease in the catch rate from the long-term average.

Further, a score of 0.25 would indicate a decrease in the catch rate that such that a bigger reduction is expected only about 1 year in 4.

By implication, then, a D grade, indicating a score somewhere between 0.25 and 0.5, would indicate a season with a decreased catch rate relative to the median reference level but no greater a reduction than that implied by a score of 0.25.

Note especially that only ***relative*** *changes in catch rate* can be assessed. As noted repeatedly above, absolute catch rates will vary widely from site to site, in an apparently stable and consistent way, for reasons probably to do with site suitability. This is partly measured by the large random effect for *Location* and partly by the systematic, or fixed effects of *Depth* and *Rock*. Thus, for example, a *multiplier* of 1.25 would represent a 25% increase in the reference level catch rate, but this reference level would vary greatly from site to site. The score would be above 0.5, but how far above would depend on the variance component and the reference distribution scatter it determines.

Provisional nature of results

Note also that as data is accumulated from season to season the variance components will change. This is inevitable and underscores the unavoidably *provisional* nature of the indices while the data record is small and still growing.

This raises the question of how stable the process is likely to become as new data is added in future years. We can only speculate on this, but we do not anticipate any large changes from one year to another. Our main reason for offering this view is that the 5 seasons included in the record to date appear to include at least one season scoring fairly low, and one reasonably high, when informally compared with the even more meagre historical data available from much earlier years.

4.3 The role of expert opinion

The analysis process is always open to the input persons with a depth of knowledge and experience in the domain of study. In there present situation there are several points at which such expert opinion could be usefully incorporated, if available. These include the following:

- *Advice on which fixed effect terms need to be in the model, including interactions.* There is no reason why models need only include terms that are "statistically significant", especially if there is a compelling case for some variables to be included on other grounds. This is particularly so when, as in the present case, there are strong confounding relationships between predictors, making some predictors partially overlap with others in their effect. Knowing some variables would be natural to include on non-statistical grounds would be a useful contribution.
- *Input on setting the spread of the reference population.* While using the variance component for this purpose is the natural choice, having only five points, that is five seasons, on which to estimate it is clearly not very satisfactory. Expert opinion could easily be used to amend this by using an adjustment factor to the variance component, for example, to reflect more clearly what the outcome should realistically be. There are obvious safeguards needed here, but expert opinion could play a useful role, at least until the data record became much more extensive.
- *Drawing the cut-off points for the grades.* As noted above, in this report we have used the unequally spaced cut-off points on the $(0, 1)$ scale specified by the ISP. *Prima facie* an equally spaced sequence of cutoffs seems more reasonable to us. We suggest that the relationship between scores and grades needs to be made more explicit and this apparently straightforward issue needs some clarification.

4.4 Suggestions for followup work

The Bream Recruitment indices consider on a single aspect of fish health in Gladstone Harbour. For the health card this would appear to be a good single index on which to focus. The survey programme, however, reports on all species caught in the castnet surveys and this offers a good opportunity to monitor more closely the progress of fish health in the harbour and report accordingly whether or not this information is incorporated into the health card.

An obvious aspect to keep in check is the continuing progress of each of the Bream species separately. For simplicity the index uses only the total of the two species; if one species were to increase at the expense of the other, for example, this would represent a negative development that the index would miss.

The general composition of the survey catch should also be examined on an annual basis to check on unexpected changes, such as, for example, the infiltration of exotic species or the rapid growth or decline of native species.

5 A rationale for the modelling approach

While a statistical modelling approach to this analysis may seem unfamiliar and overly complex, there are good reasons for adopting it in this situation. In this section we offer a brief explanation of why we recommend this approach and what costs and benefits it can give.

There are several features of the situation that need to be listed first.

- The catch of Bream in 20 casts at a site is a highly discrete response. It is a count variable with a concentration near 0. A low count result is good evidence that the mean catch rate at that site and time is low, and a high catch that it is high. However a low catch rate has much less capacity to show a *proportional* change in the mean catch rate than a high one. This feature needs to be honestly recognized in the analysis.
- There are good reasons why changes should more reasonably be assessed by *proportional* changes rather than by simply *additive* changes.
  - The mean catch rate is by nature a *positive* value. A zero mean catch rate implies that the species does not, and never shall, occur at the site, which by design we assume not to be the case. Proportional changes up or down can increase the value of the mean arbitrarily, but can never decrease the value below the natural zero boundary.
  - A change in a predictor that induces a change in the mean response is unlikely to have the same effect at all levels. It is difficult to imagine a change, for example, of 3 animals per catch, regardless of mean catch, but a change of 3% per catch is much more credible.
  - Related to the previous point, the response has much more scope for *variability* at the high end of the scale than towards the zero end. In turn this points to an assessment of change in proportional terms, recognizing implicitly the size of the effect in which the change is occurring rather than in absolute terms which ignores it.

A statistical model is essentially a device for incorporating a number of features into an analysis in the sense of guiding it in a way that honestly and effectively recognizes them.

Despite having a technical interpretation coming from probability theory, the Negative Binomial model we have chosen, along with it log link function is merely a device for encapsulating and honouring the features of our situation outlined above, namely:

- It recognizes that the response is a highly discrete count variable and sensibly adjusts the analysis that the information content of the low and high responses will not be the same: the high values will be more variable, and have more capacity to show differences than the low values.
- It also recognizes that the variance of the high responses will be higher than that of the low responses, and on a carefully graduated scale.
- The log link allows direct assessment of change in proportional terms rather than additive terms, without the need to transform the observations themselves. An analysis at the direct count scale would require a log transformation of the data itself to render it efficient, and with a preponderance of zero values this in turn would require some arbitrary adjustment to make it even feasible.
- The Negative Binomial distribution itself is a convenient and effective way of incorporating recognition of some degree of “clumping” in the data rather than having fish, in

our case, occurring entirely at random. In fish terms some degree of schooling like this seems to make sense, and ignoring it can lead to potentially unjustified inferences.

- The model we have used allows some terms to be estimated as random effects rather than fixed. This confers a number of advantages difficult to obtain any other way.

  Firstly, it increases the statistical efficiency of the analysis, and hence the information extraction from the data, considerably.

  Secondly, as for the *Season* random effect in our case, it provides not only the BLUPs to use as a relative index for the seasons, but through the variance component it provides, in as much as is possible with limited data, an estimate of the spread of a hypothetical population from which the BLUPs might reasonably have come. Without this there would be no yardstick relative to which the indices could be objectively placed on the required $(0, 1)$ scale. Expert opinion still has a role to play but without this feature it would be the *only* way possible to present the results on a finite scale with known bounds.

The main disadvantage of a statistical modelling approach *vis à vis* a simpler more directly intuitive one, is that the computations are inevitably more complex and obscure, and the results more heavily reliant on trusting the technology. However given all the features that the model is facilitating and carefully balancing, this is unavoidable. The modelling approach has been standard in statistics for over a century and the technology used now, though still in parts a research topic, is in standard use almost universally in statistical practice.

It is also necessary to realize that any analysis, even a simple computation in terms of catch per unit of effort without explicit modelling assumptions does in fact imply a statistical model, in all likelihood a very naive one. It seem much preferable to use an explicit model that has been carefully chosen to reflect all the features of the situation that need to be incorporated and use the efficient estimation techniques that it implies rather than to adopt an approach that starts with the analysis and relies on intuition alone to guide it through the array of complex interacting requirements that the analysis must have to be both faithful to the data and efficient in its inferences.

A Monitoring sites within reporting zones

The sampling sites used for surveys and their inclusion within the GHHP reporting zones are indicated by the following diagram.

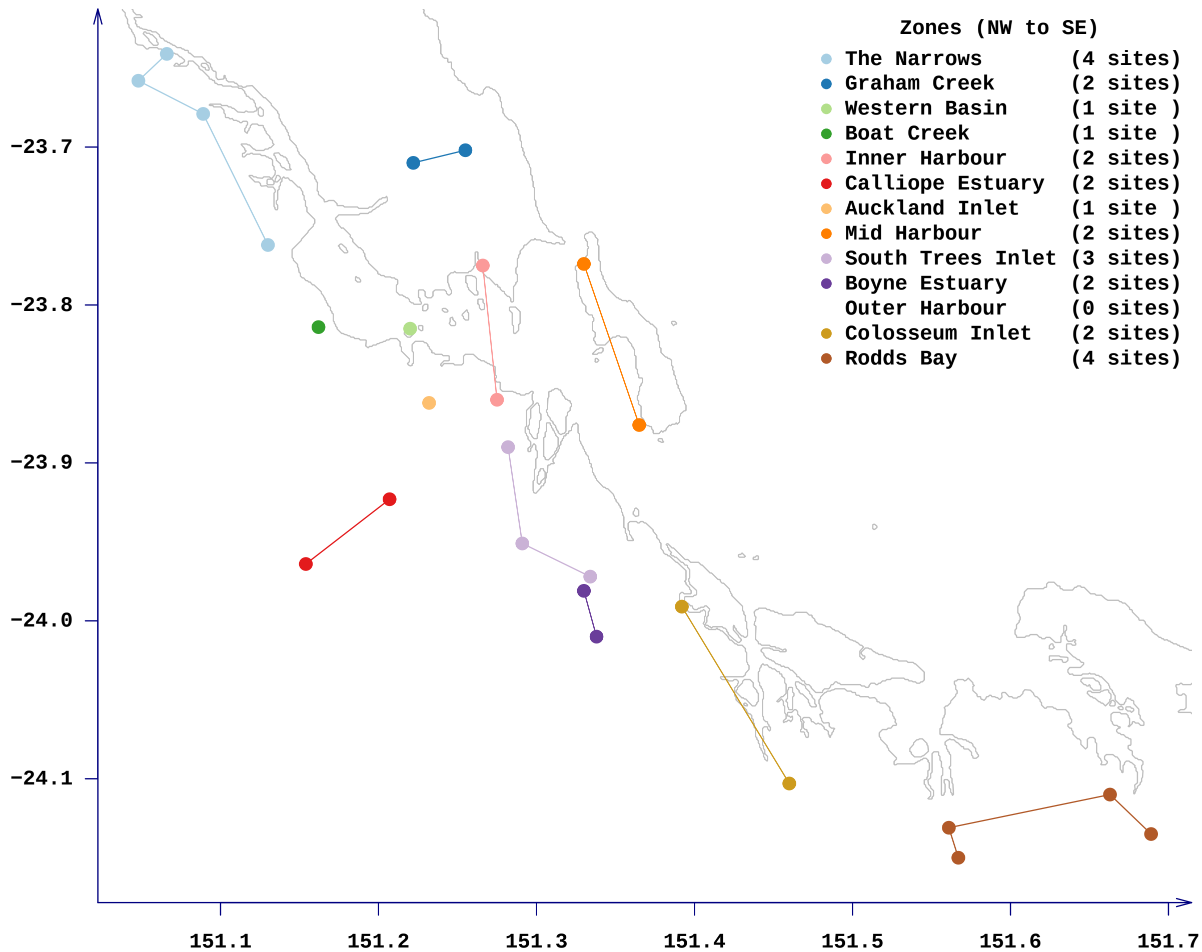


Figure 3: Monitoring sites linked by their sub-region membership

B Size profiles

Size of Bream species was measured by the customary *fork length*. The indicative fork length for year 0 recruits for either species was 0–100mm, but this restriction was not rigidly enforced when choosing data for analysis.

Figure 4 on the following page presents boxplots for the fork length distribution for each of the two species separately. The boxplots are for the five seasons used for analysis, 11-12 to 15-16 inclusive, and are classified by the month, or period, of capture.

Table 5 shows similar information in numerical form. The columns are, in order, the minimum, lower quartile, median, upper quartile and maximum fork lengths for the two species, classified in the same way as in the graphical presentation.

Species	Period	0%	25%	50%	75%	100%
Pikey Bream	Pre	43	76	90	108	140
	Dec	35	48	59	96	170
	Jan	40	57	64	74	200
	Feb	48	60	65	72	206
	Mar	50	62	75	84	210
	Apr	60	82	94	115	218
	Post	65	68	70	90	110
Yellowfin Bream	Pre	44	58	75	106	159
	Dec	30	51	59	88	180
	Jan	42	62	70	95	145
	Feb	44	60	70	80	142
	Mar	50	64	75	90	165
	Apr	50	72	80	97	160
	Post	45	70	75	81	135

Table 5: Fork length (in mm) quantiles for the two bream species at capture, for 11–12 to 15–16 inclusive, classified by month, or period, of capture.

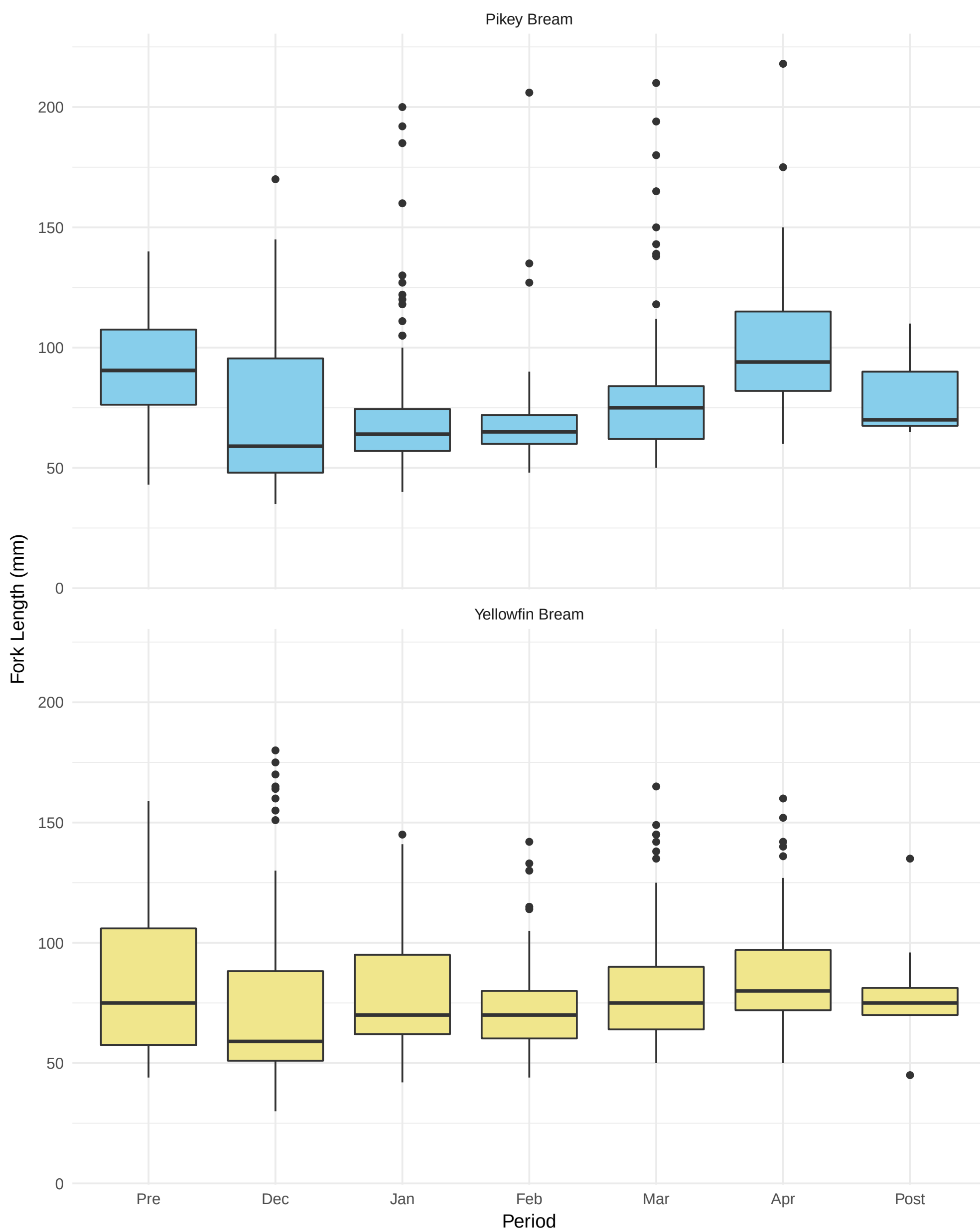


Figure 4: Fork length profiles at capture for the two Bream species, for the seasons 11-12 to 15-16 inclusive, by period of the year

C Steps required to produce the indices

An outline synopsis of the sequence of steps needed to produce the indices is listed below. This sequence should be read in the context of the description given in the body of this Part II of the report.

The computational steps are implemented in the *R* script submitted as a key output of the project, and already checked by the DIMS group in Townsville.

Survey and data collection: The established monitoring sites will be surveyed in future seasons four times, between December and March, at approximately monthly intervals, aligned with the lunar cycle as detailed in Part I of this report. The effort should ideally be 20 casts by an experienced operator.

The data record should be as comprehensive as possible, recording numbers and sizes of all major species, as in the survey exercise for the 15–16 season.

Data reduction and aggregation: For the purposes of the index calculations, the Bream data will be aggregated into counts for each of the two key species, Pikey and Yellowfin Bream, on a per site visit basis. The additional information required for the site visit is as detailed in the metadata specification lodged with this report.

Data for the current season will be aggregated with the *complete data record* from all preceding seasons for purposes of model fitting. For this purpose the data record begins on 1 October, 2011.

Model fitting: [3] The Negative Binomial model, as detailed in Section 2.2 on page 5, will be re-fitted to include the additional data collected in the present season.

Extraction from the model: The key quantities to be extracted from the fitted model are the following:

- The *Season* main effect BLUP for the current season, needed to produce the "All of Harbour" score.
- The *Season*×*SubRegion* interaction BLUPs for the current season, needed for the Zone assessment scores.
- The *variance components* corresponding to each of the *Season* and *Season*×*SubRegion* random effects, needed for the reference distribution in calculating the scores.
- The *standard errors* of the *Season* and *Season*×*SubRegion* BLUPs, needed for the bootstrap simulations.

Calculation of multipliers: The "All of Harbour" multiplier is calculated from the corresponding BLUP by transferring from the log scale on which it is estimated to the natural scale.

Similarly the Zone multipliers are calculating by adding the main effect *Season* BLUP to each of the *Season*×*SubRegion* BLUPs and transferring from the log to the natural scale.

[3] This step and all those following are precisely described and implemented in the *R* script.

Calculation of scores: Scores on the required $(0, 1)$ scale are calculated as the *left tail area* in the appropriate reference distribution. This may be done either on the log scale or on the natural scale, (with identical results), but is simplest on the log scale.

- For the All of Harbour score, the reference distribution on the log scale is Gaussian with zero mean and variance given by the variance component.
- For the Zone scores, the reference distribution on the log scale is also Gaussian, with zero mean and variance given by the sum of the two variance components.

Uncertainty calculations: These are calculated using the BLUPs and their standard errors in a standard way. On the log scale, uncertainty intervals will be symmetric about the BLUP; on the natural (multiplier) scale, these will be asymmetric, and are calculated by transforming the uncertainty intervals end points onto the natural scale.

Bootstrap simulations: For error propagation assessment at higher levels of the report card process parametric bootstrap simulations of the scores are needed that reflect their estimation uncertainties. This is done in three stages:

- On the log scale, the bootstrap sample is generated as a sample from a Gaussian distribution with mean at the BLUP and standard deviation defined by the standard error, as used in the uncertainty computations above.
- The simulations are then transformed onto the $(0, 1)$ score scale by the same process as was used above for generating the score itself from the BLUP.
- Finally, a non-linear bias correction is made to compensate for the minor bias generated by the transformation from the BLUP to the score scale. This correction ensures that the mean of the bootstrap score simulations exactly matches the score itself.