Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2017

Gladstone Healthy Harbour Partnership

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SUMMARY

The objectives of this project were to:

1. Conduct a castnet sampling program based on the approved sampling design over the 2016-17 recruitment season.
2. Refine the data collection methods and statistical analytical methods developed in 2016.
3. Assist with the report card automation processes in the DIMS system.
4. Provide fish recruitment report card scores and grades for the 2017 report card.

The report is presented in 2 parts. Part 1 addresses the first objective and part of objective 2 (data collection methods). Part II addresses objectives 2-4. This summary relates to Part 1 while there is a separate non-technical summary for part II.

The Gladstone Harbour was subdivided into 13 sub-regions with 26 sites selected for sampling in 2015-16. At least 1 site was selected in each sub-region, except sub-region 11, for castnet surveys targeting Yellowfin Bream (*Acanthopagrus australis*) and Pikey Bream (*Acanthopagrus berda*) recruits. Sub-region 11 was not surveyed due to the lack of suitable habitat for Bream recruits.

The same sites were surveyed in 2016-17 with 1 changed site in sub-region 2. The site at the upper end of Graham Creek used in 2015-16 posed logistical difficulties and was not able to be surveyed in each month. A new sampling site was selected about 2km down the creek to overcome those difficulties.

Standardised castnet surveys were undertaken monthly, around the time of the full moon, at sites from Dec 2016-Mar 2017. The timing selected provided the maximum opportunity for recruits to distribute throughout each system. A survey involved 20 casts at each site covering the same area in each survey.

There were 104 surveys at 26 sites with a total of 2,080 casts resulting in a catch of 8,830 individuals. A total of 579 (27.8%) casts resulted in a nil catch. Catch rates varied considerably between sites. The highest catch rate was at Ramsay Crossing at 11.9 individuals/cast followed by South Trees at 9.6 individuals/cast. Lowest catch rates were recorded at Farmers Point at 1.3 individuals/cast and Gatcombe Anchorage at 1.5 individuals/cast.

Yellowfin Bream were recorded at 21 (80.8%) of the 26 sites and in 10 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 20 (76.9%) sites and in 11 of the 12 sub-regions surveyed. There was no sub-region where neither species of Bream was recorded.

There was a total of 574 Yellowfin Bream and 336 Pikey Bream recorded. Over the whole survey period from Dec-Mar the overall catch rate for Yellowfin Bream was 0.28 fish/cast (0.16 in 2016) and for Pikey Bream was 0.16 fish/cast (0.08 in 2016).

1. INTRODUCTION

Building on the 2015 report card, the Gladstone Harbour Report Card 2016 has been informed by 95 measures of the four components of harbour health: environmental, social, cultural and economic.

The 2016 report card is based on data collected during the period from July 2015 to June 2016. As GHHP continues to expand and refine its monitoring programs, additional measures will become available. *Figure 1* shows the results of the 2016 Report Card and *figure 2* shows the Environmental Grades of Harbour Zones.[1]

The environmental grades of Harbour Zones are based on 4 indicator groups:

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

GHHP determined that recruitment of key fish species is 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. 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.

Recruitment surveys were undertaken in 2015-16 and the results were provided in the report "Developing a fish recruitment indicator for the Gladstone Harbour Report Card using data derived from castnet sampling" (Sawynok and Venables 2016).

Figure 1: Indicators used in the 2016 Gladstone Harbour Health Report Card

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

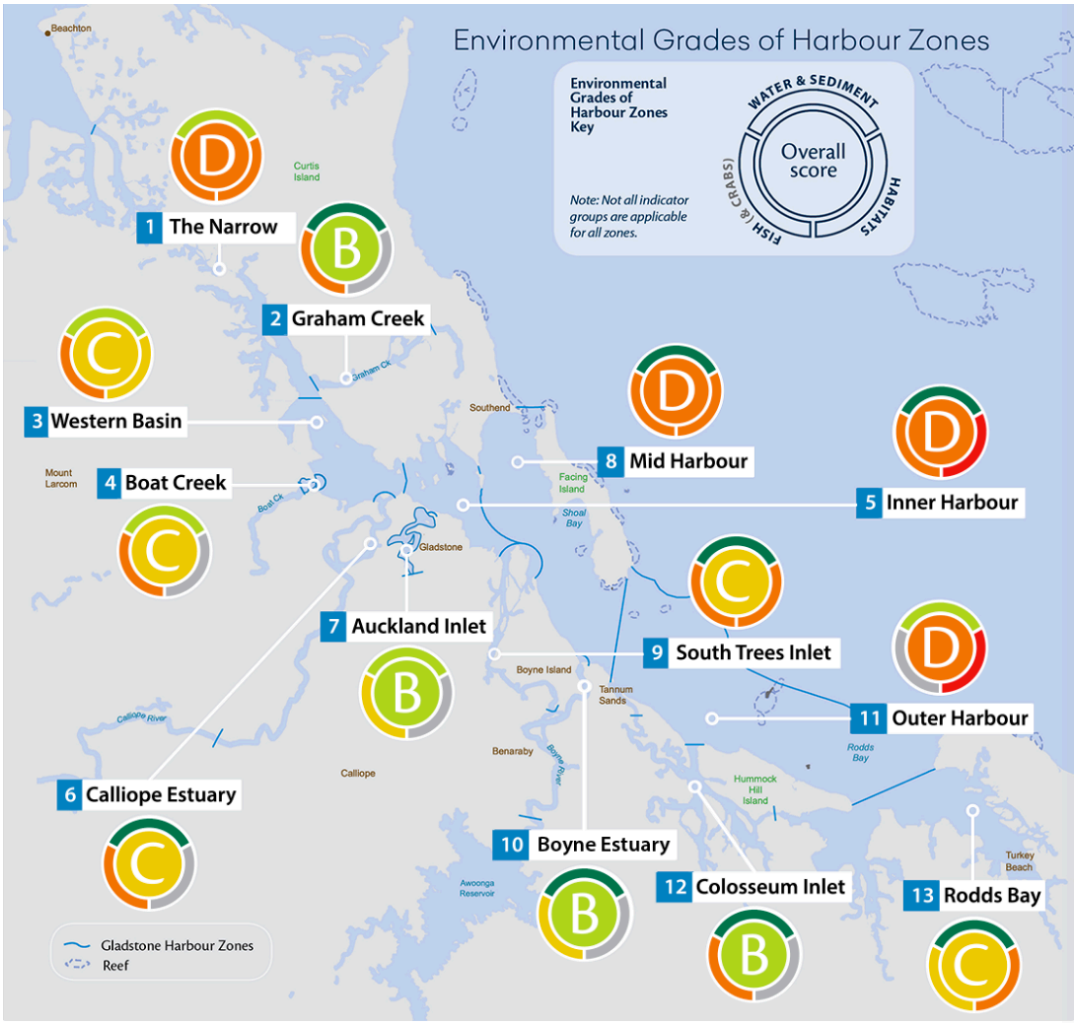


Figure 2: Environmental Grades of Harbour Zones 2016

2. OBJECTIVES

The requirements of this project were to:

1. Conduct a castnet sampling program based on the approved sampling design over the 2016-17 recruitment season.
2. Refine the data collection methods and statistical analytical methods developed in 2016.
3. Assist with the report card automation processes in the DIMS system.
4. Provide fish recruitment report card scores and grades for the 2017 report card.

3. GLADSTONE HARBOUR SUB-REGIONS

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

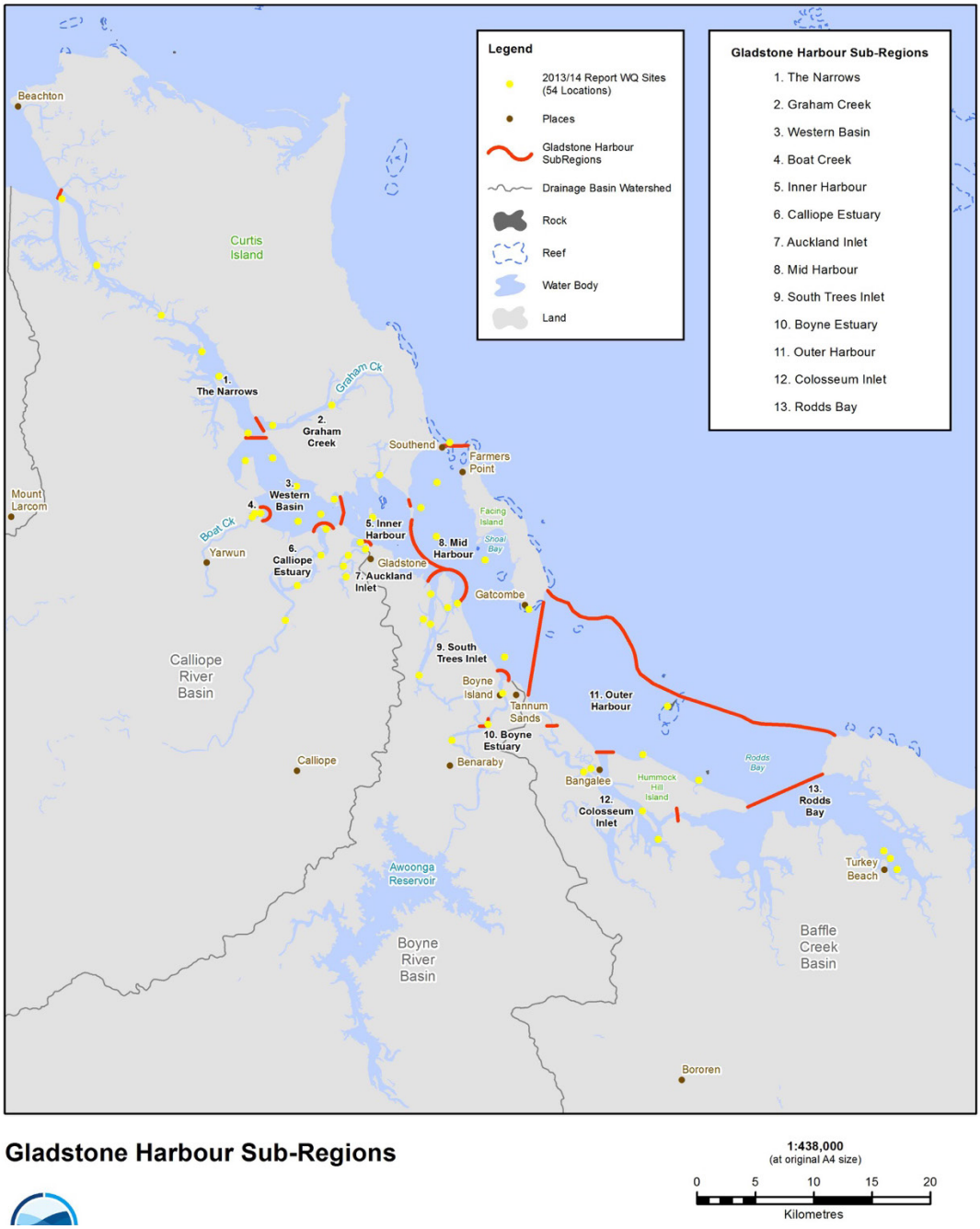


Figure 3: Gladstone sub-regions for the GHHP Report Card (from 2014 GHHP Technical Report at www.ghhp.org/publications)

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

4. 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 was selected in each sub-region.
4. In each sub-region where possible one site was selected towards the upper tidal limit and another within the area of daily tidal influence.
5. Existing sites were used where possible to allow for comparison with historically collected data.
6. Sites were 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 provided 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. Standardised surveys were undertaken at selected sites each month from Dec 2016-Mar 2017.
10. Timing of surveys was generally around 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

11. 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.
12. Yellowfin Bream reach from 130-150mm after 1 year (Brown 2007, Pollock 2011, Cowden 1995). No data on growth patterns 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 previous 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 castnet. Permit number is 187865 and is current to 31/8/2021.
16. The standard number of casts was 20 at all sites with 4 visits to each site.
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 2016 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 release, 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^{o}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 2016 online database located at http://qld.info-fish.net/infofish/. Data are also available in the GHHP DIMS system.
23. Data from the standard Microsoft Excel spreadsheet was validated by visual examination and cross checking prior to being uploaded to the database. This included spelling mistakes and any inconsistencies in fish lengths.

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 rates 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.

5. SITE LOCATIONS

The Gladstone Harbour was 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 surveyed in this sub-region.

For the remaining 12 regions, based on the criteria for site selection there were a total of 26 sites selected in 2015-16 where castnet surveys were undertaken (Sawynok and Venables 2016). There was at least 1 site in each sub-region. Existing sites were used to provide continuity with data previously collected. There were 25 existing sites and 1 new site selected. The new site was Graham Creek 2 (site ID 99) which replaced Graham Creek (site ID 60). There were access difficulties for the Graham Creek site and not all surveys in 2016 were able to be completed.

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

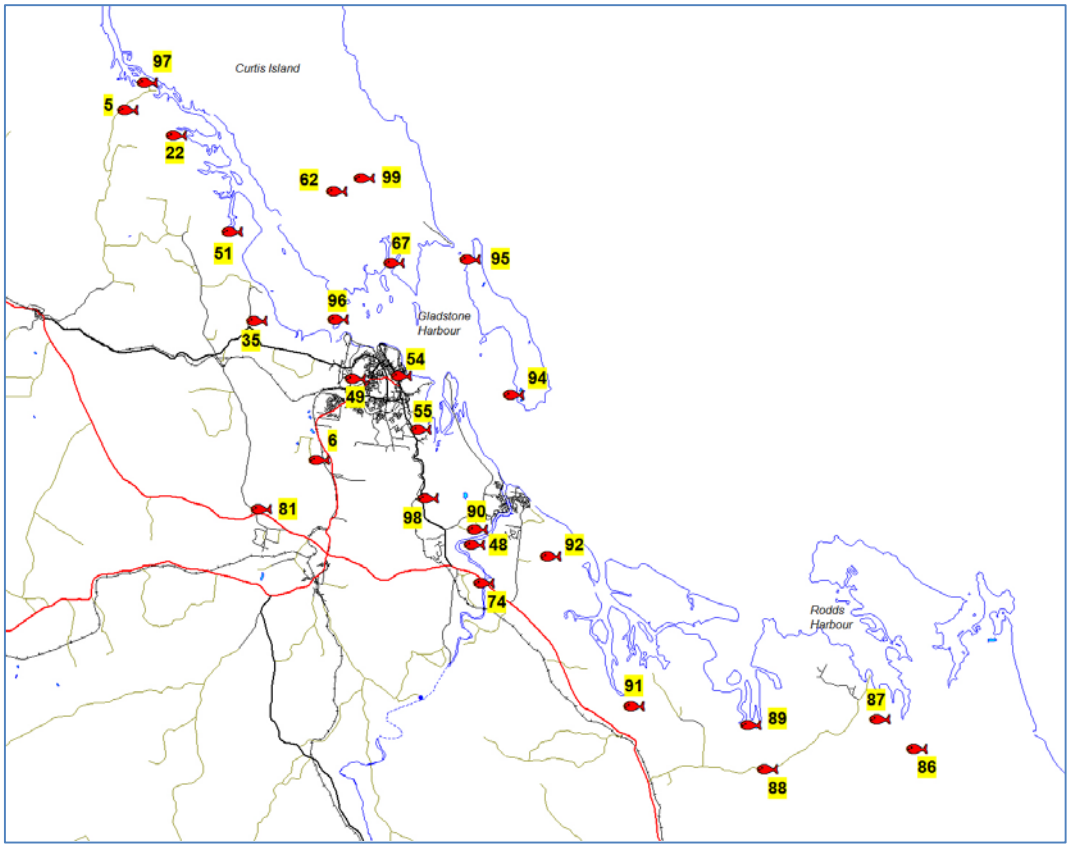


Figure 6: Site locations and site ID in the Gladstone area for Bream recruitment surveys

6. RESULTS
6.1 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	80	950	22	48
1	5	MUNDURAN CREEK	4	80	135	29	0
1	22	BLACK SWAN	4	80	270	17	77
1	51	TARGINNIE CREEK	4	80	211	21	2
2	62	HOBBLE GULLY	4	80	398	0	24
2	99	GRAHAM CREEK 2	4	80	401	0	8
3	96	MUD ISLAND	4	80	394	3	3
4	35	BOAT CREEK	4	80	152	0	1
5	67	LITTLE ENFIELD CREEK	4	80	516	4	24
5	54	BARNEY POINT POND	4	80	125	0	0
6	6	BEECHER CREEK	4	80	197	20	2
6	81	OLD BRUCE HWY BRIDGE	4	80	571	8	37
7	49	CALLEMONDAH	4	80	490	35	43
8	95	FARMERS POINT	4	80	102	26	0
8	94	GATCOMBE ANCHORAGE	4	80	120	0	1
9	55	WAPPENTAKE CREEK	4	80	129	3	1
9	76	SOUTH TREES	4	80	770	15	16
9	90	CREMATORIUM POOL	4	80	404	123	0
10	48	OLD BOYNE	4	80	248	42	0
10	74	BOYNE HIGHWAY	4	80	245	49	0
11		NO SITES					
12	92	BROADACRES	4	80	330	11	12
12	91	IVERAGH	4	80	211	20	3
13	89	7 MILE CREEK	4	80	291	19	16
13	88	SANDY BRIDGE	4	80	465	68	2
13	87	OAKY CREEK	4	80	309	25	12
13	86	WORTHINGTON CREEK	4	80	396	14	4
		TOTAL	104	2080	8830	574	336

Table 1 provides a summary of surveys at all sites from Dec 2016-Mar 2017. There were 104 surveys with 2,080 casts resulting in a catch of 8,830 individuals. A total of 579 casts (27.8%) resulted in a nil catch. The percentage of nil casts was also 27.8% in 2016.

Catch rates varied considerably between sites as shown in *figure 7*. The highest catch rate was at Ramsay Crossing at 11.9 individuals/cast (12.3 in 2016) followed by South Trees at 9.6 individuals/cast (9.6 in 2016) and then Old Bruce Highway Bridge at 7.1 individuals/cast (5.5 in 2016). Lowest catch rates were recorded at Farmers Point at 1.3 individuals/cast (2.8 in 2016), Gatcombe Anchorage at 1.5 individuals/cast (1.3 in 2016) and Barney Point Pond and Wappentake Creek at 1.6 individuals/cast (1.3 in 2016 at both sites).

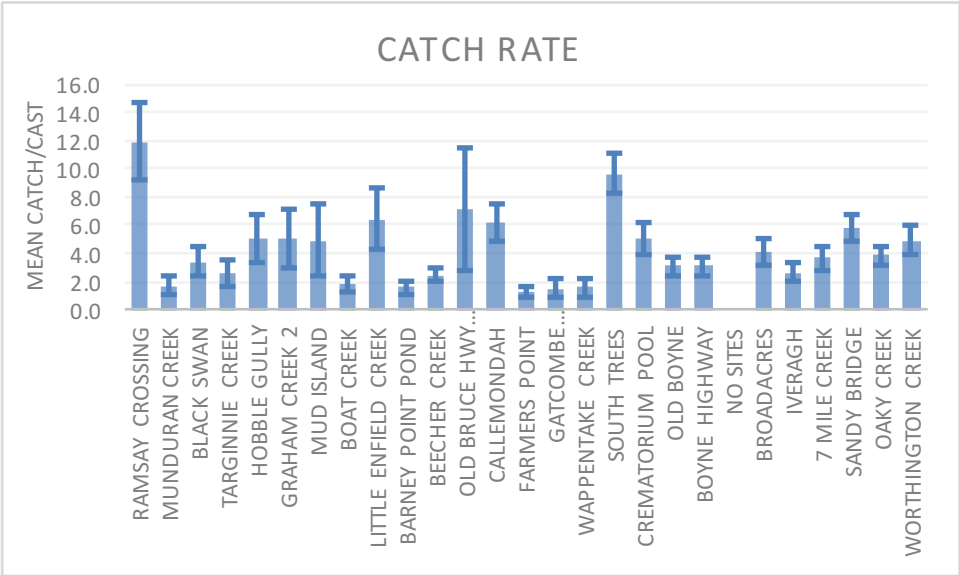


Figure 7: Catch rate at each site (mean with bars showing 95% confidence interval)

Banana Prawn (23.8%), Flattail Mullet (21.1%) and Common Silverbelly (7.6%) were the most caught species. Yellowfin Bream were the 5th most caught (6.5%) and Pikey Bream were the 8th most caught (3.8%) as shown in *figure 8*. A list of all species including scientific names is shown in Appendix 2.

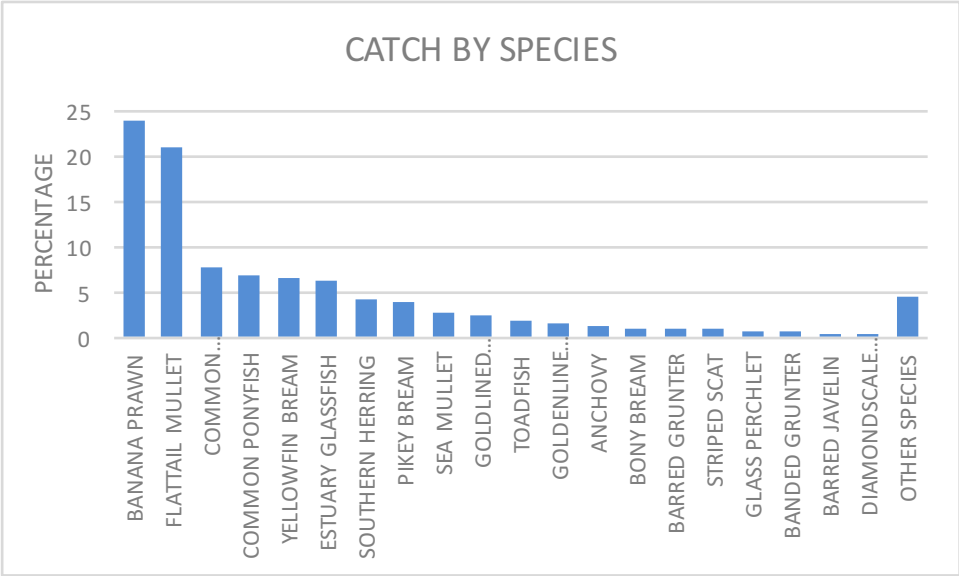


Figure 8: Percentage of individuals (fish and prawn) recorded across all sites from Dec 2016-Mar 2017

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 3.5 in Dec to a high of 4.9 in Feb. *Figure 9* shows the mean catch rate with bars representing the 95% confidence interval from each month's surveys.

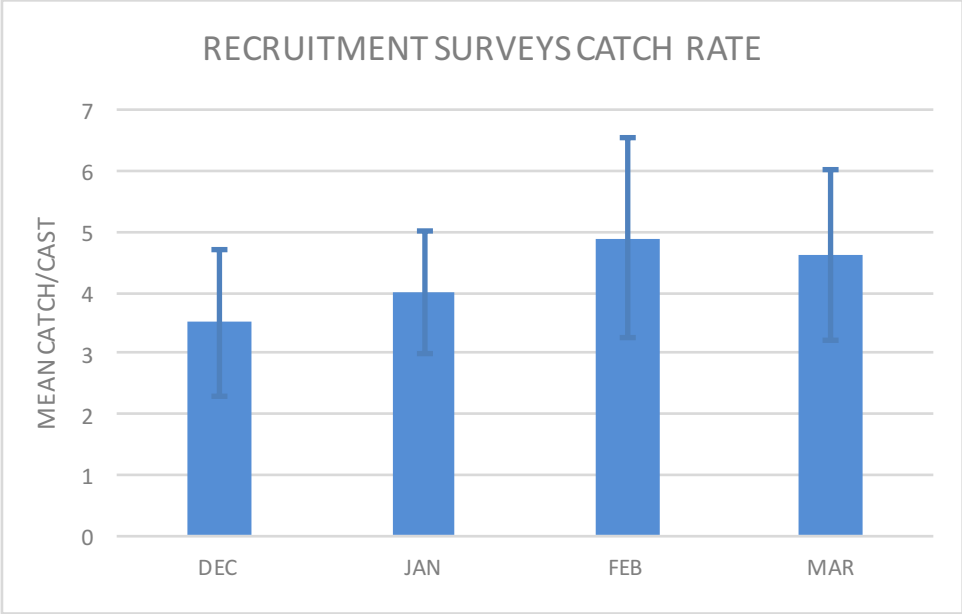


Figure 9: Mean catch rate all sites on monthly surveys from Dec 2016-Mar 2017 (mean with bars showing 95% confidence interval)

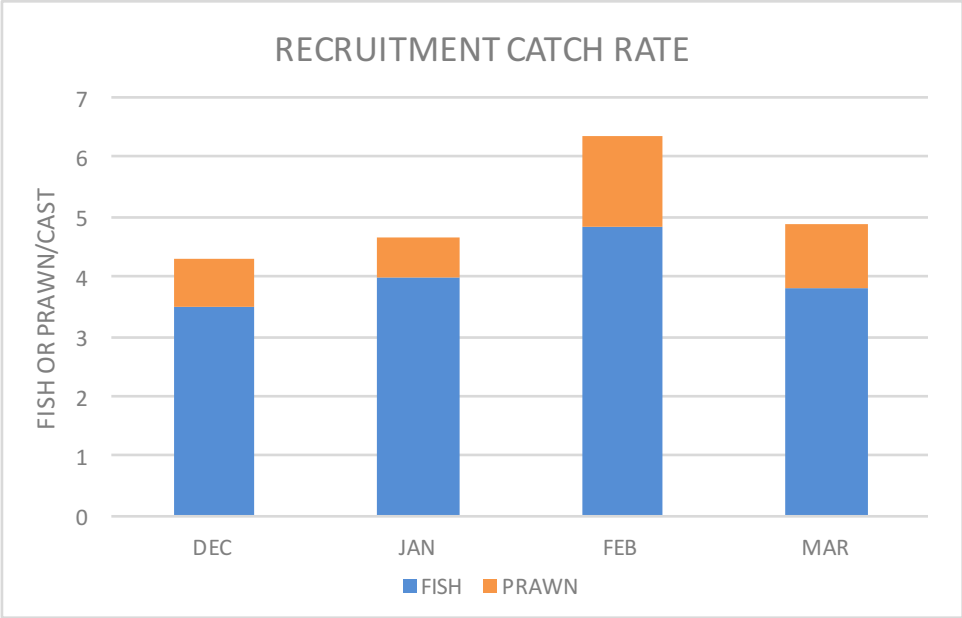


Figure 10: Catch rate for fish and prawn all sites on monthly surveys from Dec 2016-Mar 2017

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.

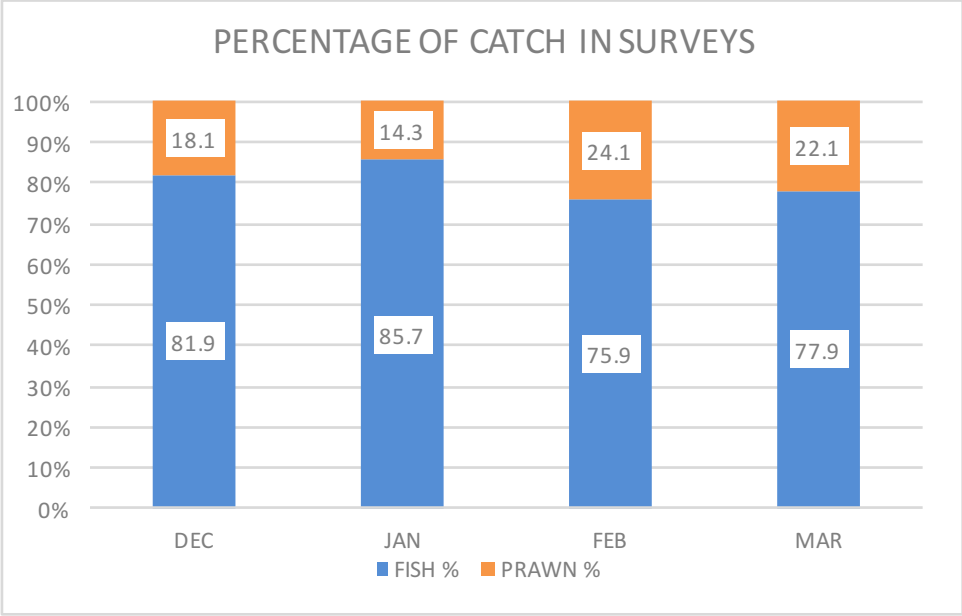


Figure 11: Percentage of fish and prawn in the catch across all sites on monthly surveys from Dec 2016-Mar 2017

6.2 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.

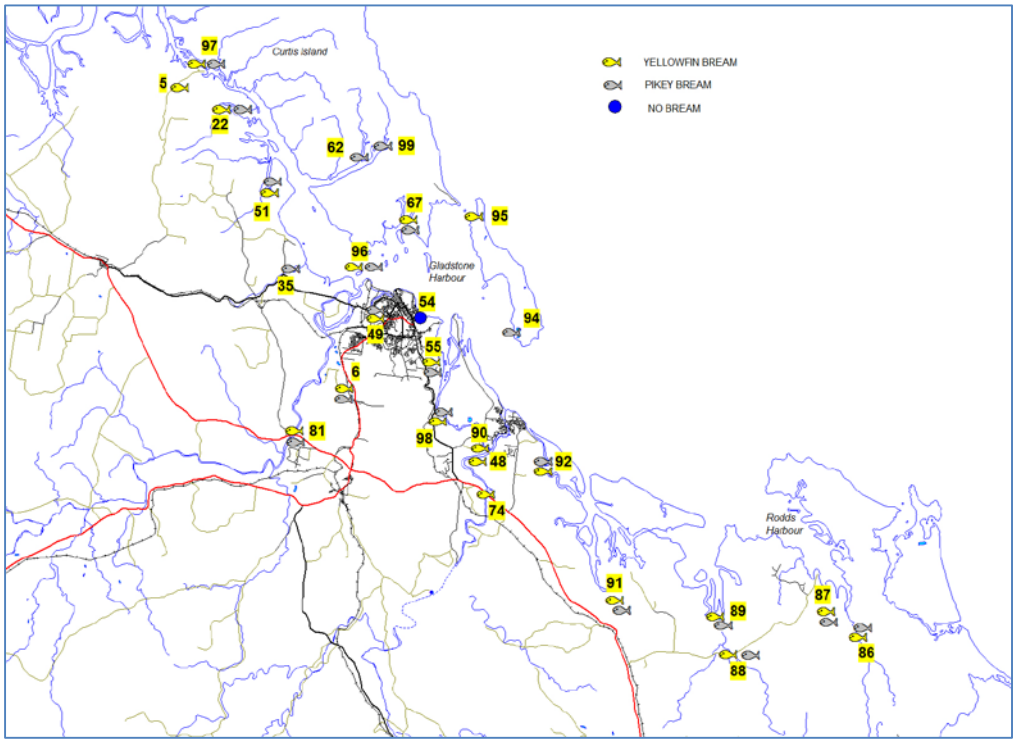


Figure 12: Sites and ID where Yellowfin (yellow) and Pikey (grey) Bream were recorded

Figure 12 shows the sites where Bream were recorded. Yellowfin Bream were recorded at 21 (80.8%) of the 26 sites and in 10 of the 12 sub-regions surveyed. Pikey Bream were recorded at 20 (76.9%) 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. *Figure 13* shows the number of each species of Bream recorded in each of the sub-regions.

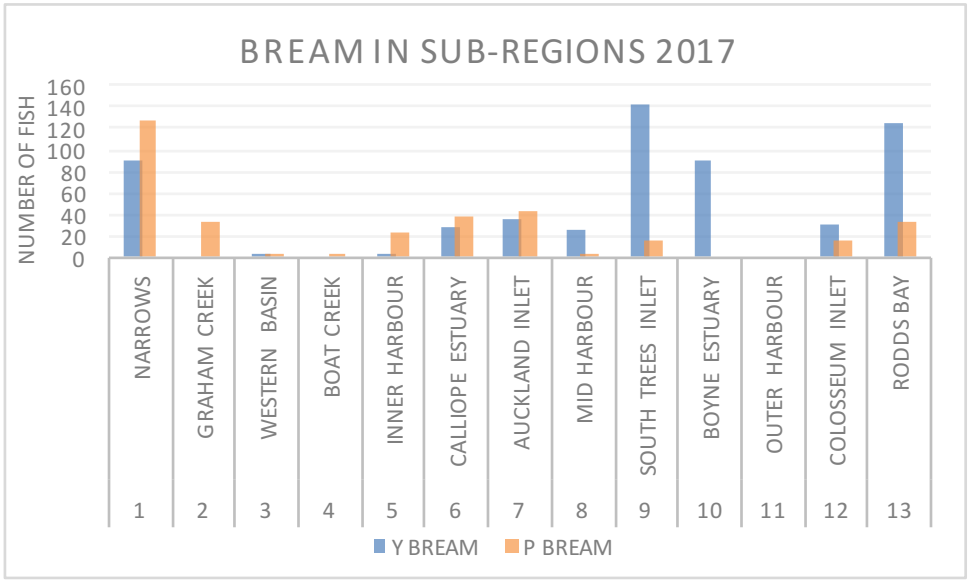


Figure 13: Sub-regions (name and number) where Yellowfin Bream and Pikey Bream were recorded (Outer Harbour not surveyed)

There were a total of 574 Yellowfin Bream and 336 Pikey Bream recorded. Over the whole survey period from Dec-Mar the mean catch rate for Yellowfin Bream was 0.28 fish/cast and for Pikey Bream was 0.16 fish/cast as shown in *figure 14*.

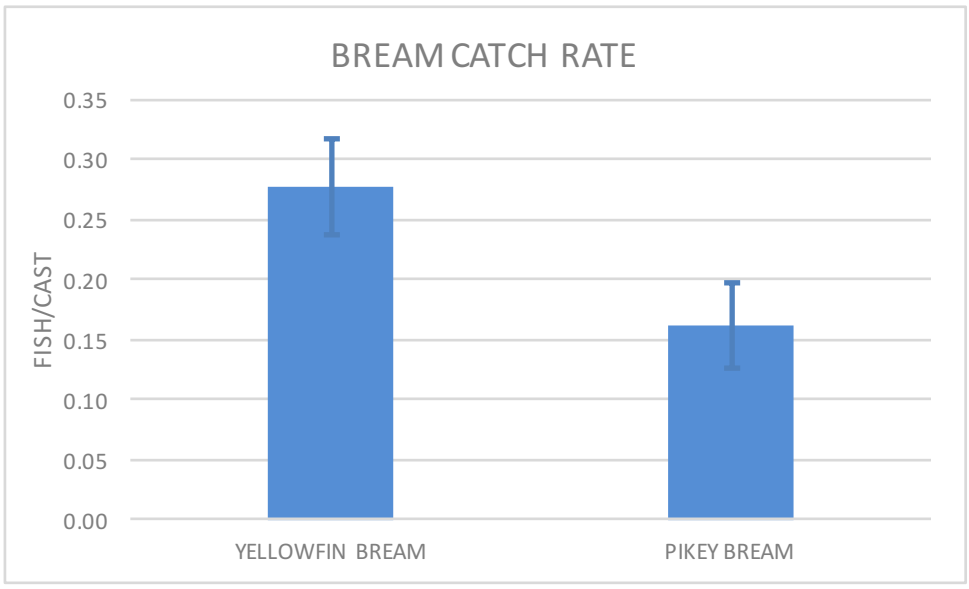


Figure 14: Mean catch rates with 95% confidence intervals for each Bream species from monthly surveys

Figure 15 shows the mean catch rate with 95% confidence intervals, for each Bream species for each of the monthly surveys.

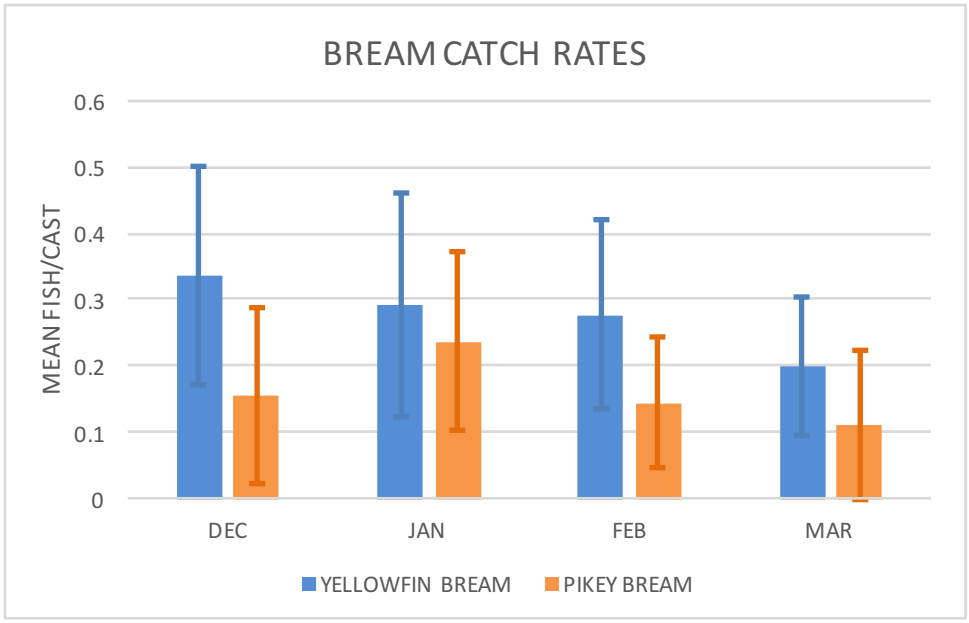


Figure 15: Mean catch rates with 95% confidence intervals for each Bream species for each of the monthly surveys

Figure 16 shows the timeline of the surveys showing fork length (mm) of Bream recorded during the monthly surveys. Surveys were undertaken around full moon tides as these provided the maximum opportunity for Bream recruits to move to all areas 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:

- 11-23 Dec 2016
- 12-23 Jan 2017
- 10-22 Feb 2017
- 10-20 Mar 2017

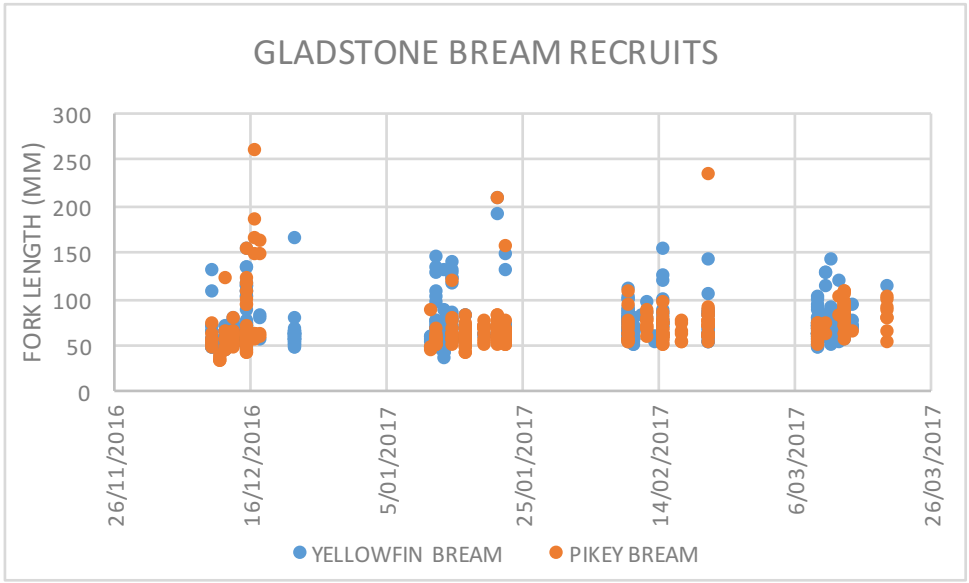
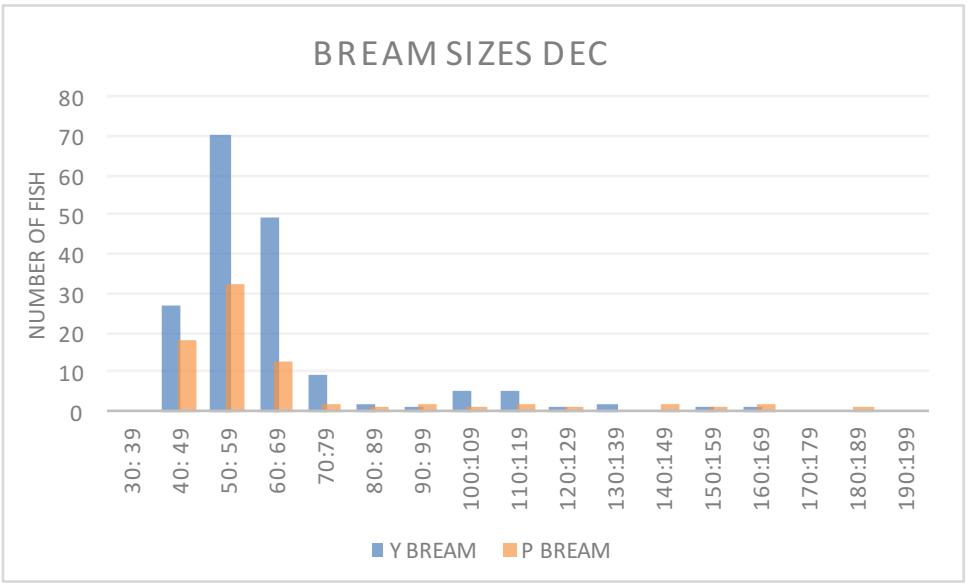
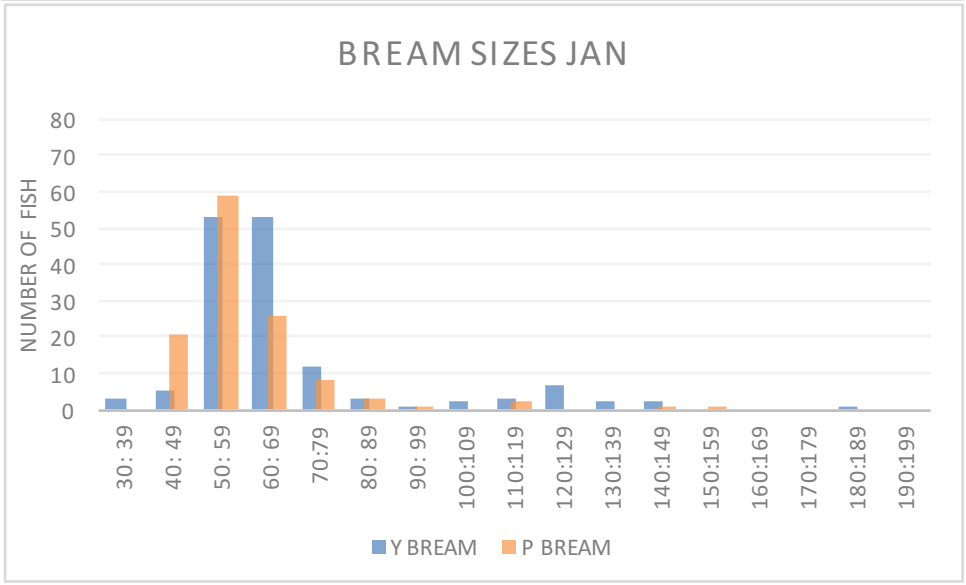


Figure 16: Timelines and fork lengths (mm) of Bream recorded during surveys





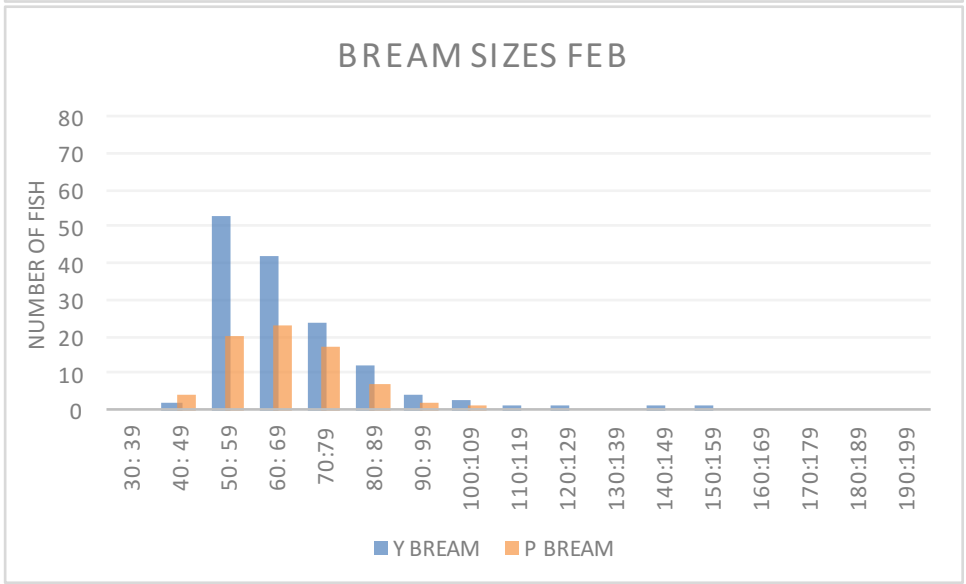


Figure 17: Bream fork lengths (mm) from Dec 2016-Feb 2017 surveys

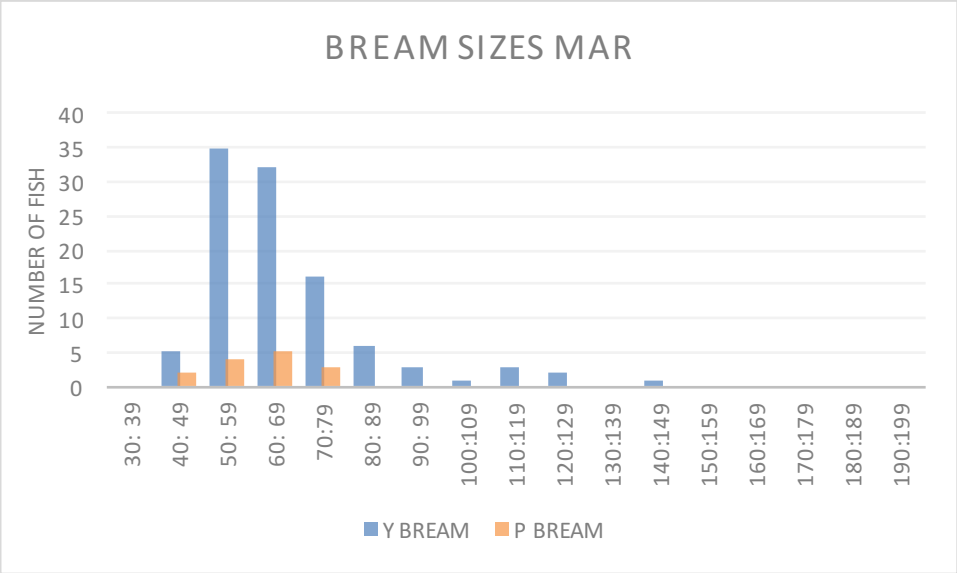


Figure 18: Bream fork lengths (mm) from Mar 2017 surveys

Figures 17 and 18 show the sizes of Bream recorded in each of the monthly surveys. The smallest Yellowfin Bream recorded was a fish of 33mm (fork length) on 14/1/2017 at the Crematorium Pool. The smallest Pikey Bream recorded were fish of 40mm on 16/12/2016 at Oaky Creek and 2 fish of 40mm on 17/1/2017 at Callemondah.

Yellowfin Bream recruits were recorded in a small fish trap in the Gladstone Marina from 1-5/12/2016. A total of 9 fish were recorded from 27-60mm. These fish were not included in any analysis however provided an additional insight into recruitment.

7. COMPARING 2017 WITH 2016

There was a total of 104 surveys with 2,080 casts in 2017 compared with 103 surveys and 2,020 casts in 2016. At Ramsay Crossing the number of casts in 2017 was increased to 20 compared to 10 casts in 2016. This meant that for all 26 sites the number of casts was 20.

The total number of individuals recorded was 8,830 in 2017 while in 2016 it was 8,653. Prawns were 23.8% of the catch in 2017 while in 2016 they were 21.6%. *Figure 19* shows the numbers of fish and prawns in each year's surveys.

There was a total of 910 Bream (both species) in 2017 compared with 504 in 2016. Yellowfin Bream were 63.1% of the Bream catch in 2017 while they were 64.5% in 2016. *Figure 20* shows the numbers of Bream in each year's surveys.

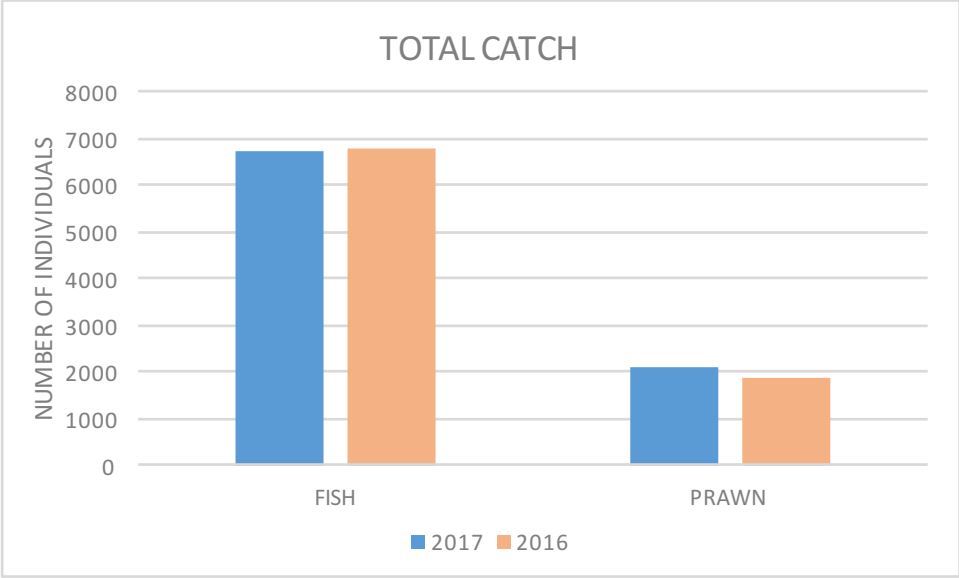


Figure 19: Comparison of total catch in 2017 and 2016

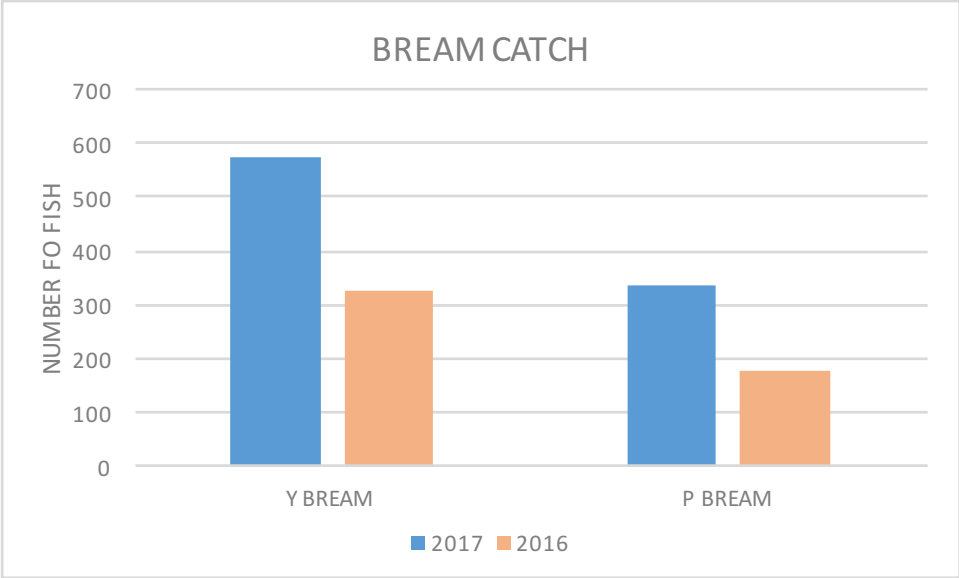


Figure 20: Comparison of Bream catch in 2017 and 2016

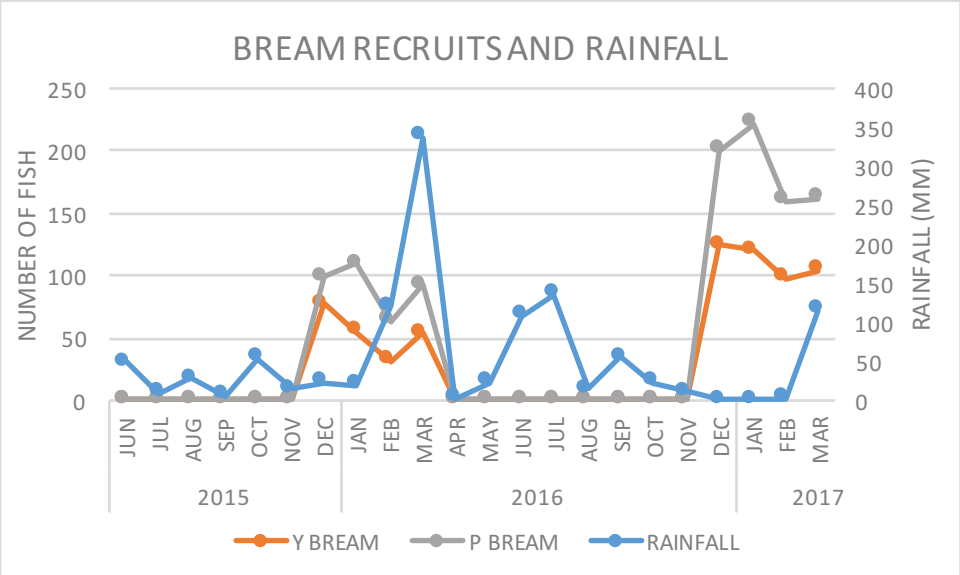


Figure 21: Bream recruits in 2016 and 2017 and rainfall from Jun 2015

Figure 21 shows the Bream recruits recorded in 2016 and 2017 and the total rainfall (mm) recorded at the Gladstone Radar station 039123.

8. OTHER SPECIES

There were 10 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, Banana Prawn at 17 sites and Goldenline Whiting at 13 sites. Flattail Mullet (1,859) and Banana Prawn (2,098) 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	10	23
CRAB – MUD	7	31
JAVELIN - BARRED	7	47
MANGROVE JACK	6	15
MULLET – FLATTAIL	26	1859
MULLET – SEA	12	233
PRAWN - BANANA	17	2098
ROCKCOD – GOLDSPOTTED	2	2
WHITING - SAND	4	11
WHITING – GOLDENLINE	13	130

9. 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.

On 6/2/2017 there was a report of 2 large dead and 1 dying Barramundi in the upper reaches of the Boyne River just below Manns Weir. No other reports of health issues were received.

10. REFERENCES

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APPENDIX 1 – SURVEY SITES

A summary of sites and site details, as stored in the Infofish 2016 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	99	GRAHAM CREEK 2	-23.712	151.24	GLD	MZ12
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

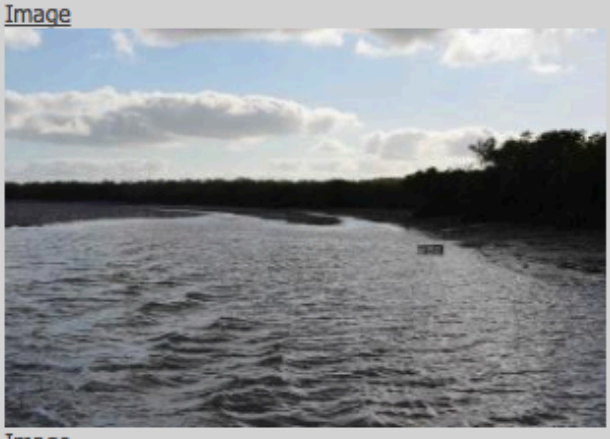
SITE DETAILS – TARGINNIE CREEK

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 2

Site Id:	99
Site Name:	GRAHAM CREEK 2
Waterway:	GRAHAM CREEK
Sub-Region:	2
Map:	GLD
Grid:	MZ12
Lat:	-23.712
Long:	151.24
Tidal Influence:	Tidal
Depth:	1
Access:	Water
Distance to Mouth:	9
Substrate:	☐ Sand ☑ Mud ☐ Gravel ☐ Rock
Description	TIDAL GUTTERS AT UPPER END OF GRAHAM CREEK
Vegetation	MANGROVES
Image:	 Image
Second Image:	 Image

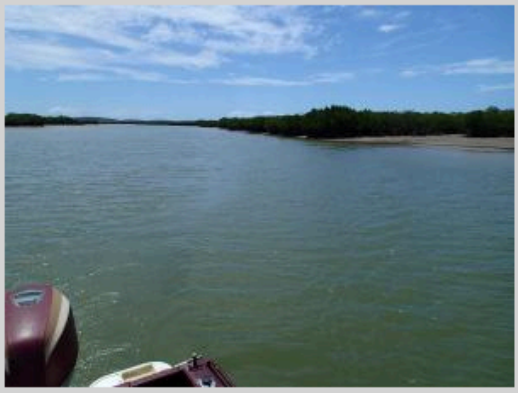
SITE DETAILS – MUD ISLAND

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

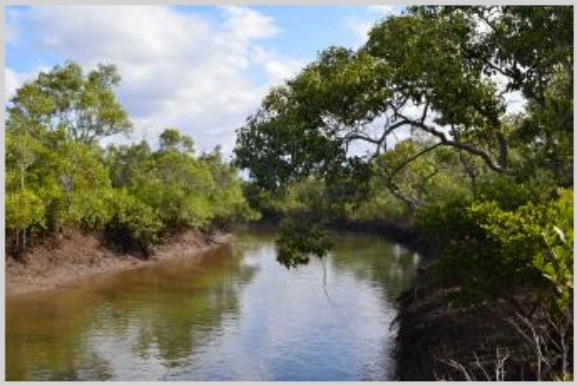
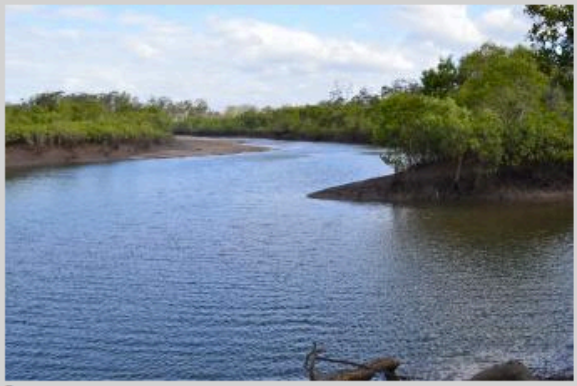
SITE DETAILS – BROADACRES

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 – WORTHINGTON 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	120
BARRAMUNDI	*Lates calcarifer*	0	0
BREAM - BONY	*Nematalosa erebi*	14	90
BREAM - PIKEY	*Acanthopagrus berda*	20	336
BREAM - YELLOWFIN	*Acanthopagrus australis*	21	574
BULLROUT	*Notesthes robusta*	1	2
CATFISH – BLUE	*Arius graffei*	1	4
CRAB – MUD	*Scylla serrata*	7	31
CRAB – SAND	*Portunus pelagicus*	1	1
DIAMONDFISH	*Monodactylus argenteus*	9	39
FILEFISH		1	1
FLATHEAD - DUSKY	*Platycephalus fuscus*	10	23
FLATHEAD – BARTAIL	*Platycephalus indicus*	4	5
FLATHEAD – NORTHERN ROCK	*Sunagocia arenicola*	3	3
FLOUNDER – LARGETOOTH	*Pseudorhombus arsius*	3	3
GARFISH - SNUBNOSE	*Arrhamphus sclerolepis*	1	1
GARFISH – RIVER	*Hyporhamphus regularis*	1	1
GARFISH SPP (?)		1	1
GLASSFISH -ESTUARY	*Ambassis marianus*	17	560
GOBY – GREENSPOTTED	*Acentrogobius viridipunctatus*	1	3
GOBY/GUDGEON (?)		1	2
GOBY SPP (?)		1	1
GRUNTER - BARRED	*Amniataba percoides*	9	82
GUDGEON – SPANGLED	*Ophiocara porocephala*	2	2
GUDGEON SPP (?)		1	1
HERRING - SOUTHERN	*Herklotsichthys castelnaui*	16	379
HERRING – GIANT	*Elops machnata*	3	6
HERRING – HAIRBACK	*Nematalosa come*	2	22
JAVELIN - BARRED	*Pomadasys kaakan*	7	47
MANGROVE JACK	*Lutjanus argentimaculatus*	6	15
MILKFISH	*Chanos chanos*	4	9
MULLET – DIAMONDSCALE	*Liza vaigiensis*	2	39
MULLET - FLATTAIL	*Liza dussumieri*	26	1859
MULLET - SEA	*Mugil cephalus*	12	233
MULLET – SAND	*Valamugil seheli*	2	22
MULLET SPP (?)		1	23

PONYFISH - COMMON	*Leiognathus equulus*	21	601
PONYFISH SPP (?)		3	6
PRAWN - BANANA	*Fenneropenaeus indicus*	17	2098
PRAWN – GREASYBACK (?)	*Metapenaeus bennettae*	1	1
PRAWN SPP (?)		1	3
QUEENFISH - GIANT	*Scomberoides commersonnianus*	3	3
RABBITFISH - GOLDLINED	*Siganus lineatus*	16	224
ROCKCOD – GOLDSPOTTED	*Epinephalus coioides*	2	2
SCAT - SPOTTED	*Scatophagus argus*	5	9
SCAT - STRIPED	*Selenotoca multifasciata*	9	78
SHOVELNOSE RAY – EASTERN	*Aptychotrema rostrate*	1	1
SHRIMP – FRESHWATER (?)	*Macrobrachium spp*	3	17
SILVERBIDDY - COMMON	*Gerres subfasciatus*	22	681
SILVERBIDDY - THREADFIN	*Gerres filamentosus*	7	36
SNAPPER - MOSES	*Lutjanus russellii*	7	19
SOLE SPP (?)		8	22
STEELBACK	*Leptobrama mulleri*	3	4
TARWHINE	*Rhabdosargus sarba*	4	27
TOADFISH - COMMON	*Tetractenos hamiltoni*	11	175
TUSKFISH – BLACKSPOT	*Choerodon schoenleinii*	1	1
WHIPRAY – LEOPARD	*HIMANTURA UNDULATA*	1	1
WHITING – GOLDENLINE	*Sillago analis*	13	130
WHITING – NORTHERN	*Sillago sihama*	2	8
WHITING - SAND	*Sillago ciliata*	4	11
WHITING SPP (?)	*Sillago spp*	3	4
WRASSE SPP (?)		1	1

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 are used to construct a Bream recruitment index. By "recruitment" we mean the annual production of juvenile fish. The index is intended 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*.

Building both on the modelling strategy developed in ISP013-2015 and using the accumulated data up to and including that collected in 2016-17, this report presents a slightly revised methodology for constructing Bream index scores and grades for the reporting zones, and delivers the results.

The additional data from the 2016-17 survey increased the number of visits to the 26 monitoring sites from 233 to 337. This additional data has, as expected, provided a greater clarity and focus on the analysis challenges needed to capture fully the available messages from the data. While the generic modelling strategy has remained the same as for ISP013-2015, the actual model itself has changed slightly and the process of deriving the scores, and hence grades, at the reporting zone level is now somewhat different. Nevertheless there is a high degree of consistency between the results presented in ISP013-2015 and those in this report.

Briefly, the strategy for constructing the index is to build a statistical model that explains variations, over time and place, in the catch per visit to a site, (typically of 20 casts). We then use the model outputs to assess *proportional* changes in catch rate between seasons, relative to a *notional*, or unspecified, reference level.

The model itself uses the so-called *Negative Binomial* discrete distribution to describe mathematically the behaviour of a small count response which in our case is, as previously, the total Bream juvenile catch per 20 cast visit to a site. This distribution, while effectively assessing the proportional change behaviour of the mean response, has the capacity not to be unduly influenced by some observed features characteristic of the situation. In particular these include the tendency of catch counts to contain sometimes larger than anticipated numbers of zero catches, (the record included 77 visits with 0 Bream caught), as well as some unexpectedly high values, possibly associated with local clustering of the fish, (there were two visits with 43 Bream and one with 39). Other features of the situation justifying a formal statistical modelling approach were given in the previous report, ISP013-2015.

As in the previous model, differences between the overall Bream productivity of sites are accounted for by a combination of some fixed effects due to environmental factors and a `Site` random effect. Time variations within a year are allowed for by a `Month` fixed effect as well. In addition there is a `Year` random effect and a `Year` × `Site` random interaction which form the main model outputs. It is the combination of these two latter random effects that are used to build the index, scores and grades.

Where the model differs from the previous version in ISP013-2015 is the inclusion of the `Year` × `Site` random interaction rather than a `Year` × `Zone` term. Modelling the interaction at the `Site` rather than at the spatially higher `Zone` level was necessary to give an adequate fit to the data, but it also implies that scores now need to be aggregated up to the reporting zone level, and on to the all-of-harbour level. This aggregation could be done previously through a model output directly; with the present model we recommend that scores at the `Year` × `Site` level, on the $(0,1)$ scale, be simply *averaged* to the reporting zone level, and these aggregated zone scores are then simply averaged again up to the all-of-harbour level. This averaging process we note is in line with similar processes employed elsewhere in the GHHP report card system.

The formal report concludes with a discussion of the results, as well as a comparison with the results from the previous model to show the stability and robustness of the scheme. We also give a proposed mechanism for assessing uncertainty in the scores, as required for integration into the higher report card system, and illustrate the level of uncertainty so obtained.

In a number of appendices we present a synopsis of the data itself, mainly to provide a background and reference to motivate the modelling choices we have adopted.

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1 Introduction

This Part II of the report contains details of the analysis of the Bream catch data, up to and including the survey data from 2016-17, and presents a recommendation for the construction of indices.

1.1 Background

In Project ISP013-2015, which included the 2015-16 survey, the authors detailed a strategy for using the Bream catch data to arrive at suitable health indices for the Gladstone Harbour reporting zones, together with an all-of-harbour index. The proposed strategy was based on some partial survey data from 2011-12 to 2014-15, together with a survey of 26 sites, 4 visits to each, in 2015-16, which included visits to all previously surveyed sites.

With only one year of full survey results the analysis and index proposals were inevitably tentative. Nevertheless they appeared to reflect the relative changes in this aspect of ecosystem health in a reasonably credible way.

The present report which focuses on the effect of the additional data collected in the 2016-17 survey, should be read in conjunction with Part II of the ISP013-2015 project report. The additional data has clarified some issues in the analysis leading to some changes, as was to be expected. The data analysis and modelling *strategy* will essentially remain the same, as we detail below, but the index proposals we offer will be somewhat different. The *post hoc* changes to the grades given for previous years are minor, leading us to the conclusion that the revised index proposal is likely to be very stable.

Note that the terminology we use in this report differs in some respects from that used in Part II of ISP013-2016. These minor changes are designed to make the language of this report more standard within the GHHP. They are detailed in Appendix A on page 19.

1.2 The statistical model

The extra data collected in year 16-17 has forced a minor change to the model details, as expected, but not the overall strategy. The new model has the following structure.

- The response variable, denoted by Y, is again taken as the total Bream catch, Pikey Bream plus Yellowfin Bream, in fish numbers for each visit.

  Catch counts for the two bream species separately, as well as effort and the crude catch per visit (CPUE) data are reported below in Appendix C on page 21.

- Catch per visit conforms to a Negative Binomial generalized linear mixed model, with log link and fixed variance parameter, θ. In conventional algebraic terms, for a single observation:

  $$Y|E \sim \text{Negative Binomial}, \quad \log \mathrm{E}[Y|E] = \log\mu = x^{\mathrm{T}}\beta + z^{\mathrm{T}}E + \log c, \quad \mathrm{Var}[Y|E] = \mu + \mu^2/\theta$$

Where the row vectors x^{T} and z^{T} specify the fixed and random effects respectively, so the fixed effect coefficient vector is β. Marginally the random effect terms are considered to have a Normal distribution, that is, $E \sim \mathrm{N}(0, \Sigma)$.[1] The precise form for the variance, Σ, is detailed below.

The final offset term, $\log c$, is the logged number of casts involved in the particular visit and allows for variations in cast numbers from the usual 20 casts per visit.

The random effects, E, are modelled as Normal (Gaussian) random variables with mean zero. The variances involved are the *variance components* used later in the discussion.

For simplicity, the model is estimated with fixed parameter $\theta = 2$, which also enhances stability. We show later that this assumed fixed value is very close to the maximum likelihood estimate and the assumption has no material effect on the parameters of interest.

- The candidates for fixed effect terms included all available and relevant spatial and temporal environmental predictors.

  On model refinement the only retained fixed effect terms were

  - A `Month` term, allowing for systematically different catch rates within the survey year,
  - A `Depth` term and a `Rock` presence/absence term as the only environmental predictors shown to be effective.

- The random effect terms included

  - A `Site` random effect, allowing for productivity differences between sites not explained by the fixed effects. This is a "blocking" term; the variance component is σ^2_S.
  - A `Year` random main effect, with variance component σ^2_Y.
  - A `Year` × `Site` random interaction, with variance component σ^2_{YS}.

1.2.1 The modelling strategy differences

The only difference between the present model and the former one is the presence of a `Year` × `Site` random interaction rather than a `Year` × `Zone` term as was used previously.

The reason the `Year` × `Zone` term was preferred was that it provided a result for the zone directly, without the need to aggregate in some way over sites within zone to give a result at the required spatial reporting level.

[1] Notice that whereas a normal linear regression model would have an additional error term added to the mean formula, no such normal error term is added here. That additional component of variation is covered by (conditional) Negative Binomial distributed ascribed to the response; it is not additive in the usual sense. In a sense, though, the random effect terms *are* very like normal additive "error" terms.

Even without the data collected in the present survey period the model appeared rather fragile, and the proposal given in the ISP013-2016 report was tentative. With the additional data, the model essentially fails, resulting in a *zero* estimate for the `Year × Zone` variance component, σ^2_{YZ}, and hence failing to detect any differences between zones within years. (This may, in fact, be a reasonable outcome.)

On the other hand, a model with a `Year × Site` random interaction fits well and all terms are estimated with comparable variance components. The `Site` main effect variance component, however, is the largest, which indicates that the sites themselves have large and reasonably consistent differences in Bream catch rates which are not explained by the spatio-temporal fixed effect predictors available. See Table 1 on page 8. In essence, the site is the natural spatial level in this context and the reporting region, the zone, is an artificial construct.

This leaves the problem of aggregating to the zone level, and further to the all-of-harbour level, to provide the scores and grades required for the health report. We propose a simple method for this task below which is also consistent with aggregation methods employed elsewhere in the health card. Despite its unsophisticated nature, tests so far seem to suggest that the method provides robust, credible indices.

1.2.2 Score estimation and aggregation

The proposed method for generating scores and grades from the model outputs begins with a score, on the $(0,1)$ range at the site rather than the zone level. If E_Y is the random effect estimate, (which is usually referred to as a 'BLUP', an acronym for "Best Linear Unbiased Predictor"), for a particular year and E_{YS} the random interaction BLUP for a site within the year, then their sum, $E_Y + E_{YS}$ is the combined BLUP which forms the basis for the corresponding site level score.

Since according to the model

$$E_Y + E_{YS} \sim \mathrm{N}\left(0, \sigma^2_Y + \sigma^2_{YS}\right)$$

Using exactly the same argument as presented in ISP013-2015, a score at the site level, for a given year, on the $(0,1)$ range, is given by the cumulative probability less than the sum of BLUPs in this distribution:

$$\mathrm{Score}_{YS} = \Phi\left(\frac{E_Y + E_{YS}}{\sqrt{\sigma^2_Y + \sigma^2_{YS}}}\right)$$

Where $\Phi(z)$ is the standard normal (cumulative) distribution function.

We propose that these site scores then aggregated to the reporting levels in the obvious way, namely

- The zone score for a year is the simple average of the site scores within that zone. In some cases there is just one site within a zone, (and in one case, *Outer Harbour*, there are none).
- The score for All of Harbour is then the simple average of the zone scores.

- Grades are generated from scores by finding the interval to which they belong, as per the GHHP standard:

E	D	C	B	A
0.00–0.25	0.25–0.50	0.50–0.65	0.65–0.85	0.85–1.00

We note here that the scores, particularly at the site level, have a meaning in terms of the assumed statistical model and form an objective scaling of the sites. Whether this scaling, and the resulting scaling of the zones and harbour coincides precisely with the intuitive meaning given to the grades is an issue for resolution.

2 Data manipulation and cleaning

The data as recorded had a few inconsistencies, most of which were reconcilable through inbuilt redundancy.

There was some inconsistency in the way site names were recorded and these were resolved as in the following table:

Recorded name	Analysis name used
`7 Mile Creek`	`7 Mile`
`Black Swan Creek`	`Black Swan`
`Oakey Creek`	`Oaky`
`Oaky Creek`	`Oaky`
`Graham Creek 2`	`Graham Creek`
`Worthington Creek`	`Worthington`

Most of these are recording glitches but it is important to note that `Graham Creek 2` is technically a different site from `Graham Creek`. The former is a site new to the study chosen to replace the latter for easier access, but remaining as close to it as possible. *In the analysis only*, we have chosen to identify it with the original site to simplify and strengthen the process. This appears to be a reasonable decision as the catch performance of the old and new sites, with respect to both species of Bream, turn out to be very similar. Nevertheless there is no proposal to alter the official data record in any way.

3 Results

In this section we present the results of the analysis. The main results are the scores and grades for the current survey year, 16-17, but to do so requires the model to be fitted using the historical data as well.

One of the important concerns is the stability of the process itself. To examine this we will present the results for two cases, namely for the data set up to last year only, that is for 11-12 to 15-16 inclusive, and compare that with the results for the entire data record, including

16-17 as well. In this way we can show the result for last year as if we had used the method now suggested, and the effect on it of adding this year's additional data.

3.1 Negative binomial variance parameter, θ

The estimated negative binomial $\theta-$parameters are very stable close to $\theta = 2$. Re-estimating them from the final fitted model, for the restricted and full data sets, yields

- $\hat{\theta} = 2.0683$ for the model fitted with data up to year 15-16 only, and
- $\hat{\theta} = 2.1084$ when the further data for year 16-17 is included.

Fixing this parameter at $\theta = 2$ confers a degree of stability on the process, but leaves the crucial estimates, and the scores and grades, negligibly affected.

3.2 Variance components

The additional data gained in the 16-17 surveys also leaves the variance component estimates relatively unaffected, as shown in Table 1.

Component	(a) data to 15-16	(b) data to 16-17
Site	0.8676	0.8292
Year	0.3240	0.3111
Year × Site	0.3291	0.3577

Table 1: Variance component estimates (as standard deviations) for the main model using (a) only data up to year 15-16 and (b) all available data. A stability check.

The quantity required to standardize the BLUPs, $E_Y + E_{YS}$, leading to the scores is the standard deviation:

$$\hat{\sigma}_{\text{BLUP}} = \sqrt{\hat{\sigma}_Y^2 + \hat{\sigma}_{YS}^2} = \sqrt{0.3111^2 + 0.3577^2} = 0.4740$$

3.3 Site main effects

The site main effects, $E_S \sim \text{N}(0, \sigma_S^2)$, indicate how different sites are in bream abundance. These are on a log scale so comparisons are in a proportional rather than a difference sense. Sites with naturally low average bream abundance have a low capacity to show small proportional differences, whereas those with higher natural abundance have a greater capacity. It is making justifiable allowance for these natural differences between sampling sites that is a key challenge of this analysis.

In order to show the relative stability of the site main effects with the addition of new data Figure 1 on the following page shows the BLUPs using data up to 15-16, (horizontal scale) and estimates using the full data set (vertical scale). The diagram is partitioned into zone

cells to show the high degree of heterogeneity even within zones. It is this heterogeneity that complicates the production of fully justifiable scores at the zone level, of course. The diagonal line in each panel indicates where the two estimates would be equal. Points relatively distant from the line had the greatest change.

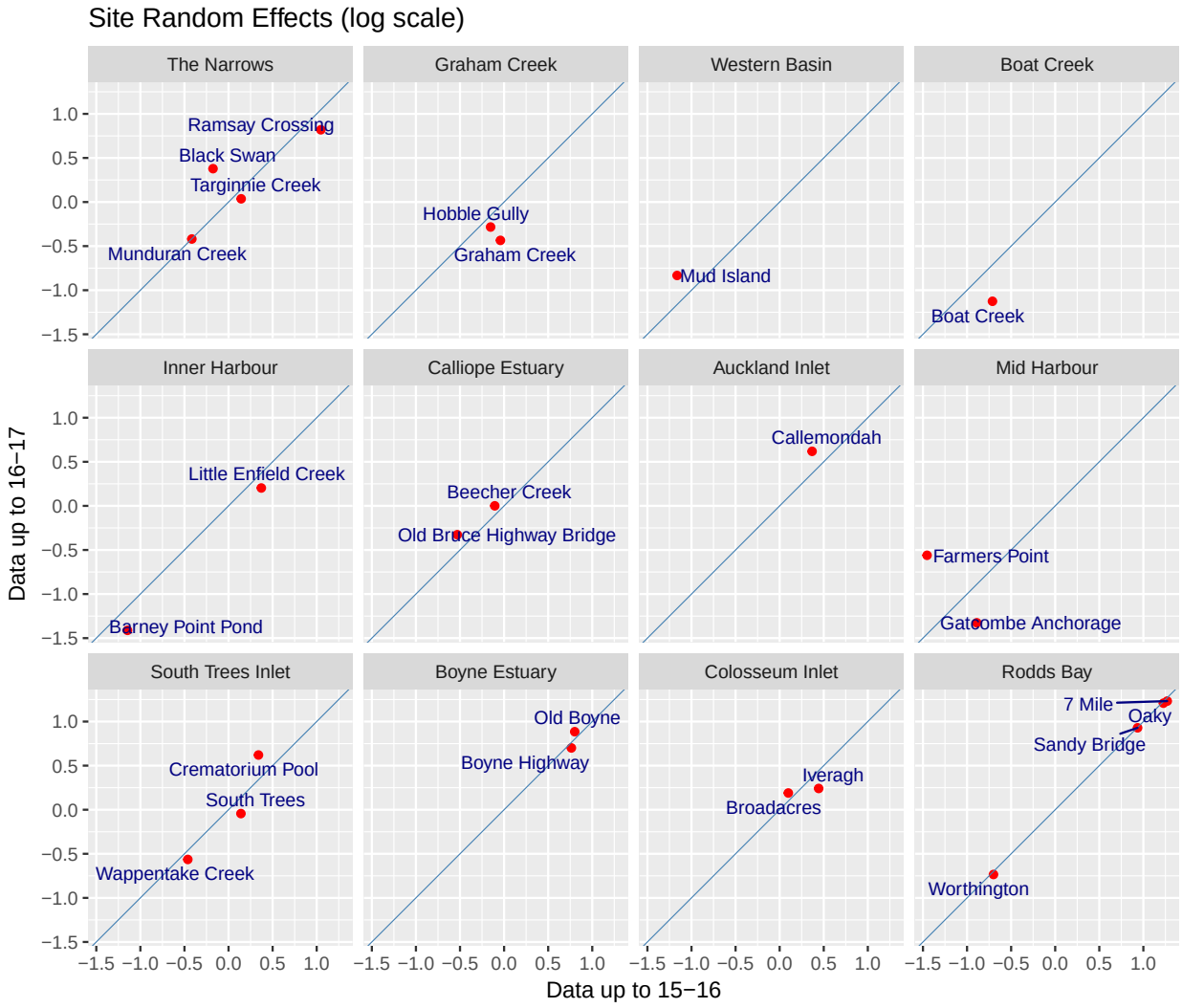

Figure 1: Site random effect estimates. A comparison of BLUPs using the restricted data set with those using the full data set.

3.4 Site by year random effects

Table 2 shows the combined year and year by site BLUP estimates, that is $E_Y + E_{YS}$, for all years in the study. The year BLUP, E_Y, is the representation of how much each year differs in aggregate from a conceptual long-term mean in catch rate, and the year by site BLUP, E_{YS}, represents the deviation of each site from its year aggregate. Both of these are *after the allowance* for aggregate site differences, as encapsulated by the site BLUPs, E_S as detailed in section 3.3 on page 8.

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					0.09	0.13
	Munduran Creek	0.41	-0.34	-0.22	-0.02	-0.17	0.25
	Black Swan				0.19	-0.74	0.85
	Targinnie Creek	0.21	-0.44		0.52	-0.48	0.30
Graham Creek	Graham Creek				0.33	-0.25	0.07
	Hobble Gully				0.07	-0.02	0.14
Western Basin	Mud Island					-0.46	0.37
Boat Creek	Boat Creek		-0.40	-0.09	0.39	-0.29	-0.04
Inner Harbour	Little Enfield Creek				0.32	-0.29	0.24
	Barney Point Pond		-0.37	-0.08	0.23	-0.35	0.08
Calliope Estuary	Beecher Creek	0.46	-0.58	-0.13	0.19	-0.27	0.32
	Old Bruce Highway Bridge				-0.07	-0.19	0.43
Auckland Inlet	Callemondah	0.12	-0.68	-0.15	0.22	-0.02	0.63
Mid Harbour	Farmers Point					-0.65	0.61
	Gatcombe Anchorage					-0.20	0.02
South Trees Inlet	Wappentake Creek		-0.38	-0.02	0.10	-0.24	0.20
	South Trees					-0.11	0.16
	Crematorium Pool					-0.30	0.48
Boyne Estuary	Old Boyne	0.23	-0.26		0.12	-0.08	0.25
	Boyne Highway				0.04	-0.02	0.35
Colosseum Inlet	Broadacres					-0.18	0.28
	Iveragh					-0.12	0.23
Rodds Bay	Oaky					-0.03	0.32
	7 Mile					-0.01	0.30
	Worthington					-0.30	0.23
	Sandy Bridge					-0.15	0.38

Table 2: Random effects estimates (BLUPs), $E_Y + E_{YS}$, for the Gladstone Harbour Bream survey sites for all study years

The BLUPs are transformed into *scores* by dividing by their standard deviation and finding the cumulative probability in the standard normal distribution. In symbols:

$$Z_{YS} = \frac{E_Y + E_{YS}}{\sqrt{\sigma_Y^2 + \sigma_{YS}^2}}, \qquad \text{Score}_{YS} = \Phi(Z_{YS})$$

Where $\Phi(z)$ is the standard normal (cumulative) distribution function. The resulting scores are shown in Table 3 on the next page.

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					0.57	0.61
	Munduran Creek	0.81	0.24	0.32	0.48	0.36	0.70
	Black Swan				0.66	0.06	0.96
	Targinnie Creek	0.67	0.18		0.86	0.15	0.73
Graham Creek	Graham Creek				0.76	0.30	0.55
	Hobble Gully				0.55	0.48	0.61
Western Basin	Mud Island					0.16	0.78
Boat Creek	Boat Creek		0.20	0.42	0.80	0.27	0.46
Inner Harbour	Little Enfield Creek				0.75	0.27	0.70
	Barney Point Pond		0.22	0.44	0.69	0.23	0.56
Calliope Estuary	Beecher Creek	0.83	0.11	0.39	0.66	0.29	0.75
	Old Bruce Highway Bridge				0.44	0.34	0.82
Auckland Inlet	Callemondah	0.60	0.07	0.38	0.68	0.48	0.91
Mid Harbour	Farmers Point					0.08	0.90
	Gatcombe Anchorage					0.34	0.52
South Trees Inlet	Wappentake Creek		0.21	0.49	0.58	0.31	0.66
	South Trees					0.41	0.63
	Crematorium Pool					0.26	0.84
Boyne Estuary	Old Boyne	0.69	0.29		0.60	0.44	0.70
	Boyne Highway				0.53	0.48	0.77
Colosseum Inlet	Broadacres					0.35	0.72
	Iveragh					0.40	0.69
Rodds Bay	Oaky					0.48	0.75
	7 Mile					0.49	0.74
	Worthington					0.26	0.69
	Sandy Bridge					0.38	0.79

Table 3: Score estimates on a $(0,1)-$scale, for the Gladstone Harbour Bream survey sites for all years

3.5 Aggregation to zone level

The present project proposes a rather simple method for aggregating scores to the zone level within years, as required for reporting purposes, and further aggregating to all of harbour. As described previously, we use simple averaging over sites within zones (i.e. equally weighted) and simple averaging over zones to all of harbour.[2]

The results of this averaging process are shown in Table 4, and the resulting grades are shown in Table 5 on the following page.

[2]This arbitrary process is nevertheless consistent with those used in other components of the report card.

Zone	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	0.74	0.21	0.32	0.67	0.29	0.75
Graham Creek				0.66	0.39	0.58
Western Basin					0.16	0.78
Boat Creek		0.20	0.42	0.80	0.27	0.46
Inner Harbour		0.22	0.44	0.72	0.25	0.63
Calliope Estuary	0.83	0.11	0.39	0.55	0.32	0.79
Auckland Inlet	0.60	0.07	0.38	0.68	0.48	0.91
Mid Harbour					0.21	0.71
South Trees Inlet		0.21	0.49	0.58	0.33	0.71
Boyne Estuary	0.69	0.29		0.57	0.46	0.73
Colosseum Inlet					0.38	0.70
Rodds Bay					0.40	0.74
All of Gladstone Harbour	0.72	0.19	0.41	0.65	0.33	0.71

Table 4: Score estimates on a $(0,1)-$scale, averaged over sites within zones, and over all of harbour, using the revised system developed in this report.

Zone	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	B	E	D	B	D	B
Graham Creek				B	D	C
Western Basin					E	B
Boat Creek		E	D	B	D	D
Inner Harbour		E	D	B	E	C
Calliope Estuary	B	E	D	C	D	B
Auckland Inlet	C	E	D	B	D	A
Mid Harbour					E	B
South Trees Inlet		E	D	C	D	B
Boyne Estuary	B	D		C	D	B
Colosseum Inlet					D	B
Rodds Bay					D	B
All of Gladstone Harbour	B	E	D	C	D	B

Table 5: Alphabetic grades for (unadjusted) averaged scores over sites within zones, and over all of harbour, using the revised system developed in this report.

3.6 Grade stability aspects

For comparison with the previous project report, Table 6 shows the grade results when the approach advocated in this report is used with the data set up to year 15-16 only, (that is, had the present approach been used last year), and Table 7 shows the actual grades presented last year and used for the report card.

Zone	11-12	12-13	13-14	14-15	15-16
The Narrows	B	E	D	B	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	C	D
Boyne Estuary	B	D		C	C
Colosseum Inlet					D
Rodds Bay					D
All of Gladstone Harbour	B	E	D	B	D

Table 6: Zone grades with the present system if only data up to up to year 15-16 is used. A stability check.

Zone	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 7: Grades for reporting zones using the previous scoring and grading scheme. *[This table is taken verbatim from the ISP013-2015 report.]*

For some time to come new data will inevitably revise the assessments of previous years simply because the knowledge base is changing. Comparing Tables 6 and 7 with Table 5, it

appears that such revisions will be minor. In other words, the process seems to be reasonably robust.

3.7 Bootstrap simulations

Uncertainty propagation within the report card system requires that we produce credible simulations of our scores, on the $(0,1)$ scale, for the reporting regions that reflect the uncertainty in the process itself. We detail one proposed method below.

A by-product of the generalized linear mixed model fitting process is that standard errors for the BLUP estimates, E_Y and E_{YS} components in particular, become easily available. These are shown in Table 8.

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					0.304	0.305
	Munduran Creek	0.303	0.310	0.300	0.286	0.286	0.288
	Black Swan				0.301	0.307	0.298
	Targinnie Creek	0.338	0.347		0.299	0.306	0.299
Graham Creek	Graham Creek				0.336	0.319	0.314
	Hobble Gully				0.301	0.300	0.299
Western Basin	Mud Island					0.332	0.328
Boat Creek	Boat Creek		0.353	0.321	0.316	0.320	0.316
Inner Harbour	Little Enfield Creek				0.297	0.303	0.299
	Barney Point Pond		0.342	0.334	0.329	0.338	0.333
Calliope Estuary	Beecher Creek	0.309	0.314	0.304	0.291	0.299	0.293
	Old Bruce Highway Bridge				0.307	0.302	0.300
Auckland Inlet	Callemondah	0.305	0.304	0.291	0.283	0.289	0.285
Mid Harbour	Farmers Point					0.321	0.316
	Gatcombe Anchorage					0.328	0.328
South Trees Inlet	Wappentake Creek		0.332	0.331	0.315	0.323	0.316
	South Trees					0.306	0.307
	Crematorium Pool					0.303	0.304
Boyne Estuary	Old Boyne	0.318	0.335		0.288	0.292	0.291
	Boyne Highway				0.316	0.301	0.300
Colosseum Inlet	Broadacres					0.310	0.310
	Iveragh					0.308	0.309
Rodds Bay	Oaky					0.307	0.308
	7 Mile					0.306	0.308
	Worthington					0.312	0.312
	Sandy Bridge					0.304	0.305
Harbour		0.227	0.226	0.217	0.169	0.147	0.145

Table 8: Standard error estimates for the BLUP components. The body of the table is for the E_{YS} component and the last line is for the E_Y.

The method we propose is as follows. Consider producing simulated versions of the scores for year 16-17, that is for the last column of Table 4 on page 12.

- Generate a Normal sample of values $E_Y^\star$ and $E_{YS}^\star$ using the actual values of E_Y and E_{SY} as the means and their standard errors, (from the last column of Table 8) as the standard deviations.
- Repeat the process until the required number of simulations is achieved.
- Form values for the simulated site level scores in the obvious way, that is using

$$Z_{YS}^\star = \frac{E_Y^\star + E_{YS}^\star}{\sqrt{\hat{o}_Y^2 + \hat{o}_{YS}^2}}, \qquad \text{Score}_{YS}^\star = \Phi\left(Z_{YS}^\star\right)$$

  where $\Phi(z)$ is the standard normal (cumulative) distribution function.
- For each site, adjust the entire vector of simulations so that their mean matches as closely as possible the original zone score. This is to compensate for the non-linear transformation involved in proceeding from BLUPs to scores. The actual process involves adding a small perturbation, ε, to the standardized BLUPs:

$$\text{Score}_{YS}^{\star\star} = \Phi\left(\Phi^{-1}\left(\text{Score}_{YS}^\star\right) + \varepsilon\right)$$

  where ε is chosen so that the arithmetic mean of the (so adjusted) simulated scores is made equal to the original score itself. In all cases the perturbation required is small, but it ensures a form of consistency between the original scores and their simulated versions.[3]
- Aggregate the simulated scores to the zone level, and to all-of-harbour level as for the index itself.

Zone	Score 16-17	2.5%	97.5%
The Narrows	0.7529	0.5173	0.9358
Graham Creek	0.5843	0.2278	0.8973
Western Basin	0.7832	0.3031	0.9928
Boat Creek	0.4629	0.0611	0.9047
Inner Harbour	0.6309	0.2725	0.9222
Calliope Estuary	0.7863	0.4722	0.9714
Auckland Inlet	0.9065	0.6041	0.9982
Mid Harbour	0.7094	0.4225	0.9512
South Trees Inlet	0.7139	0.4179	0.9303
Boyne Estuary	0.7338	0.3945	0.9566
Colosseum Inlet	0.7042	0.3521	0.9499
Rodds Bay	0.7410	0.4727	0.9342
All of Harbour	0.7091	0.5242	0.8634

Table 9: Original scores, together with the lower (2.5%) and upper (97.5%) simulated uncertainty intervals. The mean of the simulations is constrained to agree with the 16-17 score.

Table 9 shows the lower (2.5%) and upper (97.5%) simulated uncertainty intervals for the 16-17 season, as generated by the process detailed above, along with the original scores. The table is based on 10000 simulations.

[3]This form of consistency is also assumed in later processes of uncertainty propagation to higher levels in the Health Index.

4 Discussion

4.1 Changes from the previous proposal

A second season in which the 26 survey sites have been visited a further four times over the December-March period has, as expected, clarified the data position and compelled us to make some changes in the process we recommend for index construction.

The first point to note is that the basic strategy of extracting from the data the material for an index that reflects year-by-year changes using a modelling process remains intact. The generic model also stands up quite well. The key quantities estimated from the model are also reasonably stable, suggesting the approach has the required degree of robustness.

As previously, the model specifies a negative binomial distribution for the *total bream catch* per visit, generally of 20 casts. It has a log link, meaning that the log of the mean of the distribution is linearly related both to the predictors and the random effects. This in turn implies that influences on the mean due to predictors and random effects are represented as *proportional* rather than absolute changes. The parent negative binomial distribution has a fixed variance parameter of $\theta = 2$, for stability purposes, but in any case as we shall see, is in line with an estimated value.

Consistent site differences in catch rates are partially explained by fixed effects and partly by a random effect `Site` term. Both of these remain fairly stable with the introduction of the current year's survey data. The stability of the random effect component is shown in Table 1 on page 9. Allowing for small regular differences in catch rates *within a season* is done using a `Month` fixed effect term. To this point the model is the same as for ISP013-2015.

The index is then based on the combination of two random effect terms through their BLUP estimates, namely a `Year` random effect and a `Year × Site` random interaction. The sum of these two terms is then referred to its distribution, as inferred by the estimated variance components, to produce scores on the required $(0, 1)$ scale.

In ISP013-2015 a `Year × Zone` random effect was fitted rather than the `Year × Site` term in the present model. This was an attempt to achieve scores at the zone level directly rather than at the lower site level, but this model, which was fragile even with the 2015-16 data, simply failed when the extra data from 2016-17 was added. The model with the random interaction at the lower level, however, appears stable. This appears to be because the sites are heterogeneous and even sites within the same geographically compact reporting zone can show sharp differences.

Fitting the stable model at the `Year × Site` level then leaves the problem of aggregating scores up to the zone level, as required for reporting purposes. Our suggestion is that this be done in the simplest way possible, namely by averaging site scores up to the zone level, and further averaging zone scores up to the all-of-harbour level. Given that the zone has to be the reporting level, this simple averaging process appears unavoidable, but it should be noted that it conceals two potential flaws: Firstly, some zones have more sites suitable for sampling than others, so their averages will be over more sites. Secondly, in some cases the sites within a zone are distinctly heterogeneous, (the nub of the difficulty with modelling at

the zone level in the first place), and averaging will smooth over these possibly important features.

There is reason to be confident that the present scoring and grading system will be reasonably consistent with that produced in 2015-16. Tables 6 and 7 on page 13 show that had the present procedure been adopted in 2015-16 the grades would have been almost identical, and Table 5 on page 12 shows that including the additional data from the present survey does not greatly alter the grades from the past year, either.

4.2 Notes on the uncertainty simulations

The health card system requires not only integration of indices across various strata but also uncertainty assessments to be propagated as well. This is done by a process involving simulations of the component indices that reflect the inherent uncertainty. We have proposed a method for this in sub-section 3.7 on page 14. This is a simple and informal procedure that will capture the major component of uncertainty, but not all. The resulting uncertainty assessments are large, but this is possibly not surprising given the nascent status of the data.

To display the extent of the uncertainty, Table 9 on page 15 gives the simulation-based 95% confidence intervals. The stand out example is the zone *Boat Creek*, where the uncertainty interval essentially covers the full range of possibilities. This is hardly surprising though, when we note that *Boat Creek* has just one survey site with a consistently low catch rate (1 bream only in 16-17, for example). Its capacity to reflect even large (proportional) changes in the bream catch rate is almost negligible and its score essentially relies on the mixed model shrinkage property, thus 'borrowing strength' from neighbouring sites. Its uncertainty assessment, however, sensibly sounds a warning that the score comes with considerable tentativeness.

This shrinkage property of mixed models could be seen as a flaw in the system or a strength depending on the purposes to which the indices are put. Essentially it allows the estimates to concede a "benefit of the doubt" advantage to those zones, particularly, where the sites are such that even making a case for an index of change based on bream catch rates is unrealistic. Conversely, in zones where the the catch rates are possibly felicitously high, the index is tempered to some extent.

4.3 Unresolved issues

The indices we have produced here are based on the assumption that the sites themselves have fairly consistent differences in potential catch rates for bream, effectively due to natural differences in their environment. These different "baseline" catch rates for the sites are reflected partly by the fixed effect terms (apart from the temporal term, `Month`) but mainly by the `Site` random main effect, which is used to capture the large unexplained variations remaining.

Figure 1 on page 9 provides some evidence that these notional "baseline" catch rates, in

a relative sense, can be reasonably well estimated from the data, as the BLUPs involved remain fairly stable when the additional data for the present survey is included. (This brings the number of site visit records up to 337 from 233 in 2015-16.)

In any year site catch rates will vary up or down from this notional baseline, and such (proportional) changes are the target of the indices. These are based, at the site level, on the sum of the `Year` random main effect BLUP and the `Year × Site` random interaction BLUP. To produce indices on the $(0,1)$ scale, these are referred to the conceptual normal distribution from which according to the model they are drawn. The conceptual distribution is, in turn, determined by the variance component estimates which, as shown in Table 1 on page 8, are also reasonably stable.

The two issues to which we draw attention here are the following:

- The baseline site differences in catch rates will clearly be partly natural and partly anthropogenic. There is no way in the data to isolate these. It may be useful to report these baseline site catch rates, at least in some relative sense, (even more explicitly than in Figure 1), so that the users of the indices are aware that an allowance for them has been made for them in arriving at the indices. The issue of to what extent such baseline differences are natural or anthropogenic has to remain unresolved in the absence of usable data.
- Currently the grades, A–E, are simply assigned according to the automatic way the $(0,1)$ scores are computed, that is by reference to their conceptual random effect distribution, using the GHHP standard. There is no particular reason, however, for a score in *our* range 0.50–0.65 *necessarily* to be allocated a C grade, for example. Just what any grade is intended to imply for users and how the scores we generate should be related to such an implication is, for want of an explicit definition, unresolved.

  Put another way, it is conceivable that expert opinion could, from the scores we produce, arrive at different cut-off levels to reflect the true situation given the understood meaning of the grades. In this case a simple re-scaling of the scores could be done to ensure conformity with the GHHP standard. Now that we have two years' data, it may be possible, and appropriate, for this issue to be considered and explicitly resolved by environmental professionals.

A Terminology

This report will use some different names for various entities from those used in the previous report, ISP013-2015. The new terms we use are more in line with those used in other parts of the GHHP project, and hence hopefully less open to misunderstanding.

Site: A section of the harbour where cast net samples are taken on a regular basis. (The previous term used was **Location**.)

Visit: A time and site where a survey sample is taken. A site visit generally uses 20 casts for the sample. (The previous term used was **Trip**.)

Zone: A section of the harbour for which local indices are required. That is, a reporting region of the harbour. (The previous term used was **Sub-region**.)

Month: A period of the calendar year within which all, or most, sites are surveyed at least once. These are generally the calendar months December, January, February and March, though in the historical data other periods of the calendar have been used. (The previous term used was **Period**.)

Year: A 12 month period notionally beginning on 1 October and extending to 30 September in the following calendar year. (The previous term used was **Season**.)

Score: A numerical result on a $(0,1)$ scale. This is consistent with previous usage, but repeated here for convenience.

Grade: A letter, A, B, C, D, or E, got by translating a score into an ordinal scale. This is also consistent with previous usage.

B Size profiles

Figure 2 and Table 10 show the size distribution of the Bream catch, by species, for each of the four months of the survey, for all of harbour.

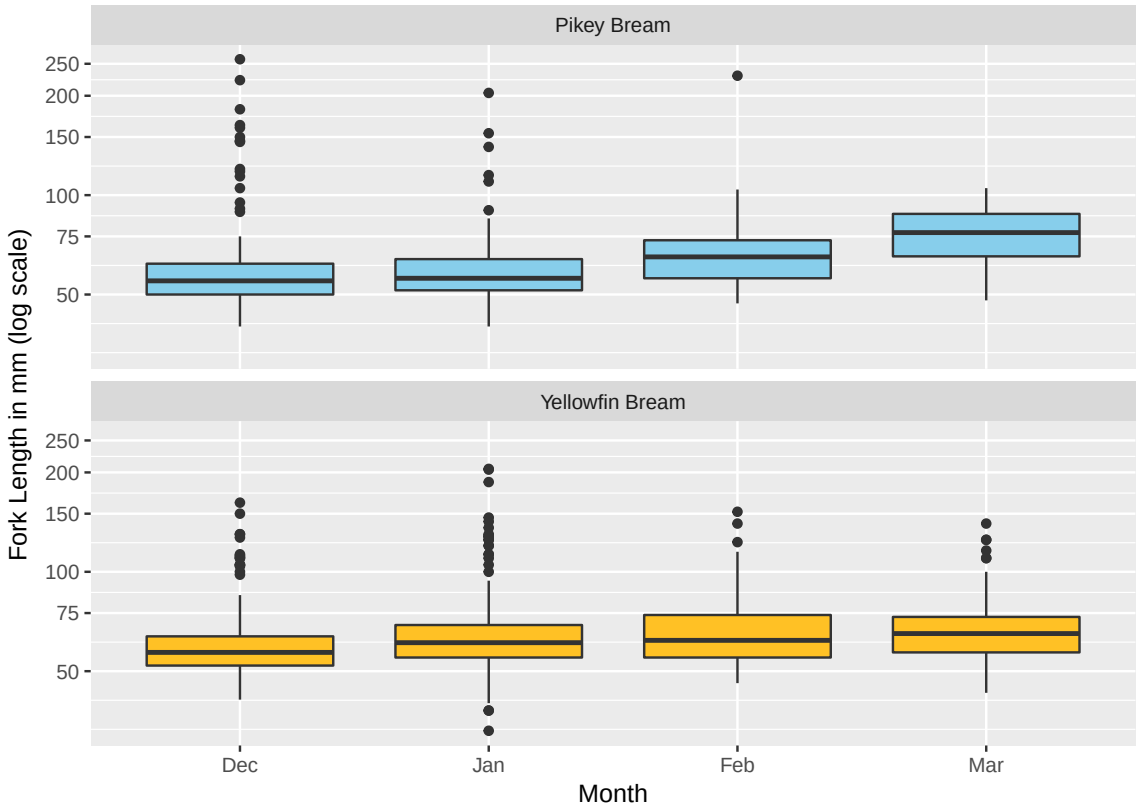

Figure 2: Fork length distribution for 2016-17 Bream catch data over the four survey months

Species	Month	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Pikey Bream	Dec	40	50	55	71	62	258
	Feb	47	56	65	68	73	230
	Jan	40	52	56	61	64	204
	Mar	48	65	77	76	88	105
Yellowfin Bream	Dec	41	52	57	62	64	162
	Feb	46	55	62	67	74	152
	Jan	33	55	61	70	69	205
	Mar	43	57	65	68	73	140

Table 10: Bream size distribution summary statistics: Fork length (in mm).

These figures are included for information. Perhaps the only mildly surprising aspect of them are the small numbers of large Pikey Bream individuals caught in the December surveys. Most of these are likely year 1 fish rather than year 0 recruits, but have been included in the analysis nevertheless. The result is unlikely to have been affected.

C Basic catch and effort data

In this section we present catch and effort data as a reference for discussion.

C.1 Casts

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					50	80
	Munduran Creek	60	60	80	100	100	80
	Black Swan				80	80	80
	Targinnie Creek	10	10		80	80	80
Graham Creek	Graham Creek				20	60	80
	Hobble Gully				80	80	80
Western Basin	Mud Island					100	80
Boat Creek	Boat Creek		10	80	75	80	80
Inner Harbour	Little Enfield Creek				100	80	80
	Barney Point Pond		80	100	100	80	80
Calliope Estuary	Beecher Creek	50	70	80	100	80	80
	Old Bruce Highway Bridge				50	80	80
Auckland Inlet	Callemondah	50	70	100	100	80	80
Mid Harbour	Farmers Point					90	80
	Gatcombe Anchorage					100	80
South Trees Inlet	Wappentake Creek		70	60	100	80	80
	South Trees					90	80
	Crematorium Pool					100	80
Boyne Estuary	Old Boyne	20	20		100	80	80
	Boyne Highway				40	80	80
Colosseum Inlet	Broadacres					100	80
	Iveragh					100	80
Rodds Bay	Oaky					100	80
	7 Mile					100	80
	Worthington					100	80
	Sandy Bridge					100	80

Table 11: Numbers of casts per site, per survey year, for all surveys included in the study

C.2 Pikey Bream

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					56	48
	Munduran Creek	0	0	2	0	0	0
	Black Swan				25	1	77
	Targinnie Creek	0	0		0	0	2
Graham Creek	Graham Creek				3	2	8
	Hobble Gully				21	30	24
Western Basin	Mud Island					0	3
Boat Creek	Boat Creek		0	0	5	2	1
Inner Harbour	Little Enfield Creek				30	13	24
	Barney Point Pond		0	2	1	0	0
Calliope Estuary	Beecher Creek	0	0	0	1	1	2
	Old Bruce Highway Bridge				0	10	37
Auckland Inlet	Callemondah	2	0	12	17	15	43
Mid Harbour	Farmers Point					0	0
	Gatcombe Anchorage					2	1
South Trees Inlet	Wappentake Creek		0	1	1	1	1
	South Trees					11	16
	Crematorium Pool					1	0
Boyne Estuary	Old Boyne	2	0		4	1	0
	Boyne Highway				0	1	0
Colosseum Inlet	Broadacres					2	12
	Iveragh					2	3
Rodds Bay	Oaky					13	12
	7 Mile					23	16
	Worthington					1	4
	Sandy Bridge					0	2

Table 12: Total numbers of Pikey Bream caught per site, per survey year

C.3 Yellowfin Bream

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					6	22
	Munduran Creek	33	13	10	20	23	29
	Black Swan				4	0	17
	Targinnie Creek	2	0		38	5	21
Graham Creek	Graham Creek				4	5	0
	Hobble Gully				1	2	0
Western Basin	Mud Island					0	3
Boat Creek	Boat Creek		0	5	4	1	0
Inner Harbour	Little Enfield Creek				7	1	4
	Barney Point Pond		1	0	2	0	0
Calliope Estuary	Beecher Creek	18	3	11	18	9	20
	Old Bruce Highway Bridge				9	11	8
Auckland Inlet	Callemondah	9	5	13	25	16	35
Mid Harbour	Farmers Point					0	26
	Gatcombe Anchorage					2	0
South Trees Inlet	Wappentake Creek		2	2	3	2	3
	South Trees					17	15
	Crematorium Pool					50	123
Boyne Estuary	Old Boyne	8	6		35	34	42
	Boyne Highway				10	42	49
Colosseum Inlet	Broadacres					17	11
	Iveragh					23	20
Rodds Bay	Oaky					23	25
	7 Mile					15	19
	Worthington					11	14
	Sandy Bridge					47	68

Table 13: Total numbers of Yellowfin Bream caught per site, per survey year

C.4 Bream total

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					62	70
	Munduran Creek	33	13	12	20	23	29
	Black Swan				29	1	94
	Targinnie Creek	2	0		38	5	23
Graham Creek	Graham Creek				7	7	8
	Hobble Gully				22	32	24
Western Basin	Mud Island					0	6
Boat Creek	Boat Creek		0	5	9	3	1
Inner Harbour	Little Enfield Creek				37	14	28
	Barney Point Pond		1	2	3	0	0
Calliope Estuary	Beecher Creek	18	3	11	19	10	22
	Old Bruce Highway Bridge				9	21	45
Auckland Inlet	Callemondah	11	5	25	42	31	78
Mid Harbour	Farmers Point					0	26
	Gatcombe Anchorage					4	1
South Trees Inlet	Wappentake Creek		2	3	4	3	4
	South Trees					28	31
	Crematorium Pool					51	123
Boyne Estuary	Old Boyne	10	6		39	35	42
	Boyne Highway				10	43	49
Colosseum Inlet	Broadacres					19	23
	Iveragh					25	23
Rodds Bay	Oaky					36	37
	7 Mile					38	35
	Worthington					12	18
	Sandy Bridge					47	70

Table 14: Total numbers of Bream caught, Pikey Bream plus Yellowfin Bream, per site, per survey year

C.5 Pikey Bream catch per site visit of 20 casts

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					22.40	12.00
	Munduran Creek	0.00	0	0.50	0.00	0.00	0.00
	Black Swan				6.25	0.25	19.25
	Targinnie Creek	0.00	0		0.00	0.00	0.50
Graham Creek	Graham Creek				3.00	0.67	2.00
	Hobble Gully				5.25	7.50	6.00
Western Basin	Mud Island					0.00	0.75
Boat Creek	Boat Creek		0	0.00	1.33	0.50	0.25
Inner Harbour	Little Enfield Creek				6.00	3.25	6.00
	Barney Point Pond		0	0.40	0.20	0.00	0.00
Calliope Estuary	Beecher Creek	0.00	0	0.00	0.20	0.25	0.50
	Old Bruce Highway Bridge				0.00	2.50	9.25
Auckland Inlet	Callemondah	0.80	0	2.40	3.40	3.75	10.75
Mid Harbour	Farmers Point					0.00	0.00
	Gatcombe Anchorage					0.40	0.25
South Trees Inlet	Wappentake Creek		0	0.33	0.20	0.25	0.25
	South Trees					2.44	4.00
	Crematorium Pool					0.20	0.00
Boyne Estuary	Old Boyne	2.00	0		0.80	0.25	0.00
	Boyne Highway				0.00	0.25	0.00
Colosseum Inlet	Broadacres					0.40	3.00
	Iveragh					0.40	0.75
Rodds Bay	Oaky					2.60	3.00
	7 Mile					4.60	4.00
	Worthington					0.20	1.00
	Sandy Bridge					0.00	0.50

Table 15: Pikey Bream catch per visit of 20 casts, (CPUE), per site, per survey year

C.6 Yellowfin Bream catch per site visit of 20 casts

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					2.40	5.50
	Munduran Creek	11.00	4.33	2.50	4.00	4.60	7.25
	Black Swan				1.00	0.00	4.25
	Targinnie Creek	4.00	0.00		9.50	1.25	5.25
Graham Creek	Graham Creek				4.00	1.67	0.00
	Hobble Gully				0.25	0.50	0.00
Western Basin	Mud Island					0.00	0.75
Boat Creek	Boat Creek		0.00	1.25	1.07	0.25	0.00
Inner Harbour	Little Enfield Creek				1.40	0.25	1.00
	Barney Point Pond		0.25	0.00	0.40	0.00	0.00
Calliope Estuary	Beecher Creek	7.20	0.86	2.75	3.60	2.25	5.00
	Old Bruce Highway Bridge				3.60	2.75	2.00
Auckland Inlet	Callemondah	3.60	1.43	2.60	5.00	4.00	8.75
Mid Harbour	Farmers Point					0.00	6.50
	Gatcombe Anchorage					0.40	0.00
South Trees Inlet	Wappentake Creek		0.57	0.67	0.60	0.50	0.75
	South Trees					3.78	3.75
	Crematorium Pool					10.00	30.75
Boyne Estuary	Old Boyne	8.00	6.00		7.00	8.50	10.50
	Boyne Highway				5.00	10.50	12.25
Colosseum Inlet	Broadacres					3.40	2.75
	Iveragh					4.60	5.00
Rodds Bay	Oaky					4.60	6.25
	7 Mile					3.00	4.75
	Worthington					2.20	3.50
	Sandy Bridge					9.40	17.00

Table 16: Yellowfin Bream catch per visit of 20 casts, (CPUE), per site, per survey year

C.7 Total Bream catch per site visit of 20 casts

Zone	Site	11-12	12-13	13-14	14-15	15-16	16-17
The Narrows	Ramsay Crossing					24.80	17.50
	Munduran Creek	11.00	4.33	3.00	4.00	4.60	7.25
	Black Swan				7.25	0.25	23.50
	Targinnie Creek	4.00	0		9.50	1.25	5.75
Graham Creek	Graham Creek				7.00	2.33	2.00
	Hobble Gully				5.50	8.00	6.00
Western Basin	Mud Island					0	1.50
Boat Creek	Boat Creek		0	1.25	2.40	0.75	0.25
Inner Harbour	Little Enfield Creek				7.40	3.50	7.00
	Barney Point Pond		0.25	0.40	0.60	0	0
Calliope Estuary	Beecher Creek	7.20	0.86	2.75	3.80	2.50	5.50
	Old Bruce Highway Bridge				3.60	5.25	11.25
Auckland Inlet	Callemondah	4.40	1.43	5.00	8.40	7.75	19.50
Mid Harbour	Farmers Point					0	6.50
	Gatcombe Anchorage					0.80	0.25
South Trees Inlet	Wappentake Creek		0.57	1.00	0.80	0.75	1.00
	South Trees					6.22	7.75
	Crematorium Pool					10.20	30.75
Boyne Estuary	Old Boyne	10.00	6.00		7.80	8.75	10.50
	Boyne Highway				5.00	10.75	12.25
Colosseum Inlet	Broadacres					3.80	5.75
	Iveragh					5.00	5.75
Rodds Bay	Oaky					7.20	9.25
	7 Mile					7.60	8.75
	Worthington					2.40	4.50
	Sandy Bridge					9.40	17.50

Table 17: Total Bream, Pikey Bream plus Yellowfin Bream, catch per visit of 20 casts, (CPUE), per site, per survey year

C.8 Catch per site visit of 20 casts 2015-16 versus 2016-17

The following diagram shows the total Bream CPUE per site for survey year 2016-17 plotted against the same total Bream CPUE per site for survey year 2015-16, partitioned into recording zones. Points above the diagonal line correspond to sites whose CPUE increased in 2016-17 from what it was in 2015-16, and points below the line to those for which CPUE decreased.

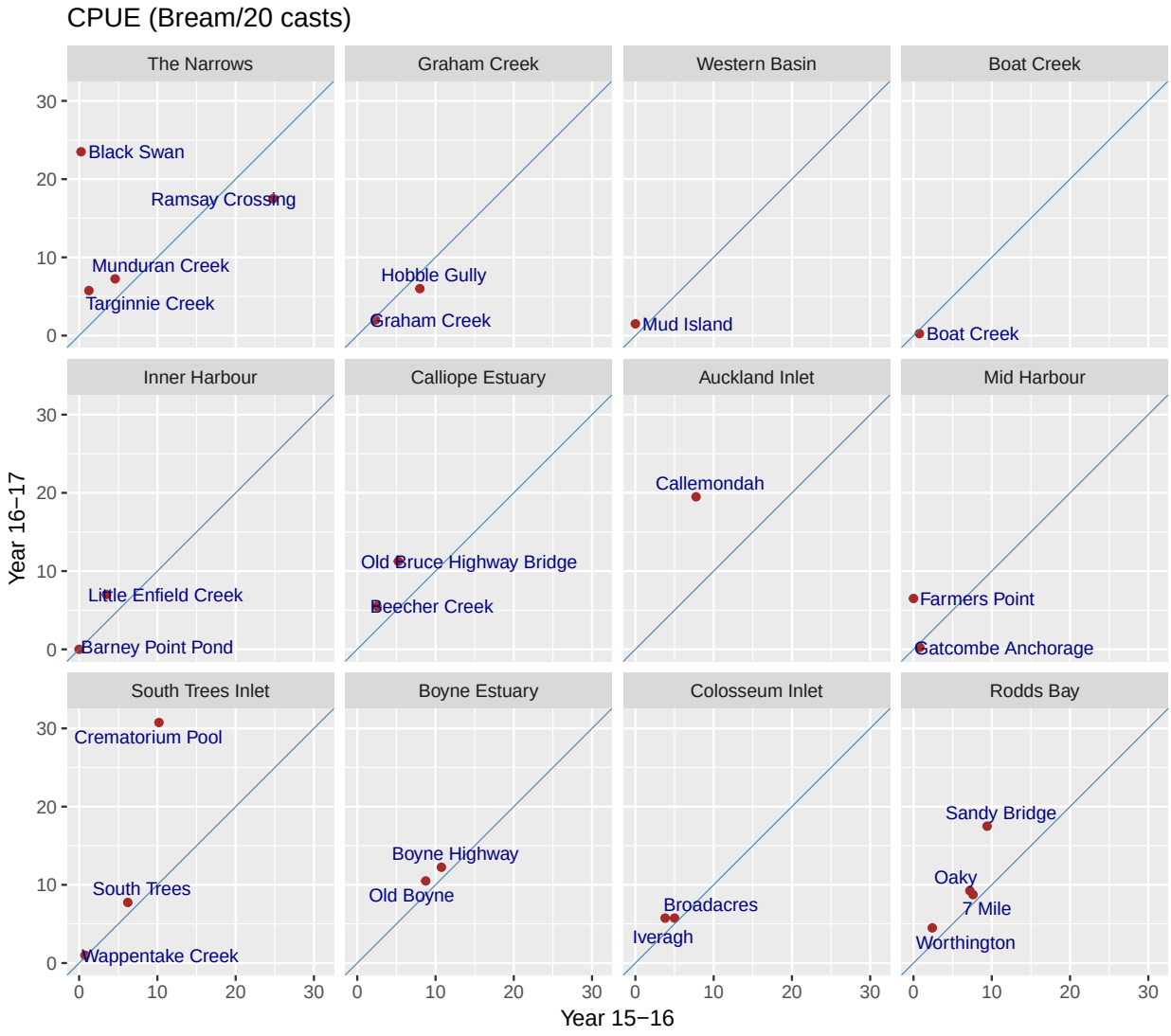

Figure 3: Bream CPUE for 2016-17 against CPUE for 2015-16 per site partitioned into recording zones