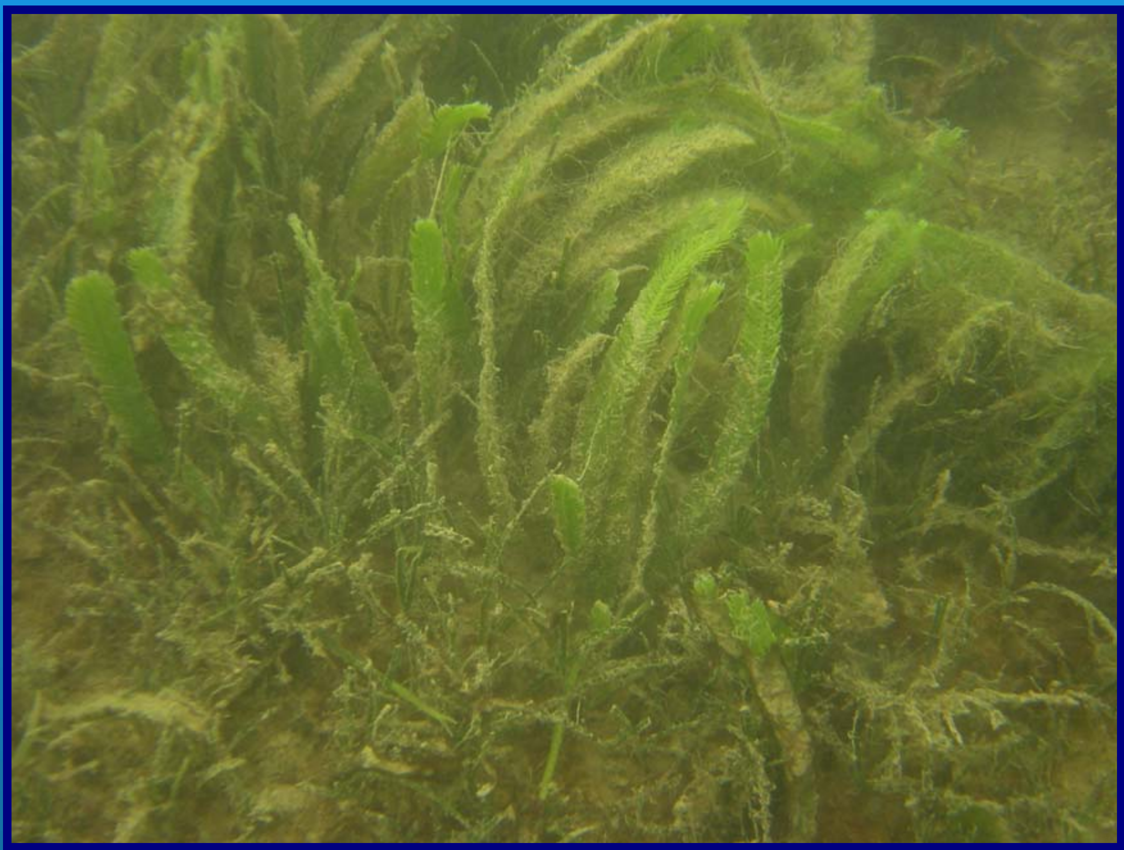
Marine Environment and Ecology

Caulerpa taxifolia - 2010 survey of current distribution and high risk areas, and summary of distribution patterns 2003-2010



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July 2010

Government of South Australia

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EXECUTIVE SUMMARY

The invasive alga *Caulerpa taxifolia* is established in the Port River-Barker Inlet system. Knowledge of its distribution is important for management, so the population has been surveyed annually since 2003. Data collected during these surveys were compiled and investigated to determine patterns in the distribution of the alga that may be useful for future monitoring and management. This report gives the results of the 2010 survey and summarises patterns in the distribution of *C. taxifolia* from 2003-2010.

From 2006-2010 the distribution of *C. taxifolia* has remained almost static; overall abundance has varied, but the areas of greatest *C. taxifolia* density have consistently been:

1) the Port River along the western edge of Torrens Island,
2) North Arm - Eastern Passage, and,
3) the Angas Inlet-Barker Inlet junction.

Exploration of data collected during the 2006-2010 surveys revealed areas that may indicate trends in the population, including parts of Section Bank, Barker Inlet and the North Arm. Since 2008, abundance of *C. taxifolia* was found to be moderately and significantly positively correlated with abundance of *C. racemosa* var. *cylindracea* and weakly but significantly negatively correlated with abundance of *Zostera* spp.

The 2010 surveys found a decreased density of *C. taxifolia* through much of the survey area compared to recent previous surveys, although the highest density continued to be found in the same area as previous surveys. *Caulerpa taxifolia* continues to occur in the upper Port River in the same areas it was found in 2008, but also with decreased density.

Surveys of the Bolivar coast as well as St Kilda, West Beach, North Haven and O'Sullivan Beach boat ramps did not find any *C. taxifolia*, but, as in previous surveys, *C. racemosa* was found at St Kilda and O'Sullivan Beach boat ramps as well as along the Bolivar coast.

1. INTRODUCTION

The alga *Caulerpa taxifolia* (Vahl) C. Agardh has a native circumtropical distribution and has formed invasive populations in numerous areas outside its native range, particularly in the Mediterranean (Meinesz *et al.* 2001; Cevik *et al.* 2007), with impacts on seagrass, macroalgae, fish and invertebrates reported (de Villèle and Verlaque 1995; Boudouresque *et al.* 1996; Ferrer *et al.* 1997; York *et al.* 2006; Gribben *et al.* 2009). In Australia, invasive populations have established in New South Wales (Creese *et al.* 2004; NSW DPI 2009) and South Australia (SA) (Cheshire *et al.* 2002; Rowling 2007).

The population of *C. taxifolia* in the Port River-Barker Inlet system, SA, cannot be eradicated with current technology (Manning and Deveney 2008; Westphalen 2008) and the approach to the alga has shifted from attempting eradication to containment of the population. Ongoing monitoring of the population is important for informing management of the alga, and surveys of the *C. taxifolia* distribution in the Port River-Barker Inlet system have been conducted annually since 2003. The population of *C. taxifolia* in the upper Port River was not included in annual surveys until the present (2010) survey, but was investigated separately in 2004 (Westphalen *et al.* 2004) and 2008 (Rowling 2009). The following areas regarded as at high risk of invasion have also been surveyed annually: Adelaide metropolitan boat ramps (since 2007) and the Bolivar coast (since 2009) (Rowling 2007, 2008; Wiltshire and Rowling 2009). In 2005 the North Haven-Semaphore coast (Westphalen and Rowling 2005; Rowling 2008) and Inner Harbour (Theil *et al.* 2005) were surveyed. Data from all of these surveys except the 2004 upper Port survey, which used different methodology, has recently been compiled into a GIS-linked database.

Reports on the distribution of *C. taxifolia* published in 2004 (Westphalen *et al.* 2004) and 2007-2009 (Rowling 2007, 2008; Wiltshire and Rowling 2009) include some observations on patterns of the distribution of the alga, but these were not based on spatial analysis of the data. Compilation of the data set, including spatial information, into a single database allowed direct comparison of the distribution of *C. taxifolia* between years. Spatial analysis showed changes in the distribution and areas of greatest density over time. Analysis of the survey data also allowed identification of areas that may characterise trends in the population and so be useful for future monitoring.

Cover of major habitat types (including seagrasses) and other marine pest species (e.g. *Sabella spallanzanii*) has also been recorded during the surveys, as has cover of *Caulerpa racemosa* var. *cylindracea.* This species was recorded because it is believed to be a good indicator of areas suitable for *C. taxifolia* colonisation (Westphalen *et al.* 2004; Rowling 2007, 2008; Wiltshire and Rowling 2009); it is native to south-western Australia, but in the Mediterranean has shown similar invasive characteristics to *C. taxifolia* (Klein and Verlaque 2008). Patterns in the cover of *C. racemosa* and seagrass (*Zostera* spp.) from 2008-2010 were investigated to determine how these varied in relation to *C. taxifolia* cover. Only cover data for *Caulerpa* and *Zostera* species were considered, as cover of these taxa may be related to cover of *C. taxifolia* through either competitive interactions or changes in environmental conditions that may favour growth of one taxon over another, whereas cover of other marine pests is not likely to be meaningfully related to cover of *C. taxifolia*. The presence of *Posidonia* spp. seagrass has also been recorded in some surveys, but only in the northern reaches of Barker Inlet along Section Bank (SARDI unpublished data) where *C. taxifolia* has rarely occurred.

This report presents the findings of the spatial analysis of survey data from 2003-2010 and of the 2010 survey of *C. taxifolia* distribution in the Port River-Barker Inlet (including the upper Port River), and of high risk areas: Bolivar coastline and boat ramps at St Kilda, West Beach, North Haven and O'Sullivan Beach.

2. METHODS

2.1. 2010 survey

The Port River, Barker Inlet and Bolivar coast surveys comprised >40 km of 100 m snorkelling or SCUBA diving transects along the major channels and areas of likely occurrence of *C. taxifolia* (Figure 1). The Bolivar coast transects were conducted in the shallow subtidal zone (low tide water depth 0.5 to 2 m) along an ~2 km stretch near the Bolivar outflow creek. These targeted the region where *C. racemosa* was found in 2009 (Wiltshire and Rowling 2009) as this area is believed most likely to be suitable for growth of *C. taxifolia.* Two areas of the upper Port River were surveyed: the area surrounding Jervois Bridge including eastern and western banks, and the wharf areas and substrate along the northern bank to the west of Birkenhead Bridge. These areas were selected as they were areas where *C. taxifolia* occurred with >5% cover in 2008 (Rowling 2009) and because new marinas along the western bank near Jervois bridge may be expected to increase boat traffic in the area with a concomitant risk of *C. taxifolia* translocation. Coverage of *C. taxifolia* was estimated in terms of a modified Braun-Blanquet scale (Table 1). The start and end point of each transect was referenced using a GPS (Garmin GPS60) from the tender vessel.

There were also Braun-Blanquet estimates made of the cover of seagrasses (*Zostera* and *Posidonia* spp.), other *Caulerpa* species (notably *C. racemosa* var. *cylindracea*); and any visible marine pests (*Sabella spallanzanii*, *Ciona intestinalis*, etc) for future reference. The surveys were completed between 23rd March and 14th May 2010.

Table 1. Braun-Blanquet scale that was used to record coverage of *Caulerpa taxifolia* (and other major community types) during the survey (based on a method developed in Mueller-Dombois and Ellenberg 1974).

Score	**Percent Cover**
0	Absent
1	< 5 %
2	5 – 25 %
3	26 – 50 %
4	51 – 75 %
5	76 – 95 %
6	> 95 %

Four major boat ramps across the metropolitan coast were surveyed: St Kilda, North Haven, West Beach and O'Sullivan Beach. At each site, approximately 2 hours of SCUBA or snorkel surveys were conducted. No Braun-Blanquet cover data was collected, but the presence of any visible marine pests was noted. Position fixing of the survey area was achieved using shore referenced GPS points and features. The surveys accounted for man-made structures (pontoons, pilings) and the adjacent soft substrate. The boat ramp surveys were undertaken on 21st April (St Kilda), 29th April (West Beach and O'Sullivan Beach), and 18th May 2010 (North Haven).

2.2. Spatial analysis

Surveys of the *C. taxifolia* distribution in the Port River-Barker Inlet undertaken by SARDI Aquatic sciences have used the same methodology as described above for the 2010 surveys since 2003 (Westphalen *et al.* 2004; Rowling 2007, 2008; Wiltshire and Rowling 2009), except for the 2004 upper Port survey, where transects varied in length depending on the amount of *C. taxifolia* found, and cover was scored as "nil", "light", "heavy" (>~30%) or "complete" rather than using the Braun-Blanquet scale (Westphalen *et al.* 2004). Due to the different method and scoring, these data were not included. The 2005 North Haven coast (Westphalen and Rowling 2005) and Inner Harbour (Theil *et al.* 2005) surveys, and the 2008 upper Port River survey (Rowling

2009) used the same method as the Port River-Barker Inlet surveys but with varying transect lengths of 35-40m around berths in Inner Harbour and 50 -100m in the upper Port River. In all cases, data were assigned a position based on the end point of the transect as determined by GPS. These spatially referenced data were compiled into a database by assigning a unique identifier to each GPS waypoint (waypointID). Compiled data included the waypointID, co-ordinates (latitude and longitude in decimal degrees), date, and Braun-Blanquet scores of *C. taxifolia, C. racemosa, Zostera* spp. and *Posidonia* spp. seagrasses, and other recorded marine pests.

The Geographic Information Systems (GIS) package ArcView (ver 9.3 ESRI California) was used to visualise data, perform spatial analyses and produce maps.

Exact locations and the extent of the survey area varied between years; in total, >2800 individual data points have been collected during these surveys. To facilitate visualisation and allow comparison between years, the “Integrate” tool in ArcView was used to group waypoints from an area into a single location. A radius of 250 m was selected so that data for a transect length of ~500m (including both channel edges where surveyed) were made coincident. This resulted in data being grouped to a total of 73 areas over the entire 2003-2010 survey area (including the upper Port River, North Haven-Semaphore and Bolivar coasts).

The extent of *C. taxifolia* cover was compared between years by determining the number of areas (out of 73) where the alga was recorded. Total abundance in each survey year was determined as the sum of Braun-Blanquet scores for that year. Abundance was not standardised to overall survey extent because the 2003-2005 surveys covered a wide area to ascertain the total extent the alga, while more recent surveys have targeted the area where *C. taxifolia* is known or is likely to occur. As all surveys have aimed to cover the entire area of *C. taxifolia* occurrence, the total abundance score should reflect actual abundance rather than sampling effort. The frequency distribution of Braun-Blanquet scores within four regions: Barker Inlet, Angas Inlet, North Arm-Eastern Passage, and Port River, was also determined for 2006-2010. The areas assigned to each region are shown in Table 2.

For the most recent 5 years of data (2006-2010), relative local density of *C. taxifolia* cover in each of the 73 areas was determined as the sum of Braun-Blanquet scores divided by the number of waypoints (i.e. average score). This allowed comparison of density between years and identification of areas of greatest density. To identify areas where *C. taxifolia* cover may be indicative of the overall extent and abundance of the alga, correlation co-efficients between density in areas surveyed in each of the past 5 years and a) overall abundance and b) number of areas where the alga occurred were determined.

Table 2. Survey areas by region. See Figure 2 for a map of the Port River-Barker Inlet system and surrounds with area locations shown.

Region	Includes areas
Offshore (shipping Channel and Spoil ground)	1-8
Bolivar coast	9-11
Section Bank	12-17
St Kilda	18-20
Barker Inlet	21-29
Angas Inlet	30-31
North Arm-Eastern Passage	32-36
Upper Port River	37-38
Inner Harbour	39-44
Port River	45-53
Outer Harbor (including revetments)	54-61
North Haven-Semaphore coast	62-73

Spearman rank correlation was performed using PASW statistics (ver 17 SPSS Inc) to determine the correlation between Braun-Blanquet scores for *C. taxifolia* and a) *C. racemosa* and b) *Zostera* for the period 2008-2010. Only the 3 most recent years of data were used as prior to this recording of these other taxa was inconsistent.

3. RESULTS

3.1. Current distribution

The current distribution of *Caulerpa taxifolia* from the 2010 survey is shown in Figure 1. Braun-Blanquet scores for cover (see Table 1) were mapped as: Absent (0), Light (1-2, i.e. <25 %), Medium (3-4 i.e. 26-75 %) and Heavy (5-6 i.e.76-100 %).

No *C. taxifolia* was detected along the Bolivar coast or around the surveyed boat ramps. *Caulerpa racemosa* was present at Bolivar, around the boat ramp at St Kilda, and within the marina at O'Sullivan Beach. No *Caulerpa* species were found at West Beach or North Haven.

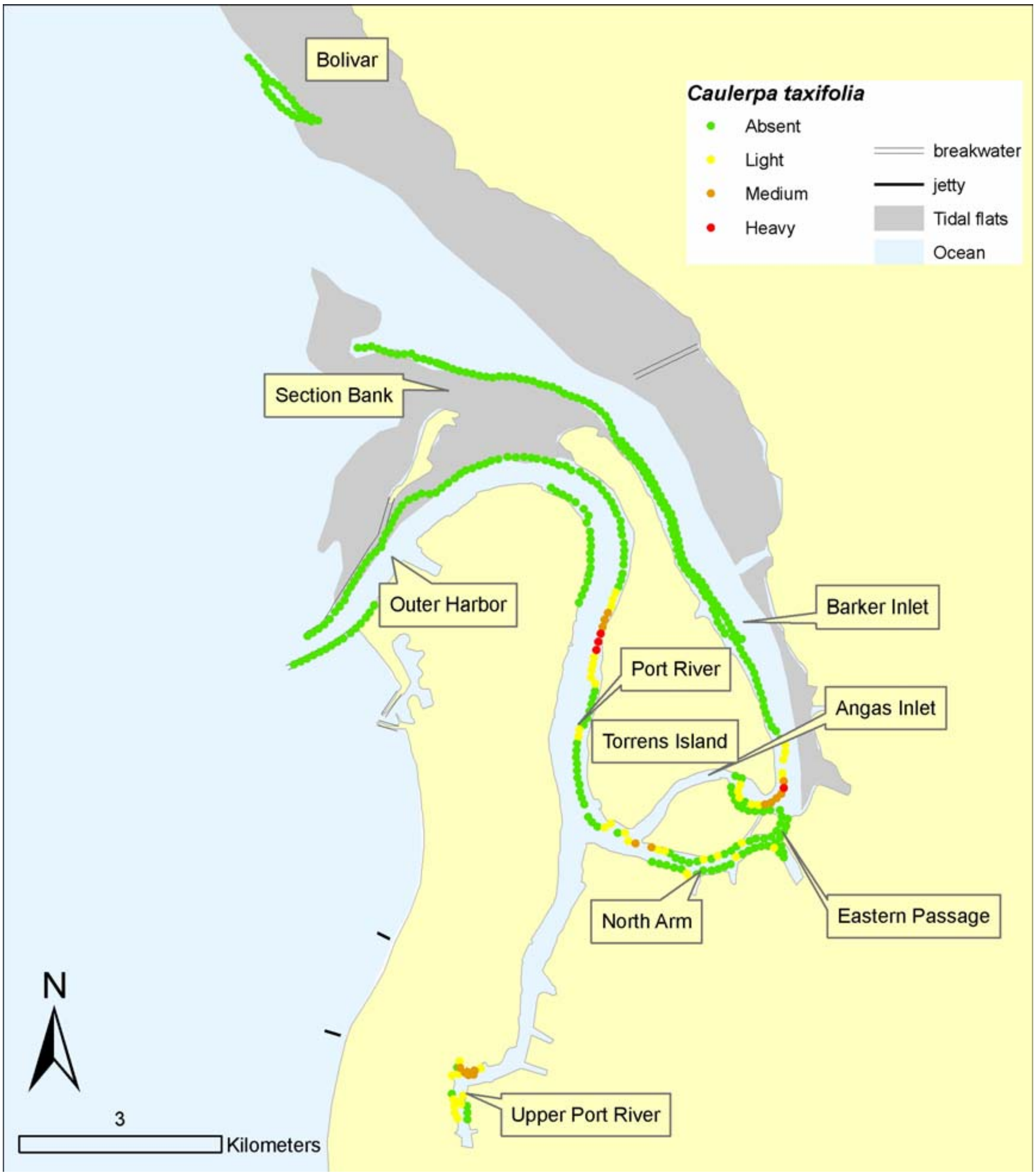

Figure 1. Location of 2010 Port River-Barker Inlet and Bolivar Coast surveys showing current distribution of *C. taxifolia*.

3.2. Distribution patterns 2003-2010

The locations of the 73 survey areas and a summary of *C. taxifolia* occurrence throughout the Port River-Barker Inlet system are shown in Figure 2. From 2003-2010 the alga has occurred in 34 of the 73 areas investigated. In 12 of these areas no score higher than 1 has been recorded (i.e. cover <5%). Two areas each have had a maximum score of 2 (5-25%) and 3 (26-50%). Four areas have had a maximum score of 4 (51-75%), and 5 a maximum score of 5 (76-95%), while 9 areas in the North Arm-Eastern Passage and Port River have recorded a maximum score of 6 (>95% cover).

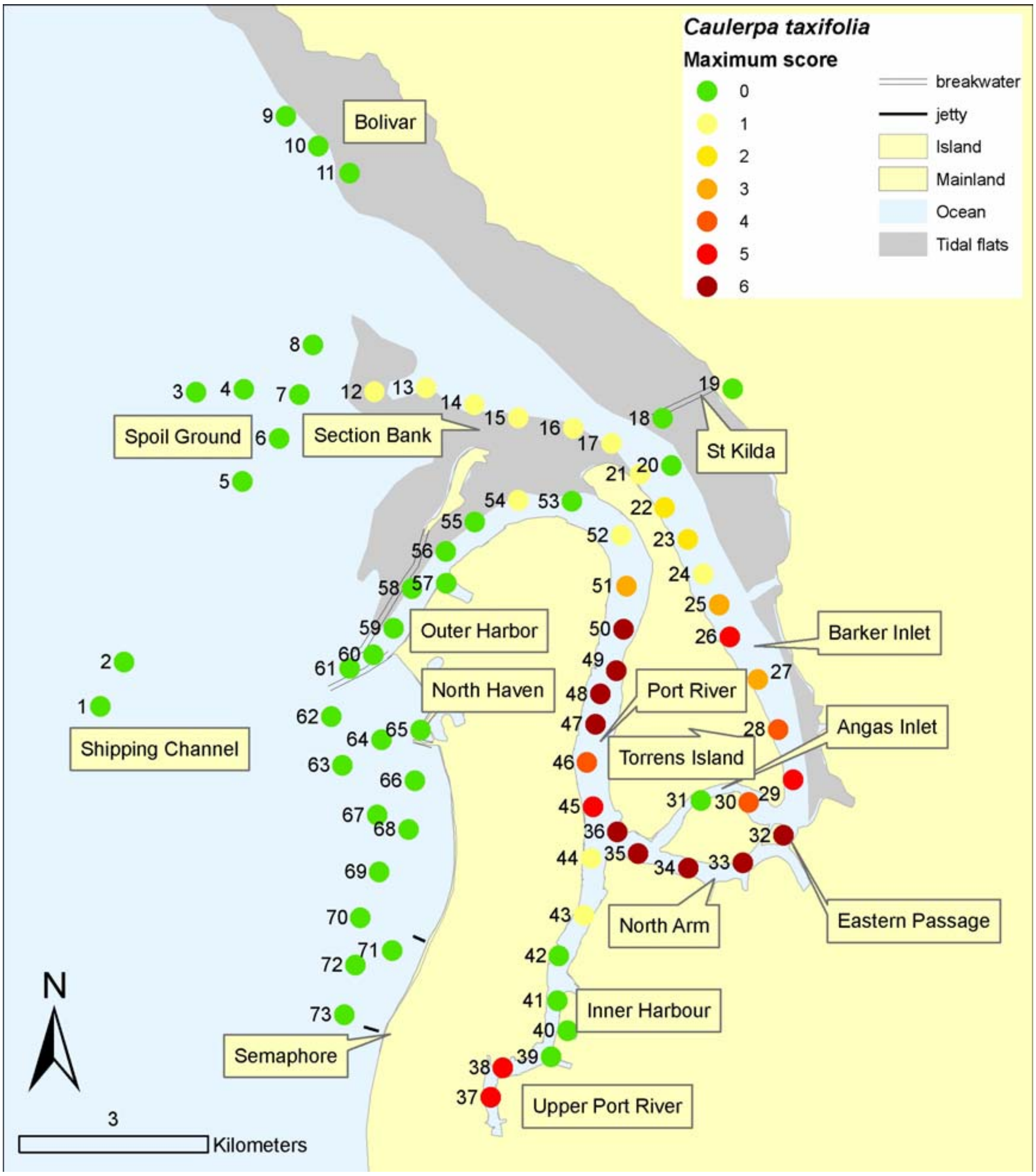

Figure 2. Location of the 73 survey areas used for comparison of annual data for 2003-2010 showing the maximum Braun-Blanquet score recorded for *C. taxifolia* in each location over all surveys.

Table 3 shows the number of areas where *C. taxifolia* occurred, total abundance score and the area with greatest density by year. Areas 32 and 35 (North Arm-Eastern Passage) had the greatest density of *C. taxifolia* in surveys in 2004-2005, but by 2005 there was also substantial *C. taxifolia* in the Port River including areas 48-49 (average score 1.7 -1.8). Since 2006 area 49 has consistently had the greatest density, with average scores ranging from 4.25 to 6.00 (i.e. all transects in the area had >95% cover).

Figure 3 shows the average *C. taxifolia* score for each year 2006-2010 by area.

In 2006 *C. taxifolia* was recorded for the first time in the middle to outer reaches of Barker Inlet (areas 21-26) to a point on Section Bank approximately opposite St Kilda (area 17). Increased density from 2005 was found in the Port River, particularly in areas 47 and 49.

In 2007, average *C. taxifolia* scores decreased in Barker Inlet and the alga was only found as far north as area 27, except for a small amount recorded on Section Bank further out than previously found in area 15. Overall extent of the alga was less, but total abundance was greater due to increases in density of the alga in the Port River (areas 47-50), North Arm-Eastern Passage (32-36) and southern Barker Inlet (29). A single record of *C. taxifolia* was found at area 54 in the Port River toward Outer Harbour, but investigation of the original data shows that this was suspected to be a drift fragment, so we show area 50 as the outer extent of the distribution for 2007. Angas Inlet (area 30) and areas 45-46 in the Port River were not included in the 2007 survey so total *C. taxifolia* abundance may have been greater than shown by Table 3; the alga occurred in all of these areas in both 2006 and 2008.

A large increase in the extent and abundance of *C. taxifolia* was observed in 2008, with the alga occurring throughout Barker Inlet to the outer extents of Section Bank (area 12). There was increased density observed through North Arm-Eastern Passage (32-36), and the extent of the alga in the Port River increased with occurrences in areas 51-52. Density remained similar at areas 47-50 where the alga had already reached near 100% cover, but increased density was observed at area 46.

Decreased total abundance and a reduced number of sites where *C. taxifolia* occurred were observed in 2009. There were fewer occurrences of the alga in Barker Inlet although it was still found as far north as area 17. In the Port River the extent of the alga also reduced slightly with none found north of area 51. The greatest reductions in density occurred in Barker Inlet (areas 25-27, 29), Eastern Passage (32) and the western end of North Arm (35). The highest average scores for 2009 were found in the same areas as 2008, i.e. Port River areas 46-50, followed by North Arm areas 34-35, although density was less than in 2008.

Table 3. Summary of *C. taxifolia* total abundance (sum of Braun-Blanquet scores), number of areas where *C. taxifolia* occurred, areas marking outer extents and areas with greatest density (average Braun-Blanquet score) for each year 2003-2010. See Figure 2 for area locations.

Year	# of Areas surveyed	# of areas with *C. taxifolia*	Total abundance	Area with highest abundance (Ave score)	Outer extents Barker Inlet/Port River
2003	34	1	1	32 (0.05)	32/-
2004	52	4	36	35 (0.80)	32/44
2005	39	12	95	32 (2.15)	29/50
2006	23	20	204	49 (4.25)	17/50
2007	35	14	233	49 (6.00)	15/50 (drift at 54)
2008	41	31	670	49 (5.75)	12/52
2009	41	20	253	49 (5.50)	17/51
2010	42	14	136	49 (4.33)	29/50

Abundance and extent of the alga declined further in 2010 with none found in Barker Inlet north of area 29 or in the Port River north of area 50. Although area 49 still recorded the highest density for the year, this was lower again than in 2009, and large decreases in density were observed at the adjacent areas 46-48, as well as in North Arm, particularly in area 34. There were slight increases in density in areas 29-30 at the Angas Inlet-Barker Inlet junction.

The frequency distribution of Braun-Blanquet scores in the main regions of *C. taxifolia* occurrence (Figure 4) show that more transects recorded the alga in 2008 (i.e. lower frequency of zero scores), and higher abundance scores were more common, particularly in Angas Inlet and North Arm-Eastern Passage.

Figure 5 shows the average abundance scores for *C. racemosa* and *Zostera* for 2008-2010 for areas surveyed in each of these three years (37 areas).

There has been a decline in the total score and number of areas of *C. racemosa* in the survey area from 2008-2010 and an increase in the total score for *Zostera* (Table 4). From 2008-2009 there was a reduction in the density of *C. racemosa* through much of the survey area, particularly in the Port River (51-52), and Barker Inlet-Section Bank, with the alga disappearing from 10 areas in which it was previously recorded (12-15, 17-23, 26-27), but 6 areas showed slight increases in *C. racemosa* including North Arm (33) and Outer Harbor (60, along the revetments). In 2010 there were decreased densities of *C. racemosa* found in the Port River (particularly 45-46, 50) and North Arm (33-34), while density increased slightly in 10 areas, including the western end of North Arm (35) and around the Barker Inlet-Angas Inlet junction (29-30).

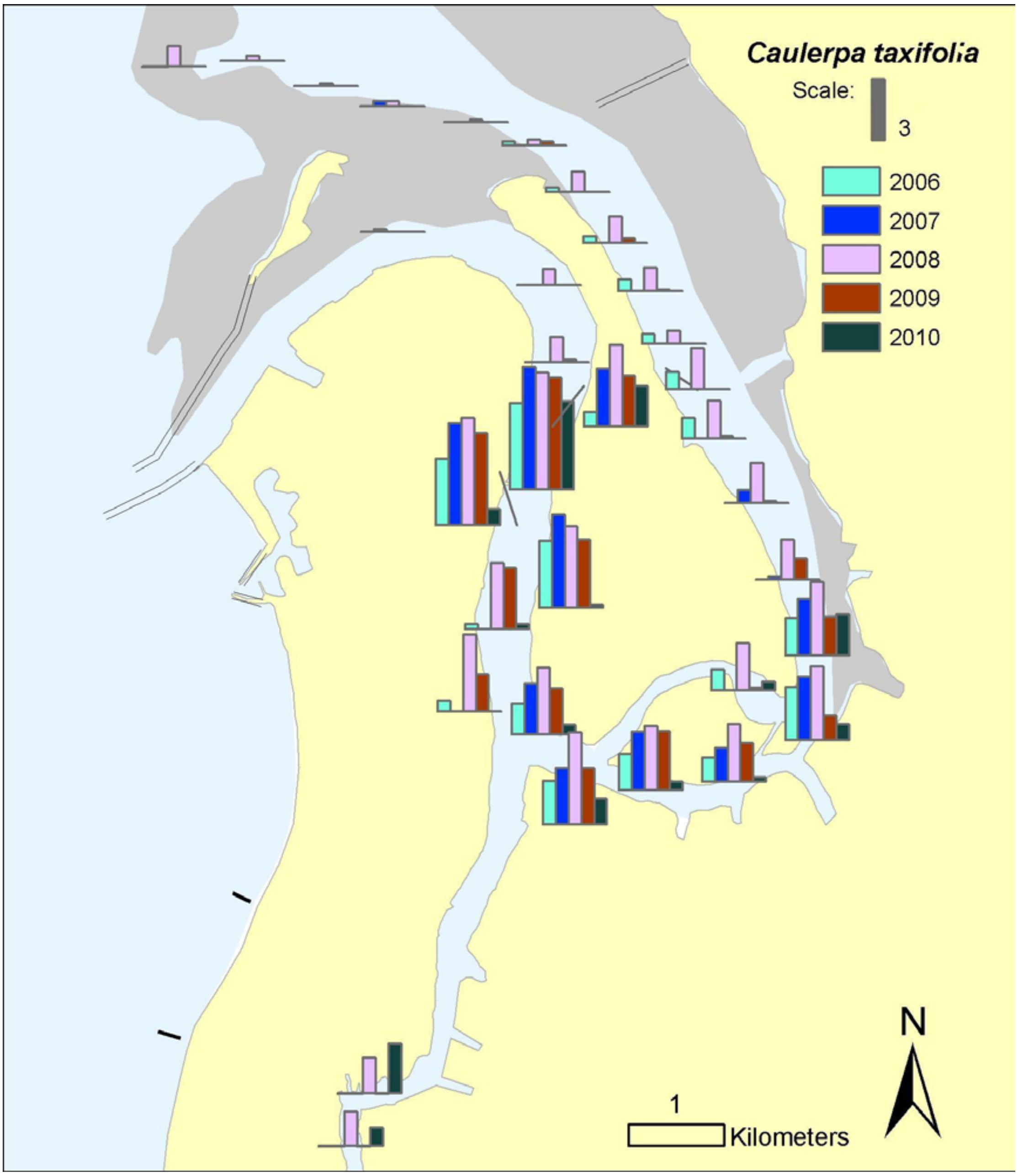

Figure 3. Relative density of *C. taxifolia* (average Braun-Blanquet score per year) by area for 2006-2010. Note: upper Port River (areas 37-38) only surveyed 2008 and 2010, 2007 survey did not include Angas Inlet or sections of the Port River immediately north of the North Arm junction (areas 30, 45-46). Refer to Figure 2 for area locations.

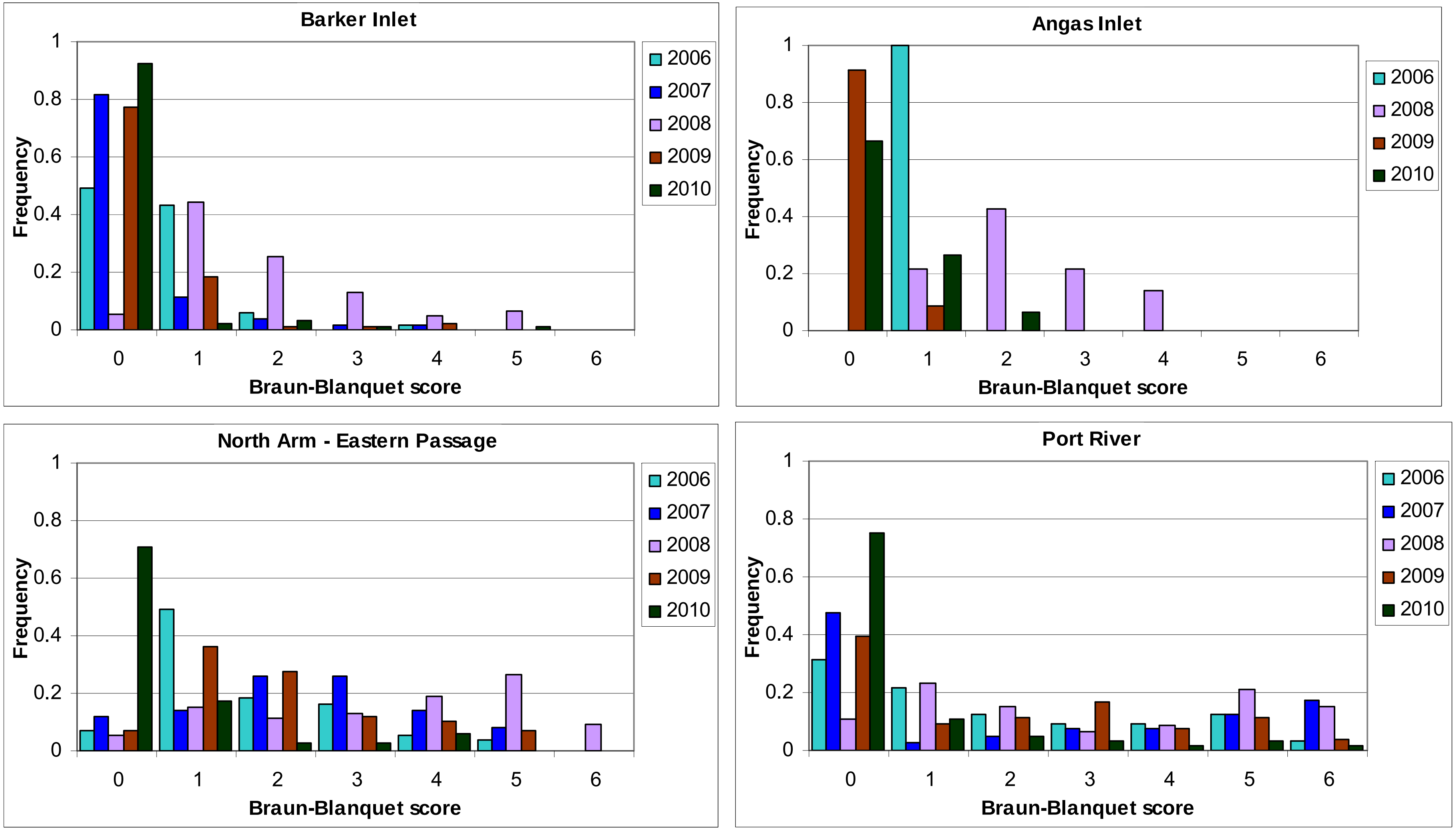

Figure 4. Frequency distribution of Braun-Blanquet scores in four regions for 2006-2010. Note: 2007 survey did not include Angas Inlet.

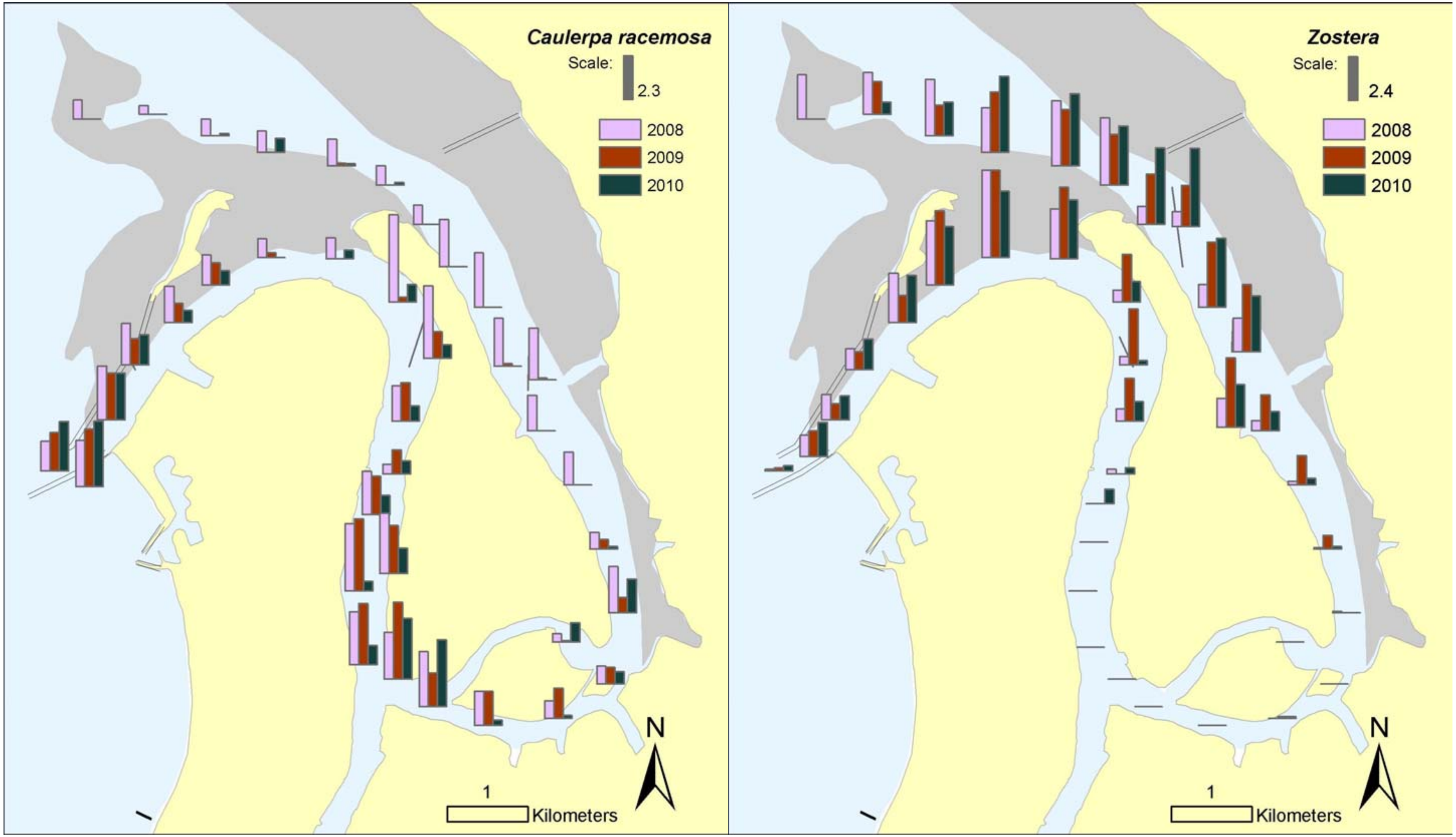

Figure 5. Relative density (average Braun-Blanquet score per year) of *Caulerpa racemosa* (left) and *Zostera* (right) by area for 2008-2010.

The abundance of *Zostera* increased overall from 2008-2009 despite a slight reduction in the number of areas where it was recorded. The greatest increases in *Zostera* density were in areas where the two *Caulerpa* species declined: Barker Inlet (23-25) and the Port River (50-51), while decreased densities were observed on Section Bank (12-14, 16) and around Outer Harbor (56-59). In 2010, the total cover for *Zostera* decreased slightly, although it occurred in more areas. Density increased in northern Barker inlet-Section Bank (14-17, 21-23) and Outer Harbor (56-61) while there were declines in southern Barker Inlet (24-28) and the Port River (50-55).

Table 4. Summary of *Caulerpa racemosa* and *Zostera* total abundance (sum of Braun-Blanquet scores), and the number of areas in which each taxa was found for 2008-2010.

Year	***Caulerpa racemosa***		***Zostera***	
	Total score	# of areas	Total score	# of areas
2008	630	37	352	27
2009	297	26	561	25
2010	252	27	534	27

From 2008-2010, cover of *C. taxifolia* was found to be significantly and moderately correlated with cover of *C. racemosa* (Spearman's ρ = 0.362, $p<0.001$) and significantly but weakly negatively correlated with cover of *Zostera* (Spearman's ρ = -0.237, $p<0.001$).

3.3. Key areas

Caulerpa taxifolia has been recorded in 21 areas that have been surveyed in each of the 5 years since 2006. Correlation co-efficients between the average score in these areas and a) the total yearly abundance and b) the number of areas where the alga occurred, are shown in Table 5, with the ten highest correlation co-efficients for each comparison shown in bold. Density of *C. taxifolia* in areas on Section Bank (14, 16), Barker Inlet (21-23, 25-26) and North Arm (35) is most highly correlated with both total abundance and number of areas. Density in areas 29 (Barker Inlet-Angas Inlet junction) and 33 (North Arm) also correlates highly with overall abundance, while density in areas 17 (Section Bank) and 24 (Barker Inlet) correlates highly with extent of the alga.

The greatest abundance and extent of *C. taxifolia* recorded was in 2008. Areas in which the alga was recorded only in this year are those at the outer extents of the distribution: 12-14 and 16 on Section Bank, and 52 in the Port River. Areas where notably higher maximum scores were recorded in 2008 compared with other years include Barker Inlet (22-23 and 25-28), Angas Inlet (area 30), North Arm (32-36), and the Port River (areas 50-51).

Table 5. Correlation co-efficients between local density (average Braun-Blanquet score) and a) total abundance, and b) number of areas where *C. taxifolia* occurred, for areas surveyed in each year 2006-2010. The ten highest co-efficients for each correlation are shown in bold. Total abundance and number of infected locations are shown in Table 2 for all survey years.

Region Area #	Correlation with total abundance	Correlation with number of areas	Density				
			2006	2007	2008	2009	2010
Section Bank							
14	**0.98**	**0.90**	0	0	0.14	0	0
15	0.66	0.36	0	0.25	0.25	0	0
16	**0.98**	**0.90**	0	0	0.13	0	0
17	0.73	**0.92**	0.17	0	0.25	0.17	0
Barker Inlet							
21	**0.96**	**0.93**	0.2	0	1	0	0
22	**0.97**	**0.98**	0.3	0	1.27	0.2	0
23	**0.87**	**0.93**	0.56	0	1.13	0.07	0
24	0.70	**0.82**	0.5	0	0.63	0	0
25	**0.89**	**0.93**	0.82	0	2	0	0
26	**0.84**	**0.92**	1	0	1.86	0.11	0
29	**0.88**	0.64	1.83	2.75	3.6	1.89	2
North Arm							
32	0.68	0.55	2.6	3.09	3.62	1.2	0.8
33	**0.86**	0.80	1.16	1.65	2.82	1.9	0.21
34	0.64	0.55	1.75	2.85	3.14	2.86	0.4
35	**0.94**	**0.85**	2.13	2.75	4.5	2.75	1.25
36	0.81	0.69	1.5	2.5	3.29	2.25	0.5
Port River							
46	0.73	0.79	0.25	0	3.25	3	0.25
47	0.47	0.39	3.29	4.57	4	3.33	0.17
48	0.63	0.53	3.25	5	5.25	4.5	0.8
49	0.53	0.28	4.25	6	5.75	5.5	4.33
50	0.77	0.52	0.71	2.83	4	2.5	2

4. DISCUSSION

The pattern of *C. taxifolia* distribution in 2010 is similar to that found in previous surveys, with areas along the Port River to the west of Torrens Island and at the Angas Inlet-Barker Inlet junction having greatest density. The total abundance of the alga and extent of its distribution, however, were reduced in comparison to previous surveys, as was the density in most areas. Analysis of data from 2003-2010 shows that *C. taxifolia* reached its greatest extent and abundance in 2008 after consistently increasing from 2003-2008 in both abundance (all years) and extent (except 2007), and there have now been two successive years with a reduction in both abundance and the number of areas where the alga occurred. In 2009 the reduced occurrence of *C. taxifolia* in Barker Inlet was noted (Wiltshire and Rowling 2009) and in 2010 the alga was not found more than 1 km north of the Angas Inlet-Barker Inlet junction (Figure 1). The greatest reductions in density, however, have occurred through North Arm-Eastern Passage and the Port River (Figure 3).

These surveys have not sought to determine factors that may be influencing *C. taxifolia* abundance. Winter senescence of the alga is well documented (Meinesz *et al.* 1995; Gacia *et al.* 1996; Thibaut *et al.* 2004) and was proposed as a possible explanation for the scarcity of *C. taxifolia* in Barker Inlet in 2007 (Rowling 2007), but does not explain the lack of the alga found in 2009 or 2010.

Caulerpa taxifolia continues to co-exist with *C. racemosa* in several areas, including North Arm and the western reach of the Port River (Figure 5). *Caulerpa racemosa* extends further downstream in the Port River than *C. taxifolia* and has appreciable cover on the revetments of Outer Harbor, but does not appear to be out-competing *C. taxifolia* where these congeners coexist. Although *C. racemosa* density has increased in some areas where *C. taxifolia* has declined, overall abundances of the two *Caulerpa* species have shown similar temporal patterns, with *C. racemosa* density also declining from 2008-2010 in North Arm, the Port River and Barker Inlet. It is likely, therefore, that the factors driving the reduction in *C. taxifolia* are also influencing *C. racemosa*. Over the same time period there has been an overall increase in *Zostera* cover, particularly in parts of Barker Inlet. Given the low density at which *C. taxifolia* occurred in Barker Inlet, even in 2008 (few scores >1), it is unlikely that lack of the alga is responsible for the increase in *Zostera*. It is more likely that environmental conditions favouring seagrass rather than *Caulerpa* have occurred recently. This has been observed in Moreton Bay, Queensland, where seagrass cover increased and *C. taxifolia* decreased in areas of improved water quality (Thomas 2003). Investigation of water quality and other environmental data may be useful in identifying possible factors influencing the growth of these taxa.

The co-existence of *C. racemosa* with *C. taxifolia* and its similar temporal patterns of abundance and density suggest that it is a good indicator of where *C. taxifolia* will grow, as has previously been assumed. Although not found in the 2010 survey through most of Barker Inlet, *C. racemosa* continues to occur along the Bolivar coast, around Outer Harbor and at boat ramps (especially O'Sullivan Beach), suggesting these areas remain at high risk of *C. taxifolia* invasion.

Caulerpa taxifolia continues to occur in the upper Port River in the same areas as in 2004 and 2008, but with generally lower density. The 2008 survey covered the entire region west of the Birkenhead Bridge, while the 2010 survey targeted areas where *C. taxifolia* was found in 2008. Deeper areas, where the alga did not occur, and the southern bank, where there were only sparse occurrences (scores of 0 to 1 in 2008, see Rowling 2009), were not re-surveyed in 2010. The higher average score recorded for area 38 in 2010 compared with 2008 therefore does not reflect an increased density of the alga. In 2008 several transects in this area recorded scores of 5 but in 2010 the maximum score for this area was 4. Figure 1, however, shows that there is still a considerable population of *C. taxifolia* along the northern bank west of the Birkenhead Bridge. Density of the alga around Jervois Bridge (area 37) has declined, despite the targeting of areas of likely abundance in 2010. Maximum scores in this area were 2 in 2010 compared with 5 in 2008. In this region no algae was found deeper than 3 m; it did not occur in the vicinity of the new marina which is ~6 m deep.

Analysis of the comprehensive survey dataset has confirmed that the greatest densities of *C. taxifolia* have consistently occurred near the northern end of its extent in the Port River, with North Arm-Eastern Passage and the Angas Inlet-Barker inlet junction also being sites of high relative density. Areas that may indicate trends in the population include Section Bank, and parts of Barker Inlet and North Arm. Correlation analyses used to determine these possible indicator locations are preliminary as they are based on only five data points and rely on the assumption that overall abundances are comparable between years. This may not be the case, e.g. in 2007 the survey extent may not have covered all areas of *C. taxifolia* occurrence, leading to a possible underestimate of algal abundance in this year. The very high abundance of the alga in 2008 also appears to drive the correlations. Nonetheless, some of the possible indicator sites may be useful for targeted monitoring since, being at the outer edges of the distribution, surveys of these areas would directly allow expansion of the distribution to be identified, as well as potentially indicating an increased population overall. A reduction in *C. taxifolia* in these areas, however, may not indicate a population decline. In 2007 there were reduced densities and fewer areas of *C. taxifolia* in Barker Inlet-Section Bank, but overall abundance of the alga and density in several other areas increased. Of the areas where *C. taxifolia* has consistently been found, density of the alga in the North Arm appears to best reflect population trends. Monitoring high-risk areas should continue as it is clear from the presence of *C. racemosa* at boat ramps and along the Bolivar coast that these areas remain suitable for colonisation by *C. taxifolia*, even if declines continue to occur in the Port River-Barker Inlet population.

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