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Large-scale seagrass dieback in northern Spencer Gulf, South Australia

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Abstract

A major dieback of seagrass occurred in South Australia where 12,717 ha of intertidal and shallow subtidal seagrasses were lost along the north eastern coast of Spencer Gulf. This was a rapid decline, occurring toward the end of summer in January or early February of 1993. The extent and location of the dieback was mapped from aerial photographs taken before (1987) and after the event (1994). Eight habitat categories were represented including sand, dieback (severe and moderate) and seagrass (dense, intermediate and sparse). Of the total area of loss, the majority (8269 ha) was classified as severe dieback. It is significant that most of the dieback was previously dense seagrass (7523 ha) compared with the smaller areas of sparse (1044 ha) and intermediate (1600 ha) seagrass which were subsequently identified as dieback. Presence of seagrass remnants and data from previous surveys indicated that subtidal *Amphibolis antarctica* and intertidal *Zostera* spp were the main species that died back. The pattern of the dieback, restricted to shallow subtidal and intertidal areas, in combination with extreme conditions associated with a hot El Niño summer, strongly suggest the loss resulted from environmental causes. Anthropogenic factors are unlikely as the sources of pollution along this sparsely populated coast cannot account for such a wide geographic impact or the pattern of loss.

Keywords: Seagrass; Die-off; GIS; *Amphibolis*; *Posidonia*; *Zostera*; *Heterozostera*

1. Introduction

Incidences of seagrass loss have been reported in tropical and temperate regions world-wide (Walker and McComb, 1992; Short and Wyllie-Echeverria, 1996; Kirkman, 1997).

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Many of these declines have been attributed to factors such as increased eutrophication, turbidity, sedimentation and pollution, often associated with a localised source (Den Hartog and Polderman, 1975; Peres and Picard, 1975; Pergent-Martini and Pergent, 1996). In Australia, significant losses of seagrass have occurred in Cockburn Sound, Western Australia, related to industrial effluent containing nutrients (Cambridge and McComb, 1984; Cambridge et al., 1986; Silberstein et al., 1986) and Western Port Bay, Victoria, from a combination of possible causes including altered sea levels and sedimentation associated with increased catchment runoff (Bulthuis et al., 1984; Stephens, 1995). In Gulf St. Vincent, South Australia, there has been a decline of 4086 ha of seagrass along the Adelaide metropolitan coast between 1949–1996 (Hart, 1997), with an additional estimated 2185 ha lost between Port Adelaide and Bolivar (Shepherd et al., 1989). Causes have been linked to eutrophication and suspended solids, originating from sewage and storm water outfalls and coastal development (Neverauskas, 1987; Shepherd et al., 1989). These declines have been relatively slow, progressing over years, with characteristic signs of decline such as high epiphytic loading and shoot thinning preceding losses (Cambridge et al., 1986; Neverauskas, 1987). By contrast, some of the most rapid losses have been associated with natural events such as storms and cyclones (Poiner et al., 1989; Preen et al., 1995) or a combination of environmental factors (Robblee et al., 1991). Such events have been aptly described as ‘dieback’ or ‘die-off’ and are characterised by extensive mortality of seagrasses occurring over a short period (days to months).

In Spencer Gulf there was an extensive and rapid loss of seagrass at the end of the 1992/1993 summer (Fig. 1). Several species were lost including complete or partial loss of seagrass from intertidal and shallow subtidal areas with a clear depth delineation between the dieback and healthy meadows of subtidal *Posidonia*. This is a significant area for inshore commercial and recreational fisheries and it was the local fishers from Port Broughton who first observed the dieback of ‘wire weed’ (*Amphibolis antarctica*) in February 1993. Browning and leaf loss of intertidal *Zostera* and *Heterozostera* was recorded at locations from Port Germein south to Warburto Point in March 1993 for areas that were previously healthy in December 1992 (Connolly, unpubl. data). Aerial photographs taken in the latter half of February 1993 confirm that an impact had occurred (or was in the process of occurring), indicating that the timing of the dieback was after December 1992 but before late February of 1993. In this paper we document the location and extent of dieback based on mapping aerial photographs pre- and post-dieback and discuss potential causes of the seagrass loss.

2. Materials and methods

2.1. Study location

Spencer Gulf is a shallow inverse estuary, with hypersaline conditions increasing toward the top of the gulf and an unusual fortnightly phenomenon, called a ‘dodge’ tide, where virtually no tidal movement occurs over 24 h (Noye, 1984). The dieback occurred on the north eastern side of the gulf, along a section of coast characterised by wide sand flats and adjacent intertidal seagrass meadows, often extending several kilometres

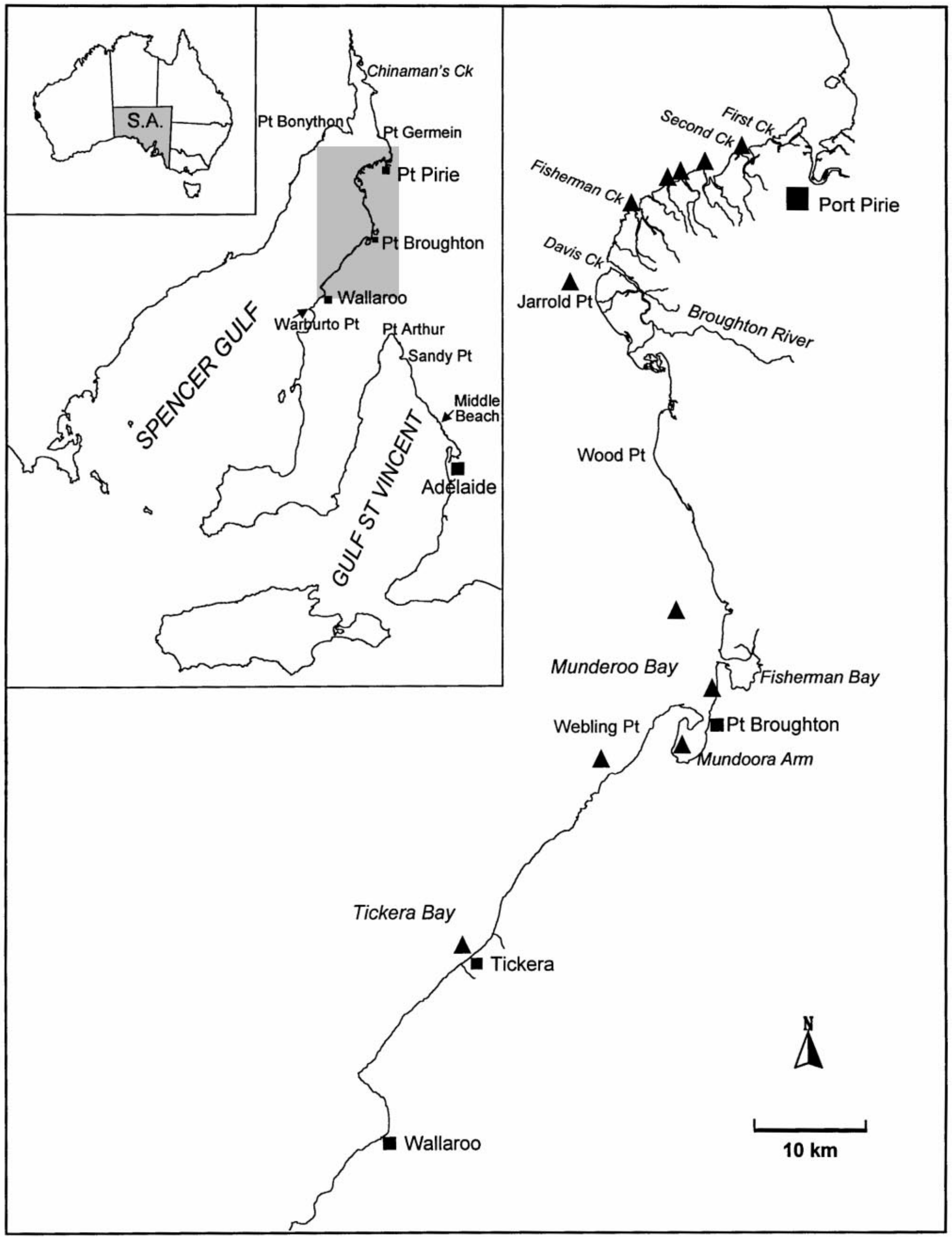

Fig. 1. Location of the Spencer Gulf seagrass dieback. Shading represents the study area in South Australia (small insert) and the location of the dieback within the study area of Spencer Gulf, South Australia (large insert). The main map shows the location of the towns, ports, creeks and other places referred to, the triangles represent the location of intertidal and subtidal permanent study sites.

out to sea (Fig. 1). The area mapped was restricted to that of continuous dieback from Port Pirie to Tickera, although there were isolated areas of browned-off intertidal seagrass (*Zostera* and *Posidonia*) further north at Port Germein and Chinaman's Creek and in northern Gulf St. Vincent at Port Arthur and Middle Beach. A local fisher also noted patches of *A. antarctica* dieback between Middle Beach and Sandy Point during the same period.

2.2. Aerial photography

Seagrass was mapped using aerial photographs taken before (1987) and after the dieback (1994). Aerial surveys are routinely flown every 6 years covering this section of coast and photographs from the December 1987 survey were used for mapping pre-dieback from Port Pirie to Tickera. The February 1993 survey was rejected because it was not clear whether the impact evident was seagrass in the process of browning-off and dying, or whether the event had occurred and dead seagrass material was obscuring the underlying substrate. An aerial survey was commissioned by the South Australian Research and Development Institute (SARDI) in February 1994 specifically to record the dieback. This series was suitable for mapping as live seagrass and sand were clearly distinguishable from dieback. However, the 1994 survey was restricted to the area between Tickera and Davis Creek and an additional post-dieback survey from November 1993 was required to complete the coverage from Davis Creek to Port Pirie. Due to the 6 year interval between aerial surveys, it was not possible to determine changes in seagrass distribution within the intervening years. Nevertheless, it is very unlikely that established beds of *Posidonia* and *Amphibolis* species could disappear and completely recolonise within 6 years without signs persisting in the post-dieback aerial photographs. Accordingly any earlier loss of these species should be detected as either a transition to sand or a sparser seagrass category and any recent loss should be detected as a transition to one of the dieback categories.

2.3. Mapping

The original aerial photographs (scale 1 : 40,000) were colour photocopied enlarged to a scale approximately 1 : 20,000. Polygons were drawn directly onto the enlargements around areas identified as belonging to one of eight habitat categories. Each category was distinguished by specific features relating to a characteristic colour and texture, as described in Table 1. Categories for post-dieback polygons were cross referenced with the same area in 1987 photographs. Assignment of categories was also based on ground truthing surveys done in the 1995/1996 summer, covering 34 locations (Seddon, unpubl. data) and data from seven intertidal (Connolly, unpubl. data) and four subtidal (Seddon, unpubl. data) permanent study sites (Fig. 1).

All polygons were digitised and re-scaled relative to a 1 : 50,000 plot of the coastline (from a topographical map), ensuring aerial photographs from both surveys were consistently scaled throughout the study location. The total area of each category and any changes between habitat categories from 1987 to 1994 were compared and a transition matrix calculated using the software ArcInfo (Environment Systems Research Institute).

Table 1
Habitat categories used for mapping polygons on aerial photograph enlargements and a description of the characteristics used to distinguish between them. All proportions are relative to the features in the enlargement (scale 1 : 20,000, except post-dieback enlargements covering from Davis Creek to Pt. Pirie were 1 : 10,000)

Category	Description
Dieback severe	characteristic brown with smudged texture, clearly distinguishable from sand or seagrass. Represents areas of high (>90%) to complete seagrass loss.
Dieback moderate	characteristic brown (usually darker than severe dieback) with smudged texture interspersed with patches of green/olive seagrass. Represents areas of high loss (>50%) interspersed with live seagrass.
Seagrass dense	dark green with relatively uniform texture. Sand patches, if present, represent less than 10% of the area.
Seagrass intermediate	dark green, often with an irregular texture. Sand patches more common and generally covering 10–70% of the area.
Seagrass sparse	small dark green patches with sand representing over 70% of the area. Or, pale green to olive with variable texture over the whole area, representing sparse cover of seagrass.
Sand	consistent pale colour, no green/olive/brown texture. Sometimes confounding features present such as debris along high water mark.
Deeper seagrass/water	dark green grading to blue with uniform texture, representing deeper beds of *Posidonia*. Areas of sand, if present, not distinguished. Or, deep section of a channel.
Mangroves	dark green areas along the high water mark, densities not distinguished.

An indication of error in the data set is given by impossible or highly improbable transitions, such as changes from mangroves or deep seagrass/channel to one of the three shallow seagrass categories. Of the possible 56 transitions (excluding 8 between the same category) 26 could be considered unlikely and, therefore, should have an area equal to 0. In addition, a further two transitions (between dense seagrass and deep seagrass/channel) need to be excluded due to the difficulty in accurately delineating the outer seaward boundary of shallow seagrass from the adjacent deeper seagrass on the aerial enlargements (this relates specifically to the main polygon on the seaward side of the map in Fig. 2), a problem not representative of the rest of the mapping. The mean and standard error for the remaining 24 transitions of 31 ± 30 ha can, therefore, be considered an estimate of the error associated with the areas presented in the results.

3. Results

In 1987 before the dieback there was continuous seagrass along the coast including significant areas of dense seagrass between Jarrold Point and Fisherman Bay (Fig. 2). A total of 1712 ha (Table 2) of seagrass dieback was evident in the aerial photographs, representing the sum of dieback from intertidal areas opposite Tickera extending north, opposite Fisherman Bay and some isolated patches further north to Jarrold Point, plus another two areas near First Creek. No ground-truthing records exist from this period and evidence for seagrass loss in these locations is based on the presence of areas with the same distinctive colour and texture representing dieback in the 1994 aerial photographs. Dieback

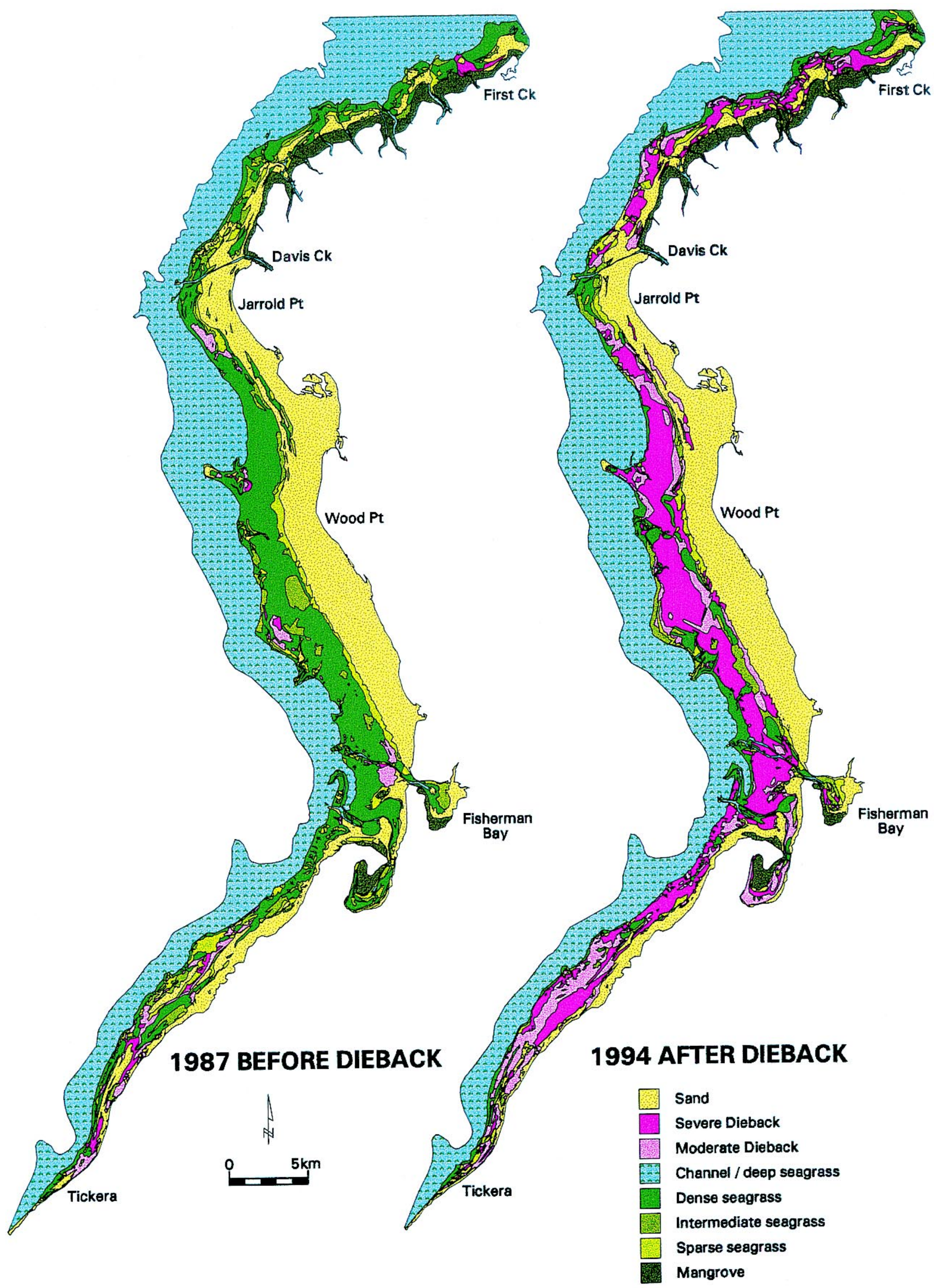

Fig. 2. Distribution of seagrass before and after the dieback mapped from 1987 and 1994 aerial photographs. Eight habitat categories are represented; sand, dieback (severe and moderate), seagrass (dense, intermediate and sparse), deep water/seagrass and mangroves. The area follows the coast from Port Pirie to Tickera (see Fig. 1) and is bounded by a continuous blue polygon representing deep seagrass to a depth of 5 m (seaward limit defined by inserting the 5 m contour from a navigational chart).

Table 2
Total area of each habitat category before and after the dieback event. Values for change show the difference between before and after, with a negative sign indicating a reduction in area. All values in hectares

Category	Before (1987)	After (1994)	Change
Dieback severe	509	8 269	7 760
Dieback moderate	1 203	4 448	3 245
Dieback total	1 712	12 717	11 005
Seagrass dense	11 458	3 732	−7 726
Seagrass interm	2 557	1 514	−1 043
Seagrass sparse	1 938	1 155	−783
Seagrass total	15 953	6 401	−9 552
Sand	12 851	11 697	−1 154
Mangroves	2 057	2 057	0
Channel/deep seagr.	23 831	23 532	−299
Total	56 404	56 404	0

clearly associated with the Port Pirie region in 1987 may be linked to several significant sources of pollution, including discharge from the lead and zinc smelter into First Creek (Ward and Young, 1981; Ward, 1987) and sewage settlement ponds discharging into upper Second Creek. The other isolated areas of dieback in 1987 are remote from known sources of pollution but are all within intertidal or shallow subtidal areas. There was a significant loss of seagrass recorded in this region 4 years earlier. Seagrass 'degradation' was first noticed in December 1982 between Fisherman Bay to Wood Point, with an estimated 1480 ha of *A. antarctica* affected (Anonymous, 1983). It is not known whether these earlier losses were fully recolonised by seagrass, or whether some of the patches of dieback evident from the same region in the 1987 photographs relate to this 1982/1983 event.

After the dieback event, photographs from 1994 showed the total area covered by dieback had increased by 11,005 ha to a total of 12,717 ha, of which 8269 ha were classified as severe dieback (Table 2). The seagrass loss clearly extends along the entire study area, approximately 95 km of coast, with most of the previously dense seagrass beds now classified as dieback (Fig. 2). The pattern along the seaward edge of the dieback follows the 0 m Indian Spring tide bathymetric contour confirming losses were limited to shallow water. Further out to sea, the area designated as deep seagrass/channel extending from Port Pirie to Tickera represents largely continuous *Posidonia* spp meadows to a depth of 5 m. A more detailed comparison of the data is presented in the transition matrix which shows the extent and direction of change in area for six of the habitat categories (Table 3). It was notably dense seagrass which was lost, here 7523 ha of dense seagrass was identified as dieback (severe and moderate combined), compared with 1044 ha of intermediate and 1600 ha of sparse. Overall, there was evidence for only a limited degree recolonisation of any dieback from 1987 as 86% of severe and 73% of moderate was classified as either severe or moderate in 1994, whereas only 12% of severe and 21% of moderate was recolonised by seagrass by 1994. There was also a total of 1120 ha (9%) of sand which changed to dieback, seemingly an unlikely transition. However, when these polygons were plotted they were mainly dis-

Table 3
Matrix showing the transitions in area between each habitat category from 1987 to 1994. All values in hectares with proportion of the transition expressed as a percentage of the total area within a category below

After dieback 1994	Before dieback 1987					
	Dieback severe	Dieback mod	Seagr dense	Seagr interm.	Seagr sparse	Sand
Dieback severe	199 39%	432 36%	5591 52%	933 37%	521 28%	517 4%
Dieback mod	235 47%	435 37%	1932 18%	667 27%	523 28%	603 5%
Seagrass dense	6 1%	147 12%	2332 21%	202 8%	172 9%	139 1%
Seagrass interm.	26 5%	60 6%	604 6%	344 14%	160 8%	206 2%
Seagrass sparse	29 6%	41 3%	111 1%	159 6%	244 13%	539 4%
Sand	9 2%	70 6%	235 2%	206 8%	268 14%	10751 84%

tributed along intertidal areas, suggesting that fast growing seagrasses (e.g. *Zostera* spp) had colonised areas of sand since 1987 and subsequently died back.

The dominance of the transition from dense seagrass to severe dieback, in terms of area and distribution along the entire study area, is clearly evident from the map in Fig. 3. These major areas of loss do not appear to be correlated with known sources of pollution associated with Port Pirie, the Broughton River or Port Broughton. The most affected area, between Wood Point and Fisherman Bay, is adjacent to agricultural land and is characterised by wide sand flats continuing seaward with no inputs from major creeks or rivers.

The seagrasses involved in the dieback were determined either by a knowledge of species distributions from earlier surveys in 1992 (Connolly, unpubl. data) or by dead seagrass remnants identified on post-dieback surveys (Fig. 1). Remnants of *A. antarctica*, *Posidonia australis* and *Heterozostera tasmanica* were present, though the majority was *A. antarctica* with densities of dead woody stems ranging from 500 to 1100 m^{-2} in areas that were previously dense meadows. In total, six intertidal and five shallow subtidal species were identified within the study area (Table 4). Of the subtidal species, *A. antarctica*, *P. australis* and *H. tasmanica* were common along the intertidal/subtidal margin making them vulnerable to exposure during negative tides. Since 1994 only small patches of live *A. antarctica* persist within *Posidonia* meadows along the seaward margin of the dieback. Observations during low tides demonstrated that these surviving beds of *A. antarctica* are slightly deeper than adjacent beds where dead remnant *A. antarctcia* stems are exposed.

Intertidal *Zostera muelleri* and *Zostera mucronata* are known to have died back at sites where meadows had been previously recorded. However, it is not known if the total extent of the loss of *Zostera* is comparable with *A. antarctica*, because *Zostera* remnants do not persist in the sediments. Both *Z. muelleri* and *Z. mucronata* have started to recolonise intertidal areas and colonise patches within areas formerly dominated by *A. antarctcia*. Two other species,

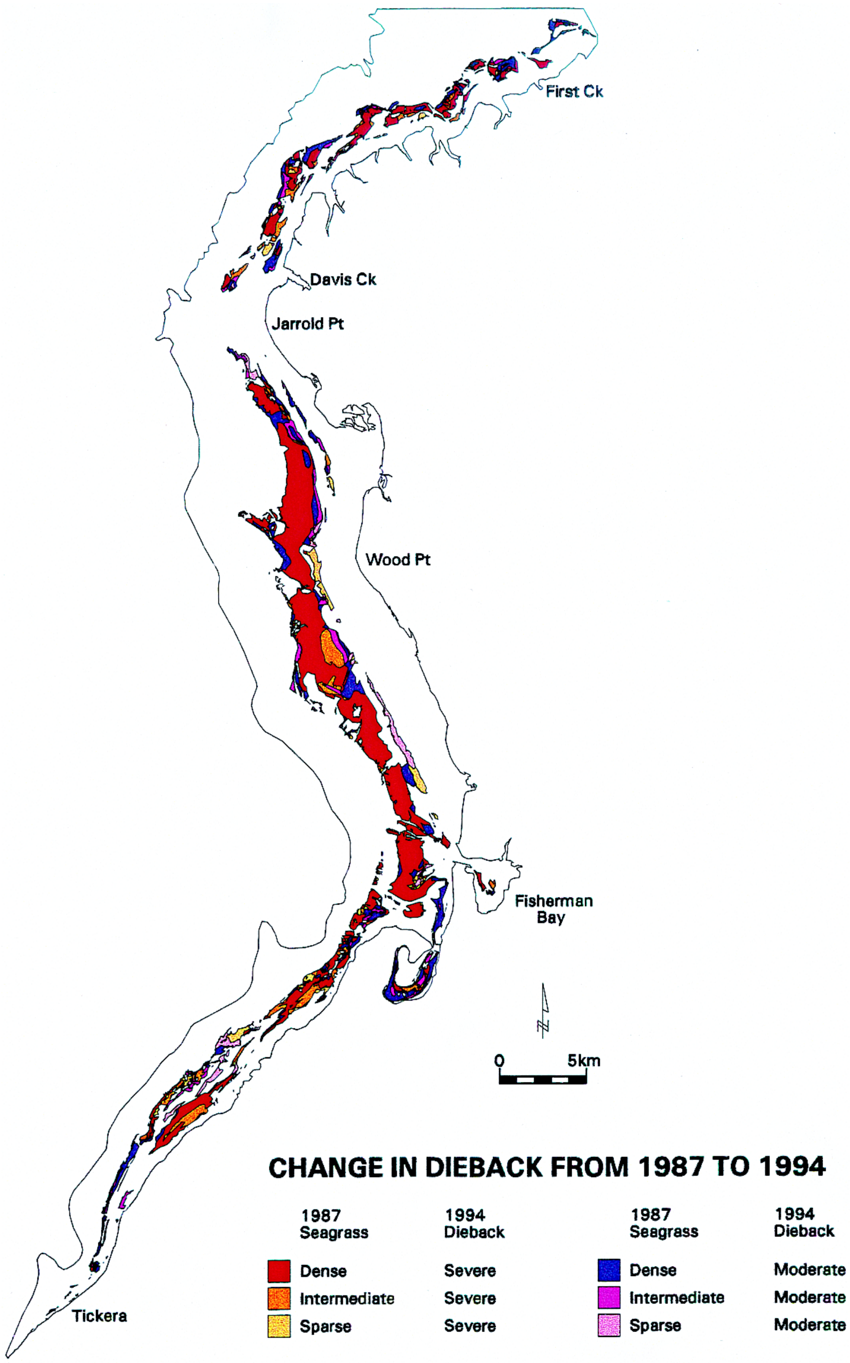

Fig. 3. Map illustrating the transitions from dense, medium and sparse seagrass in 1987 to either severe or moderate dieback in 1994 (6 of the possible 64 transitions). The key shows three colours in the red/orange range which represent seagrass to severe dieback and three colours in the purple/pink range which represent seagrass to moderate dieback.

Table 4
Depth distribution of seagrasses within the study area from surveys in the 1995/1996 summer and species confirmed to have sustained mortalities during the dieback. √: present, ×: absent, n.d.: no data

Depth range	Present 1996	Died back
Intertidal		
Zostera muelleri	√	√
Zostera mucronata	√	√
Heterozostera tasmanica	√	√
Posidonia australis	√	√
Lepilaena sp.	√	n.d.
Ruppia sp.	√	n.d.
Margin (inter/subtidal)		
Amphibolis antarctica	√	√
Posidonia australis	√	√
Heterozostera tasmanica	√	√
Shallow subtidal		
Amphibolis antarctica	√	×
Posidonia australis	√	×
Posidonia angustifolia	√	×
Posidonia sinuosa	√	×
Heterozostera tasmanica	√	×

Lepilaena sp. and *Ruppia* sp., were found in small dense patches colonising dieback areas. These two species were not previously recorded within the study area so it is not possible to confirm whether they were included in the dieback.

4. Discussion

The northern Spencer Gulf dieback is the largest single loss of seagrass recorded in South Australia. It is also significant because the pattern of dieback occurred at depths above the zone delineated by continuous *Posidonia* meadows. Extensive beds of *Posidonia* seem to form below the Indian Spring Low Water mark, where there is no risk of exposure to desiccation and in this respect, the dieback was clearly depth related. This pattern was consistent at all locations along the dieback and gives important insights into possible causes.

4.1. Anthropogenic causes

Were anthropogenic or natural factors more likely causes of the dieback? The area lost was almost twice as large as the losses in metropolitan Adelaide; however the region in Spencer Gulf adjacent to the dieback is relatively sparsely populated and appears to lack sources of pollution significant enough to account for such a vast impact. The two major sources of pollution in this region are industrial pollution associated with Port Pirie and agricultural runoff from the Broughton river (which flows through Davis Creek out to sea at Jarrold

Point). Summers are typically dry, yet the 1992/1993 summer was unusual in that there were two significant rain events in December and January producing excessive volumes of water discharged from the Broughton River. Large reductions of salinity and increases in nutrients, turbidity and other pollutants in the runoff, such as pesticides and herbicides, could have caused or contributed to the dieback. While localised impacts associated with sources of pollution near Port Pirie were evident in the 1987 pre-dieback map, there is little evidence in the 1994 aerial photographs to show an increased impact associated with the Broughton River or the Pirie region, relative to the intensity of the dieback in areas remote from eutrophication or pollution (such as Wood and Webling Points). There is an absence of dieback associated with the mouth of the Broughton River where, if runoff or freshwater were important factors in the dieback, these seagrasses should also be affected (Figs. 2 and 3). In addition, the speed of the dieback and lack of evidence from local fishers of chronic stress prior to the dieback, indicates that causes related to eutrophication are unlikely.

There was an oil spill off Port Bonython in August 1992 where 296 tonnes of oil were spilt from the 'Era' oil tanker and in addition chemical dispersants were used to help control the spill (Wardrop et al., 1996). Some of the oil landed between Third and Fifth Creeks resulting in the death of approximately 23 ha of heavily oiled mangroves, but with no apparent impact on seagrasses or associated fish within the creeks (Connolly and Jones, 1996; Wardrop et al., 1996; Edyvane, unpubl. data). By December 1992 (3 months after the spill), there was no evidence of mortality or browning off of shallow seagrasses adjacent to the oiled mangrove coast (Wardrop et al., 1996). This is not unusual as findings from significantly larger oil spills have shown that, unless the oil has come into direct contact with the seagrass, there has been no significant detrimental effect (Jackson et al., 1989; Kenworthy et al., 1993). By March 1993, when the Spencer Gulf seagrass dieback had occurred, the post-dieback map (Fig. 3) confirms that the pattern of dieback is not more intense near the oiled section of coast, nor even in the general location, relative to areas tens of kilometres south.

The incidence of disease or pathogens as a factor in the dieback is considered unlikely. The slime mould *Labyrinthula* has been blamed for the massive 1930s losses of *Zostera marina* and more recent diebacks in the northern hemisphere (Short et al., 1986; Den Hartog, 1996). In 1996 *Labyrinthula* was identified in seagrasses recolonising the dieback at the study site near Webling Point (F.T. Short, pers. commun.) but the incidence of the mould was, and continues to be, extremely rare. At the time of the dieback, there were no reports of black or necrotic tissue. Photographs taken on the ground in April 1993 show hectares of leafless *Amphibolis* stems and in combination with our observations of leaf loss and browning immediately after the dieback, indicates a sudden simultaneous loss of leaves.

4.2. Natural causes

There is compelling evidence for natural causes, particularly relating to extreme environmental conditions. It is the characteristic depth related pattern of the dieback, with a sharp distinction between unaffected *Posidonia* and dieback immediately adjacent, which strongly indicates the possibility of prolonged exposure to desiccation as a factor in the dieback. Negative tides are not predicted to occur but do during summer when meteorological conditions (such as high barometric pressure or easterly wind) force a lower tide (Noye, 1984). Tide gauges deployed by the National Tidal Facility (Flinders University) showed that several negative tides occurred during solar noon in a period of prolonged high temperatures (maximum air temperatures 35–40°C) in the first week of February. The fortnightly dodge tide occurred during this period, possibly exacerbating the effects of many factors including elevated temperatures. Observations of leaf browning and subsequent loss are consistent with the effects of high temperatures (Orth and Moore, 1986; Walker and Cambridge, 1995) and desiccation (Erftemeijer and Herman, 1994; S. Seddon, unpubl. data) on seagrasses. In addition, reports of dieback in shallow areas in north eastern Gulf St Vincent, a body of water separated from Spencer Gulf, provides supporting evidence for a wide-scale climatic event.

Several factors likely to contribute to the vulnerability of shallow seagrasses in northern Spencer Gulf are sediment accretion within the seagrass beds (Walker and Woelkerling, 1988; Smith and Veeh, 1989), contributions of sediment from agricultural runoff and continued raising of the seabed through ongoing tectonic plate uplifting (Belperio et al., 1984). Burne (1982) investigated the evidence for sea level changes in northern Spencer Gulf and found *Posidonia* fibre bearing facies extending onshore, indicating a maximum sea level up to 5 m higher than present and estimated relative rates of sea level fall of between 0.5 and 1.1 m/1000 years, based on cores from Fisherman Bay and Wood Point. In addition, the roots of live *A. antarctica* cored inshore of existing *Posidonia* beds are often attached to a mat of *P. australis* fibres indicting *Posidonia* beds once existed further inshore (S. Seddon, pers. obsv.). This suggests that dieback along this section of coast is a periodic phenomenon, where shallow seagrasses are exposed to increasing periods of desiccation resulting in seagrass loss and the continuing seaward progression of the shoreline. The relative drop in sea level would eventually preclude subtidal *Amphibolis* and *Posidonia* from recolonising areas of dieback, which would instead be recolonised by intertidal species such as *Zostera* and *Ruppia*, and these in turn would be replaced by sand. The loss of continuous meadows of *Amphibolis* is likely to accelerate this process and local fishers have commented that since the dieback, less water is retained over the sand flats during low tide due to an absence of the ‘weir’ effect produced by dense beds of *Amphibolis.* Seagrass is known to significantly modify water flow and meadows of *Thalassia testudinum* have been shown to not only slow the ebb of the tide, but also to ‘trap’ and retain a significant layer of water during low tide (Powell and Schaffner, 1991).

If seabed rising and subsequent exposure to desiccation were the main factors causing the dieback, then in the future there should be an ongoing succession along the eastern Spencer Gulf. There is evidence for this process in the past, not only in the 1987 aerial photographs, but also from the record of *A. antarctica* loss first observed in December 1982 (Anonymous, 1983). It is also notable that both the 1982/1983 and 1992/1993 summers were during El Niño years where average temperatures are typically higher in southern Australia. It is possibly this additional factor of extreme climatic conditions, combined with low sea levels, that results in a sudden and wide-scale loss of seagrass rather than a gradual regression.

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