Current and Historical Distribution of Seagrass in the Noosa Estuary

Prepared for: The Nature Conservancy

Prepared by Ecological Service Professionals Pty Ltd

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Cover: Dense *Zostera* bed growing on the edge of Weyba Creek

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Executive Summary

This report has been prepared by Ecological Service Professionals (ESP) for The Nature Conservancy (TNC) and summarises the results of a seagrass survey in the Noosa River Estuary and lakes in November 2020. Seagrass provides nursery, forage and reproductive habitat for a broad range of species including species important to recreational and commercial fisheries.

The current distribution of seagrass was assessed throughout the estuary and lakes in November 2020 using a combination of direct visual assessment, underwater georeferenced photo transects and underwater spot checks using a surface view camera, and a grapple hook for targeted confirmation of seagrass species present where necessary. Intertidal habitats were assessed on foot where possible. The coverage of seagrass was assessed visually and in photo-quadrats along several transects in areas where the composition of the seagrass bed changed. The current distribution was compared with the historical distribution of seagrass, including likely triggers for change and recommendations for future work.

In 2020, Noosa estuary was dominated by soft sedimentary habitats including extensive intertidal sand and mud flats, with several large seagrass meadows occurring throughout the lower estuary. The seagrass beds were dominated by long eel grass (*Zostera muelleri* sub sp. *capricorni*) with occasional sparse patches of *Halophila ovalis*. The seagrass beds consisted primarily of *Z. muelleri* growing in long dense, but patchy beds along the main channels and around several small islands.

Historically, there are several reports of seagrass (*Z. muelleri* and *H. ovalis*) occurring throughout the Noosa estuary, with the most comprehensive mapping of seagrass in the estuary occurring in 1987 (Hyland et al. 1989). Notable based on these previous assessments an updated mapping, there have been declines in the area of seagrass beds within the Noosa Estuary, particularly in Lake Weyba and Lake Cooroibah, with approximately 83% of the total area of seagrass lost between 1987 and 2020.

Due to the nature of the Noosa River Catchment, different sub-catchments present a good comparative opportunity to assess the cause of declines in seagrass extent and likely impact of management actions. For example, impacts in along the main river channel are likely due to broader scale impacts from the upper catchment, including runoff from catchment clearing as well as boating activity. In contrast, seagrass in the smaller sub-catchments in Lake Doonella and Lake Weyba are likely responding to changes in the hydrodynamic regime, with seagrass in Weyba Creek being particularly susceptible to shifting sand banks.

Further assessment of the potential resilience of seagrass meadows to resist environmental changes in the Noosa Estuary are considered necessary to understand where to invest in future management actions for maximum gains. Consideration should also be given to the potential for natural recovery or assisted restoration of seagrass meadows once key triggers for past change are known and potential negative inputs have been managed.

1 Introduction

This report has been prepared by Ecological Service Professionals Pty Ltd (ESP) for The Nature Conservancy (TNC), and summarises the distribution and condition of seagrass meadows within the Noosa Estuary and Lakes in November 2020. Specifically, the aim of the assessment was to identify and map the distribution, coverage and condition of seagrass within the Noosa River Estuary downstream of Lake Cooroibah and in the Weyba Creek catchment. The current distribution was compared with the historical distribution of seagrass, mapped from historical aerial and satellite imagery. An assessment of the likely triggers for change and recommendations for future work have been included.

1.1 Background

Coastal wetlands including seagrass, mangroves and saltmarsh, have a broadly important ecological function as fisheries habitat, through provision of nursery habitat, protection from predators, contributing to food webs, controlling sediment runoff and processing nutrients among other functions (Nagelkerken et al. 2008; McKenzie et al. 2021). Intertidal habitats are also important for a range of species other than fish such as migratory shorebirds, waterbirds and crustaceans (Manson et al. 2005; Skilleter et al 2005; Zharikov et al. 2005). The spatial arrangement of habitats in coastal seascapes are known to affect the composition of fisheries species at a variety of different spatial scales (Sheaves 2009; Bostrom et al 2006; Bostrom et al. 2011; Nagelkerken et al. 2015), and the abundance and diversity of fishes is typically associated with the most diverse and heterogeneous seascape types (Pittman et al. 2004). For example, species richness is higher in nekton communities (i.e. fish, crabs and prawns) when mangroves are proximal to continuous seagrass, when compared with mangroves adjacent to patchy seagrass or bare/unvegetated substrate (Pittman et al. 2004; Skilleter et al. 2005). Seagrass habitats have high ecological value, and provide connectivity between inshore (e.g. estuaries) and offshore (e.g. reef) ecosystems, which is vital for the maintenance and regeneration of numerous fish and invertebrate populations (Waycott et al. 2009; Waycott et al. 2011).

Seagrass habitats provide food and shelter for a diverse range of marine fauna; they also support benthic macroinvertebrate communities, which in turn provide a food resource for many larger, commercially important species of crustacean, mollusc and finfish (Coles et al. 1993; Carruthers et al. 2002). Epibenthic and infaunal invertebrate communities associated with seagrass meadows are diverse, and are typically dominated by high abundances of polychaetes (and other worms, such as sipunculids), molluscs (including bivalves and gastropods), and crustaceans (particularly amphipods and decapods) (Blomfield and Gillanders 2005). These communities provide a food source for larger crustaceans, molluscs and finfish, many of which are commercially important (e.g. flathead) (Coles et al. 1993; Carruthers et al. 2002; McKenzie et al. 2014), including in the Noosa Estuary.

While marine plant communities provide particularly high ecological value habitat for marine fauna, areas of non-vegetated soft-substrates (including sandy beaches, mudflats and subtidal soft sediments) are also important (Pittman et al. 2004). Soft sediment habitats in shallow areas (where suspended sediment loads are low enough to allow sufficient sunlight penetration through the water column for photosynthesis) also contain benthic microalgae (BMA) assemblages, which can be an important driver in coastal food chains and macroalgal communities (Ferguson & Eyre 2013). These types of soft sediment (sand and mud) habitats are the dominant habitat type within the Noosa Estuary.

Seagrasses are highly sensitive to changes in environmental conditions and declines in water quality (particularly high turbidity) and are therefore considered indicators of environmental degradation and natural stressors (Heck et al. 2008). As a result, their spatial distribution can be highly dynamic, and large interannual changes in the extent of seagrass habitats and community structure resulting from natural disturbances (e.g. flood events, changes in rainfall) have been documented for example in the Moreton Bay region (Lyons et al. 2015) and Great Sandy Strait particularly following extensive floods (Preen et al. 1995; Campbell & McKenzie 2004).

In the Noosa Estuary, the most comprehensive and detailed historical mapping of seagrass was completed in 1987, recording a total of 47 Ha of dense seagrass primarily in the Noosa River to Lake Cooroibah and in Weyba Creek (Hyland et al. 1989). A further 923 Ha of sparse and patchy seagrass was recorded, primarily (94%) in Lake Weyba (Hyland et al. 1989); however, the area of sparse and patchy seagrass is considered to be an overestimate due to the sparse nature of and difficulty mapping from photographs at the time. There have also been several small-scale surveys and monitoring programs completed at several sites throughout the estuary using the established seagrass watch monitoring protocols through Noosa Integrated Catchment Authority (NICA) (Seagrass Watch 2006; McKenzie & Yoshida 2013; NICA 2014; NICA 2016). These monitoring events were designed to assess long-term changes in the coverage and species composition of seagrass along permanent transects (McKenzie & Yoshida 2013). We are unaware of any broadscale assessment of the distribution of seagrass in the estuary completed since 1987. The most recent monitoring of seagrass was completed by NICA and USC researcher Dr Javier Lyon, which was used to develop a method of monitoring the distribution of seagrass using aerial drone surveys and photogrammetry (Lyon 2018).

2 Methods

2.1 Study Area

The Noosa River catchment has its headwaters in the Cooloola section of the Great Sandy National Park. There are several main tributaries, and the main river flows through several shallow lakes, and along a main river channel to the ocean.

The study area for this assessment covered a substantial section of the estuarine habitat in the Noosa Estuary and lakes, including both intertidal and subtidal zones with the most upstream extent in Lake Cooroibah (designated as the upper extend of seagrass distribution) to the mouth of the estuary; and upstream in Weyba Creek to Lake Weyba (Figure 2.1). The estuary was separated into seven reaches including:

1) Lake Cooroibah (and the main Noosa River channel upstream of the vehicle ferry);

2) Noosa River from Tewantin to the vehicle ferry;

3) Noosa River around Goat Island and downstream;

4) Noosa River mouth and Noosa Sound;

5) Lake Doonella;

6)Weyba Creek; and,

7) Lake Weyba (Figure 2.1).

2.2 Desktop Review and Initial Mapping

An initial desktop review and gap analysis of existing information available on the distribution and condition of seagrass in the Noosa River Estuary, including spatial data sets, was completed. Prior surveys and aerial imagery were used to complete an initial broadscale seagrass and marine habitat map of the study area, based on experienced visual interpretation of available aerial and satellite imagery and publicly available GIS spatial layers. This map was used to prioritise specific focal areas for more detailed field validation and seagrass characterisation (Section 2.3 below).

2.3 Field Surveys

The survey was completed over four days (3 to 5 November 2020 and 8 December 2020) using a combination of remote techniques from a vessel (including ROV, tow camera and drop cameras), and visual assessments on foot at low tide (where possible) to identify the condition and presence of seagrass. Where visibility was low (due to turbidity of waters), spot snorkel surveys and a small grapple hook were used to confirm the presence of seagrass, where it was safe to do so and following a strict risk assessment protocol. Detailed methods are described in Sections 2.3.1 to 2.3.3 below.

The work was completed under a QLD General Fisheries Permit (208641) issued to ESP and an accepted development application (received 07/09/2020), for the collection and limited disturbance of marine plants in a fish habitat area where voucher samples were required for field verification and identification.

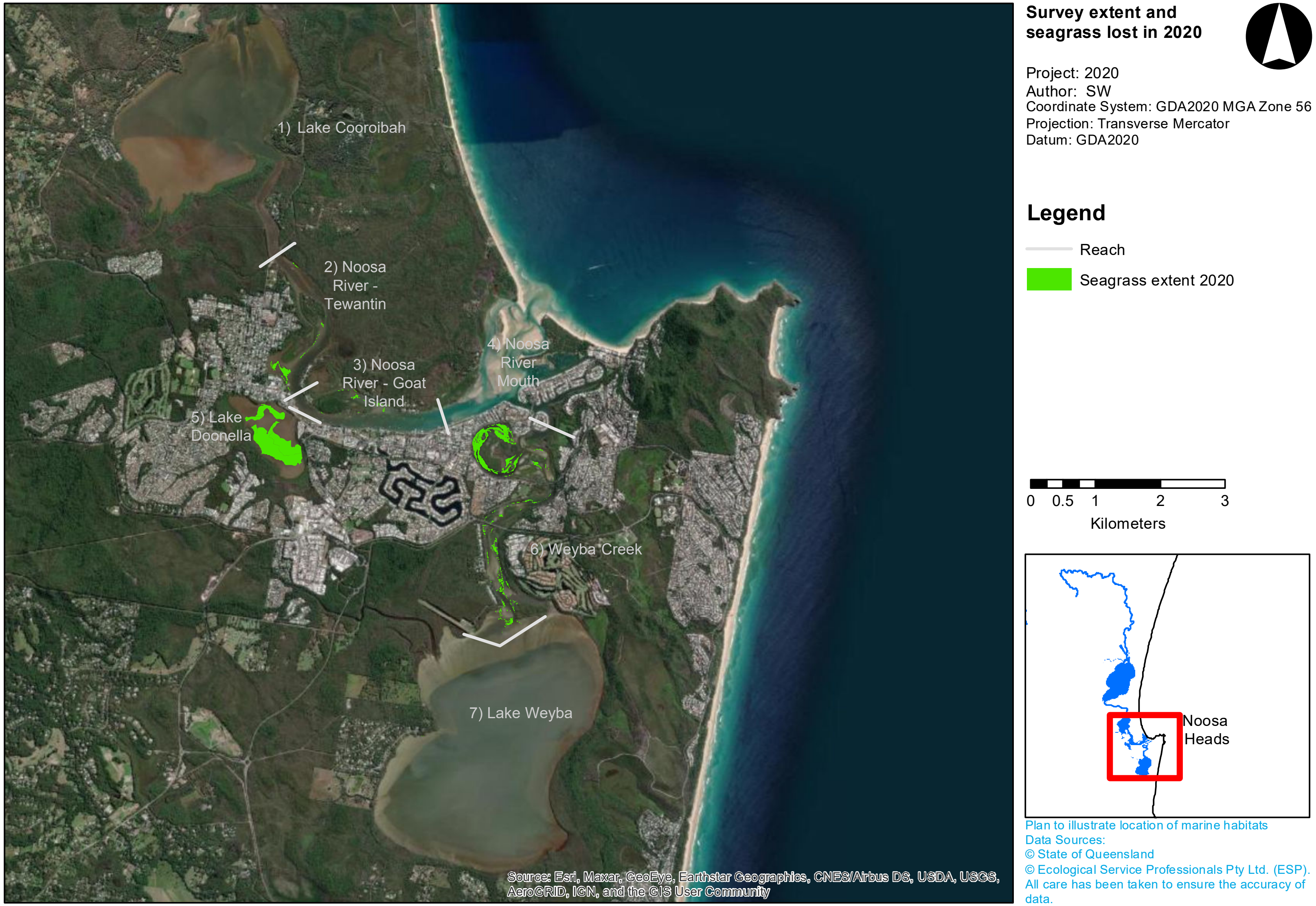

Figure 2.1 Location of study area and reaches assessed along the Noosa River in November 2020

2.3.1 Assessment of Seagrass Habitats

Where seagrass was present, the seagrass beds were assessed further for their extent (using a hand-held GPS to later define and confirm the current perimeter of patches using GIS by tracking along the perimeter of seagrass along a channel or around a patch in the lakes). This was done by taking georeferenced images along the edge of seagrass beds or walking intertidally and taking a series of points along the edge, then matching to recent aerial imagery in ESRI ArcMap. The species composition, percent coverage and condition of seagrass was also assessed qualitatively, based on expert assessment of georeferenced imagery (video and photos) at more than 1700 points across the study area, using methods adapted from Roelfsema & Phinn (2009) where a gps is either towed along the waters surface with the type of substrate recorded either on snorkel or using a drop camera from a boat. Broad seagrass coverage categories were either determined directly from imagery or in the laboratory using georeferenced imagery. Georeferenced image capture enable mapping linked to images showing the seagrass (or other benthic habitat) and allowed for rapid geo-referenced image collection over a large spatial area of the estuary. Where identification of the presence of seagrass was not possible from surface view imagery, a field sample was collected using a grapple hook to confirm identification (particularly of seagrass species).

2.3.2 Seagrass Condition and Fisheries Value

The condition of representative seagrass beds in each of the estuarine reaches was assessed along several transect completed perpendicular to the channel, with georeferenced observations and photo quadrats made at regular assessment points (approximately every 5 m) along each transect. The value of fisheries habitat in the study area was assessed using:

- desktop review of the current literature;
- condition and type of habitat present based on field results; and,
- professional judgement based on the dominant habitat category (e.g. seagrass) using the criteria adapted by ESP from Wetland Assessment Manual (Price et al. 2007) and a review of the available fisheries literature[1] linking habitat features with fisheries productivity as outlined in Appendix A (Table 7.1 and Table 7.2).
- habitat patches are scored based on the presence of various criteria, with seagrass in better condition or having higher value to fisheries species given a higher score. The total is then summed across each criteria to determine whether the seagrass habitat is poor, fair, good or very good.

[1] Bell & Westoby 1986a, b; Edgar & Robertson 1992; Boström & Bonsdorff 1997; Heck et al. 1995; Webster et al 1998; Skilleter et al. 2005; Vanderklift & Jacoby 2003; Boström et al. 2006; Jelbart et al. 2007; Price et al. 2007; Shoji et al. 2007.

2.3.3 GIS Mapping

A detailed map based on the field data showing the extent of seagrass present in the area, was produced using ArcGIS. Imagery was sourced through QLD Globe and rectified in ESRI ArcGIS to create a complete mosaic of high-resolution imagery for 2020.

2.4 Historical Distribution of Seagrass

The estuary was split into seven reaches, and the change in seagrass distribution was mapped from rectified historical aerial imagery available in QLD Globe (QLD Government 2020) and QLD Imagery (QLD Government 2021a). An analysis of the historical changes in seagrass distribution in reaches of the Noosa River estuary was completed to provide a comparison of the annual relative change in extent (areal coverage) through time from September 1989 (i.e. approximate time of Hyland et al 1989 survey, with most comprehensive aerial imagery collected at approximate 1:25000), November 2006 (18cm SISP satellite imagery), October 2008 – June 2009 (50 cm SISP satellite imagery), and May 2020 (10 cm satellite imagery) combined with survey data from November 2020. Annual assessments of the change in seagrass at several sites along Weyba Creek were also completed from 2015 until 2020 using available aerial imagery. This finer-scale assessment provided key information on the magnitude of change in seagrass extent over recent years (2015 - 2020).

3 Current Seagrass Distribution and Characteristics

3.1 Composition and Distribution

A total of 56 Ha of seagrass was recorded throughout the estuary in November 2020, with the greatest extent of seagrass occurring in Lake Donnella and along Weyba Creek (Table 3.1). Seagrass species recorded in the intertidal and shallow subtidal included *Zostera muelleri* subsp. *capricorni* and *Halophila ovalis*. Dense stands of *Z. muelleri* grew along the edge of channels in Weyba Creek (particularly around the mouth of Lake Weyba (Figure 3.1) and Keyser Island), and also along the main river channel at Tewantin (Figure 3.2). Several sparse patches of *H. ovalis* were also recorded on the edges of and between patches of dense *Z. muelleri* (Figure 3.6). Patches of dense *H. ovalis* were recorded in parts of Lake Doonella (Figure 3.3).

Table 3.1 Area (m^2 and Ha) of seagrass mapped in Noosa Estuary in November 2020

Reach	Coverage Type	Area (m^2) of Seagrass	Area (Ha) of Seagrass
Lake Cooroibah	Dense	0	0
	Sparse	0	0
	Total	0	0
Noosa River – Tewantin	Dense	25,037	2.5
	Moderate	1,505	0.2
	Sparse	3,503	0.4
	Total	30,045	3.0
Lake Doonella	Dense	0	0.0
	Sparse	318,129	31.8
	Total	318,129	31.8
Noosa River – Goat Island	Dense	737	0.1
	Sparse	1,259	0.1
	Total	9,313	0.9
Noosa River Mouth	Dense	0	0
	Sparse	0	0
	Total	0	0
Weyba Creek	Dense	18,365	1.8
	Sparse	2,133	0.2
	Total	205,510	20.6
Lake Weyba	Dense	20	0.0
	Sparse	0	0.0
	Total	20	0.0
Total Noosa Estuary		**563,018**	56.2

The condition of seagrass was generally good to very good (>57% of seagrass surveyed) with patches generally providing good to very good value for fisheries species (>65% of seagrass surveyed) (Table 3.2; Figure 3.1). The remaining patches generally remain well connected to other seagrass patches or other structural habitat such as mangroves throughout the lower estuary. The least structurally diverse seagrass beds were recorded in Lake Doonella, however due to good proximity to deeper water channels and good connectivity to the mangrove fringe, these habitats still provide good potential value for fisheries species (Table 3.2).

Table 3.2 Area of seagrass for each condition index category and value of seagrass habitat to fisheries based on current condition and structural components

			Total Area (m2)	
Reach		**Fair**	**Good**	**Very Good**
Lake Cooroibah	Seagrass Condition	–	–	–
	Fisheries Value	–	–	–
Noosa River – Tewantin	Seagrass Condition	3,783	26,262	
	Fisheries Value	3,783	2,049	24,213
Lake Doonella	Seagrass Condition	236,821	81,308	–
	Fisheries Value	191,241	126,888	–
Noosa River – Goat Island	Seagrass Condition	–	9,313	–
	Fisheries Value	–	9,313	–
Noosa River Mouth	Seagrass Condition	–	–	–
	Fisheries Value	–	–	–
Weyba Creek	Seagrass Condition	99	203,660	1,751
	Fisheries Value	446	7,927	197,136
Lake Weyba	Seagrass Condition	–	20	–
	Fisheries Value	–	20	–
Total Noosa Estuary	**Seagrass Condition**	**237774**	**320564**	**1751**
	Fisheries Value	**192542**	**146198**	**221349**

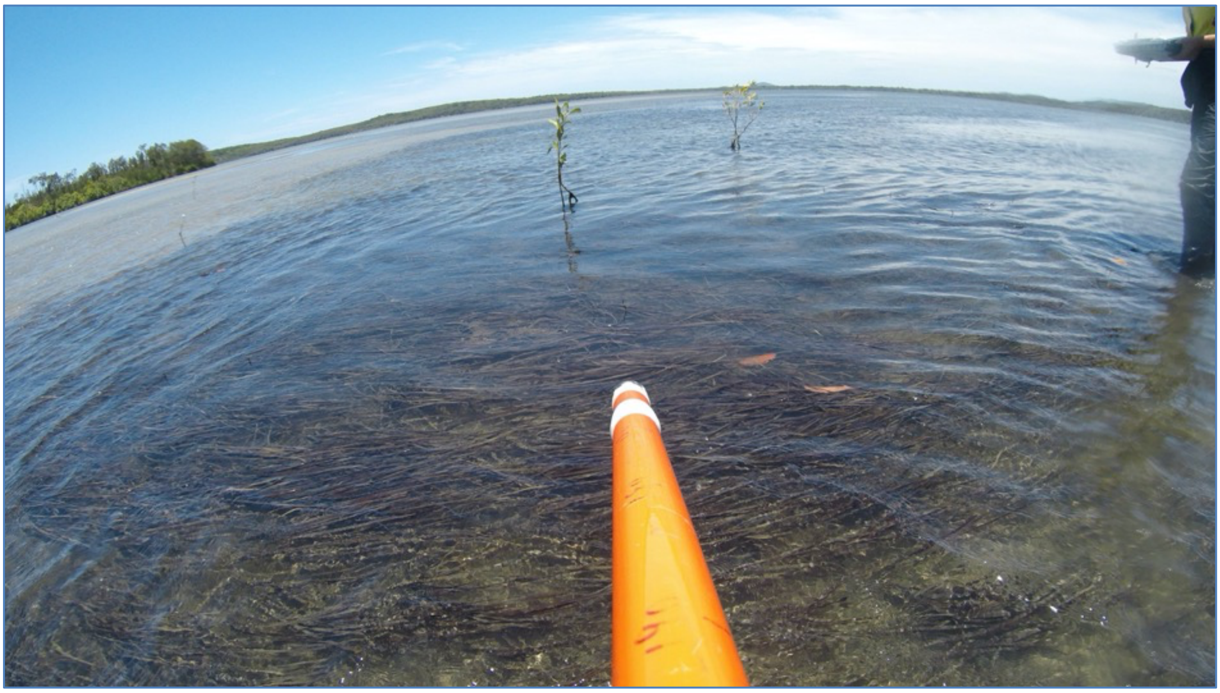

Figure 3.1 Dense *Zostera muelleri* at the mouth of Lake Weyba providing good fisheries value

Figure 3.2 Dense *Zostera muelleri* patches along the main river channel at Tewantin

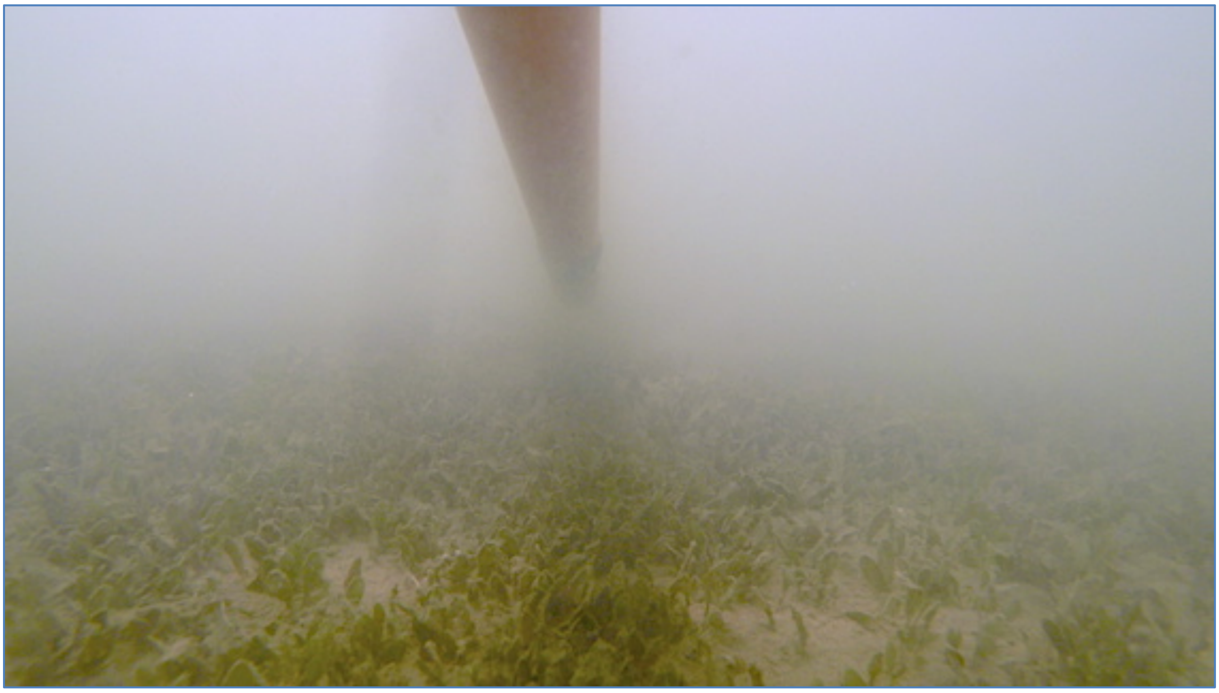

Figure 3.3 Dense *Halophila ovalis* growing in Lake Doonella in November 2020

Figure 3.4 Small patch of *Zostera muelleri* growing along the Goat Island in the main Noosa River Channel in November 2020

3.2 Seagrass Condition

The seagrass growing in the Noosa Estuary was showing signs of stress, as a result of sedimentation in some areas. Further, many of the seagrass beds growing in the relatively clear and shallow water of the estuary were covered in a high load of epiphytic algae. The dense *Z. muelleri* was typically in moderate condition, with long blades up to 50 cm long that had a high coverage of epiphytic algae (greater than 40% of the blade) (Figure 3.5). In some areas of Weyba Creek around Keyser Island, and along the main creek channel further upstream, the coverage of epiphytic algae on the *Z. muelleri* blades was extremely dense (> 80%) and in some cases it completely smothered the seagrass (Figure 3.5). The coverage of epiphytic algae was particularly high in dense beds around freshwater inputs such as stormwater drains.

Elsewhere, the coverage of epiphytic algae was sparser, particularly in areas where the coverage of *Z. muelleri* was also lower (Figure 3.6). The coverage of epiphytic algae on *H. ovalis* was typically very low, although this seagrass species was typically observed along the fringes of *Z. muelleri* beds and in areas of increased turbidity such as in Lake Doonella.

There were also instances where seagrass patches were being smothered by shifting sediment. This was particularly the case along sections of the channel in Weyba Creek and at the entrance to Lake Weyba (Figure 3.6 & Figure 3.7). The non-vegetated intertidal and subtidal habitat within the study area was generally characterised by coarse, sandy substrates. These habitats had low epifaunal activity (no burrowing crabs were observed in the sand), with a low density of burrows on the surface (average <1 m^{-2}), and no epibenthic fauna (such as sea cucumber, bivalves or sea pens) were recorded in the georeferenced videos or along photo transects. The coarse sandy habitat was unconsolidated and highly mobile due to strong tidal currents, which likely reduced the suitability for fauna that burrow into the sediment. Results from the field survey are consistent with studies from the wider region, which generally recorded low abundances of epibenthic fauna from non-vegetated soft substrates (Skilleter- et al. 2019).

Stingrays and fish were recorded in the non-vegetated soft sediment habitats in and around the study area, and numerous stingray pits occurred intertidally, particularly in channel habitat and at the mouth of Lake Weyba. Large drifts of seagrass wrack (i.e. dead seagrass fragments detached from the original plant) were not evident throughout the estuary. Seagrass wrack is an important component of coastal ecosystems, providing microhabitats and food resources for fauna, and contributing to nutrient cycling (Oldham et al. 2014).

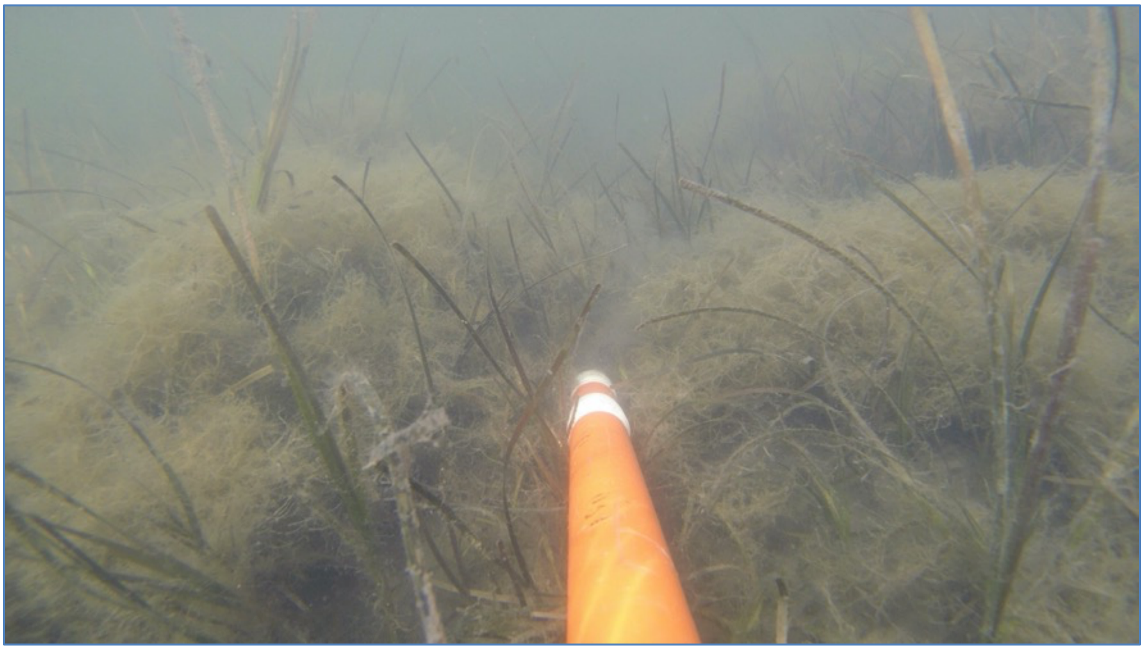

Figure 3.5 *Z. muelleri* with dense epiphytic algae in Weyba Creek in November 2020

Figure 3.6 Sparse *Z. muelleri* with moderate (40%) epiphytic algae growing along channel in Weyba Creek in November 2020

Figure 3.7 Small dense patches of *Z. muelleri becoming smothered by mobile sand bars in Weyba Creek*

4 Historical Change in Seagrass Distribution

A total of 56 Ha of seagrass was recorded throughout the estuary in November 2020, of which, the majority of area (31.8 Ha) was recorded from within Lake Doonella and 21 Ha from Weyba Creek (Table 3.1 & Table 4.1). Unlike previous assessments (e.g. Hyland et al 1989), no seagrass was recorded upstream of the ferry crossing to Noosa North Shore in 2020. In 1987, a total of 42 Ha of dense seagrass was recorded in the Main River Channel from Noosa to Lake Cooroibah, 62 Ha of patchy seagrass in Lake Doonella and 320 Ha of patchy seagrass in Lake Cooroibah (Hyland et al 1989). The Hyland et al. (1989) assessment was confirmed by assessing the area of seagrass in available aerial imagery from 1987 and 1989, which illustrates the substantial extent of seagrass at that time covering approximately 3,374 Ha (Table 4.1).

Based on the assessment of aerial imagery, there has been a large decline in the coverage of continuous and dense seagrass beds in several areas in the Noosa Estuary since 1989 (Figure 4.2, Figure 4.3 & Figure 4.4; Table 4.1). Declines have occurred around areas that are currently used as mooring areas for vessels such as around Goat Island, or focal areas for vessel movements such as upstream of Tewantin, upstream of the Eenie Creek Bridge in Weyba Creek and at the mouth of Lake Cooroibah. In particular, there has been a sustained reduction and fragmentation of seagrass habitat along the main reach of the river upstream of Tewantin (Council Chambers) to Lake Cooroibah. The reduction in seagrass coverage relative to what has been previously observed and recorded by Hyland et al. (1989), or what has been mapped from aerial imagery in this assessment, is considerable; even if you consider the coarse seagrass bed categories and nature of mapping completed by Hyland et al. (1989). We estimate that the seagrass coverage lost has been up to 83%, with only a small amount of recovery in some areas and the complete loss of seagrass in other reaches during that time (Table 4.1). The majority of seagrass lost occurred at some time between 1989 and 2006; though seagrass was completely lost in Lake Cooroibah between 2009 and 2020 (Table 4.1). An assessment of the historical changes in each reach is provided below (Section 4).

Table 4.1 Historical comparison of seagrass area within Noosa Estuary

Reach	Area (m^2) of Seagrass					% change 1989 to 2020
	1987	1989	2006	2009	2020	
Lake Cooroibah	NA	229,624	71,323	61,672	0	–100
Noosa River – Tewantin	106,651	134,541	39,360	36,731	28,540	–79
Lake Doonella	495,772	457,164	127,158	363,764	318,129	–30
Noosa River – Goat Island	93,865	105,247	28,831	23,539	9,313	–91
Weyba Creek	NA	647,065	270,366	239,551	205,510	–68
Lake Weyba	NA	1,800,445	0	0	20	–100
Total Seagrass Area (m^2) Noosa Estuary	**NA**	**3,374,086**	**537,038**	**725,258**	**561,512**	**–83**
Total Seagrass Area (Ha) Noosa Estuary	**NA**	**337.4**	**53.7**	**72.5**	**56.1**	**–83**

NA – suitable imagery not available for assessment across the estuary

4.1 Lake Cooroibah

Based on interpretation of aerial imagery, there was a substantial seagrass bed present in Lake Cooroibah in 1989 (Figure 4.2). A total of 229.6 ha of seagrass was mapped along the main navigation channel at the mouth of the lake and extending along the south-eastern shore (Table 4.1). There were substantial declines in the total area of seagrass occurring in this reach between 1989 to 2009, with the loss of seagrass along the main river channel as well as sparse patches within the lake (Figure 4.2). In 2020, the dense seagrass beds lining the navigation channel were no longer present, replaced with fine silt, particularly at the mouth of the lake (Table 4.1). The seagrass lining the main river channel upstream of the car ferry was also not recorded in 2020 (Figure 4.2; Table 4.1).

The primary cause of such a substantial decline in seagrass in this area was likely the floods in 1992, and subsequent floods in later years, reducing light penetration in the shallow lake and depositing fine sediment at the mouth of the lake and smothering existing seed banks before the beds had a chance to become re-established. This area should be prioritised for enhanced management measures, including possible support for re-establishing seagrass to improve habitat complexity and water quality outcomes in the estuary. The first step would be to identify whether there is an existing seagrass seed bank, and if there are other extraneous environmental issues that has prevented the natural reestablishment of seagrass in the area. Management actions may include the use of go-slow areas to minimise boat wash along the main channel, particularly at the mouth of the lake, managing and reducing sediment in runoff and understanding the current sediment dynamics (redistribution and resuspension) in the estuary.

4.2 Noosa River – Tewantin

Similarly, there has been an 79% decline in the coverage of seagrass between 1989 and 2020 in this reach, with the greatest declines occurring along the main river channel downstream of the car ferry (Figure 4.3; Table 4.1). Since 2006, the decline in seagrass extent has been less; although in 2020, seagrass beds were primarily located within the bay to the north of Noosa Council chambers in Tewantin (Figure 4.3). There has been a substantial contraction of beds along the river channel further north. Increased tidal connectivity relative to further upstream, may create conditions that lessen the impact of floods, with tidal flushing of less turbid waters decreasing the length of time seagrass is exposed to low light / high turbid conditions. Given the substantial changes further upstream, this area will be one to watch for further declines in extent.

4.3 Noosa River – Goat Island

The once dense seagrass beds around Goat Island have declined in extent by approximately 91% since 1989, with just under 1 ha remaining along the northern side of Goat Island and a few small patches of long dense *Z. muelleri* along the southern shore (Figure 4.3; Table 4.1). Like the other areas, the major declines in this area occurred between 1989 and 2006; however, unlike areas such as Lake Doonella (Section 4.4 below), the seagrass beds around Goat Island have not recovered and continue to decline. A major decline in the coverage of seagrass in this reach may be due to increased boat anchoring, as there has been an increase in the number of anchored vessels on aerial imagery since 2002. Damage from repeated anchoring and growler chains on moored vessels can cause significant direct physical damage to seagrass beds and creating halos many metres across (Walker et al. 1989; Hastings et al. 1995).

4.4 Lake Doonella

The area of seagrass within Lake Doonella has undergone some substantial historical changes in the extent, with a decline of 72% recorded between 1989 and 2006 (Figure 4.3; Table 4.1). This area has recovered quickly following major declines. The seagrass beds in Lake Doonella are dominated by *H. ovalis*, which is known to respond rapidly to environmental changes and can quickly recover within a few years, both through vegetative growth and regeneration from the seedbank. While the exact mechanisms of change remain unclear, it is possible that due to the configuration of the mouth of the lake, that there was lower sedimentation following major flooding in 1992 (Figure 4.7), enabling the beds in this area to recover from the disturbance in a similar timeframe as observed elsewhere, such as in Hervey Bay (Campbell & McKenzie 2004).

4.5 Weyba Creek

While the extent of seagrass in Weyba Creek has also declined, there are large areas that remain relatively intact, including the seagrass around Keyser Island at the mouth of the creek that increased in coverage between 2006 and 2009, but has since declined again in 2020. The mechanisms for substantial change in this reach based on observations appear to be shifting sand bars, which smother large areas of seagrass, particularly in areas near the mouth of Lake Weyba. There has been a substantial change in the mouth of Weyba Creek due to urbanisation and development of mangrove islands and along the foreshore, which may have altered the water quality or hydrodynamic regimes in this reach. Further investigation of the possible triggers for high epiphytic algal loads on the existing seagrass, assessments of the current water quality (including possible eutrophication from groundwater sources) and the residence time of water within this reach are needed.

4.6 Lake Weyba

The extent of seagrass in Lake Weyba has changed dramatically over the last 30 years, with large sparse seagrass beds at the mouth of the lake now just a few small patches. While not specifically mapped due to a lack of suitable aerial imagery, there were extensive seagrass beds recorded in Hyland et al 1989, which are visible in available aerial imagery (Figure 4.1). The greatest loss occurred between 1989 and 2006, where large beds of seagrass disappeared from the lake and did not recover. The triggers for the loss of seagrass within the lake remain unknown, but may be related to changes in water quality, interactive or cumulative impacts from flooding (i.e. freshwater flows allowing algae to bloom and outcompete seagrass) or changes in the hydrodynamic regime that prevent seagrass from re-establishing. This initial loss of seagrass in the early 1990s, may have triggered a regime shift to a soft sediment microalgal dominated system where constant resuspension of fine sediment particles directly smother or attenuate light sufficiently to prevent seagrass from restabilising naturally.

While the exact cause of the decline in seagrass in this reach remains to be determined, this area could be prioritised for possible remediation activities given their remnant nature and endurance and suitability of large areas to support extensive historical seagrass meadows. The restored function, including fisheries productivity gained from re-establishing these extensive seagrass beds could be substantial.

Figure 4.1 Extensive seagrass beds (shown as darker patches) at the mouth of Lake Weyba and entrance to Weyba Creek in August 1986 (Source: QLD Government 2021b)

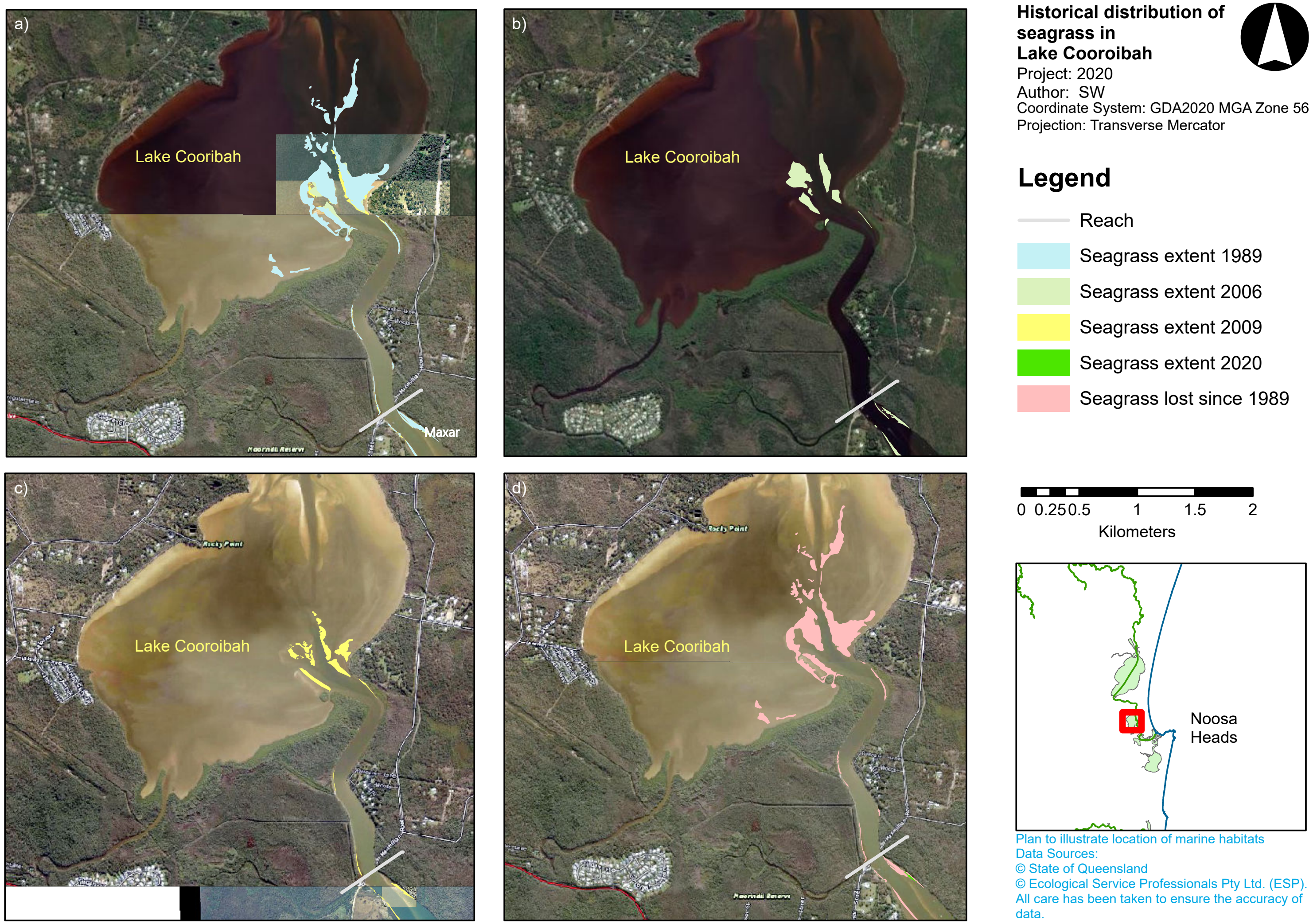

Figure 4.2 Historical distribution of seagrass in the Lake Cooroibah reach in (a)1989, (b) 2006, (c) 2009 and (d) distribution in 2020 and area lost since 1989

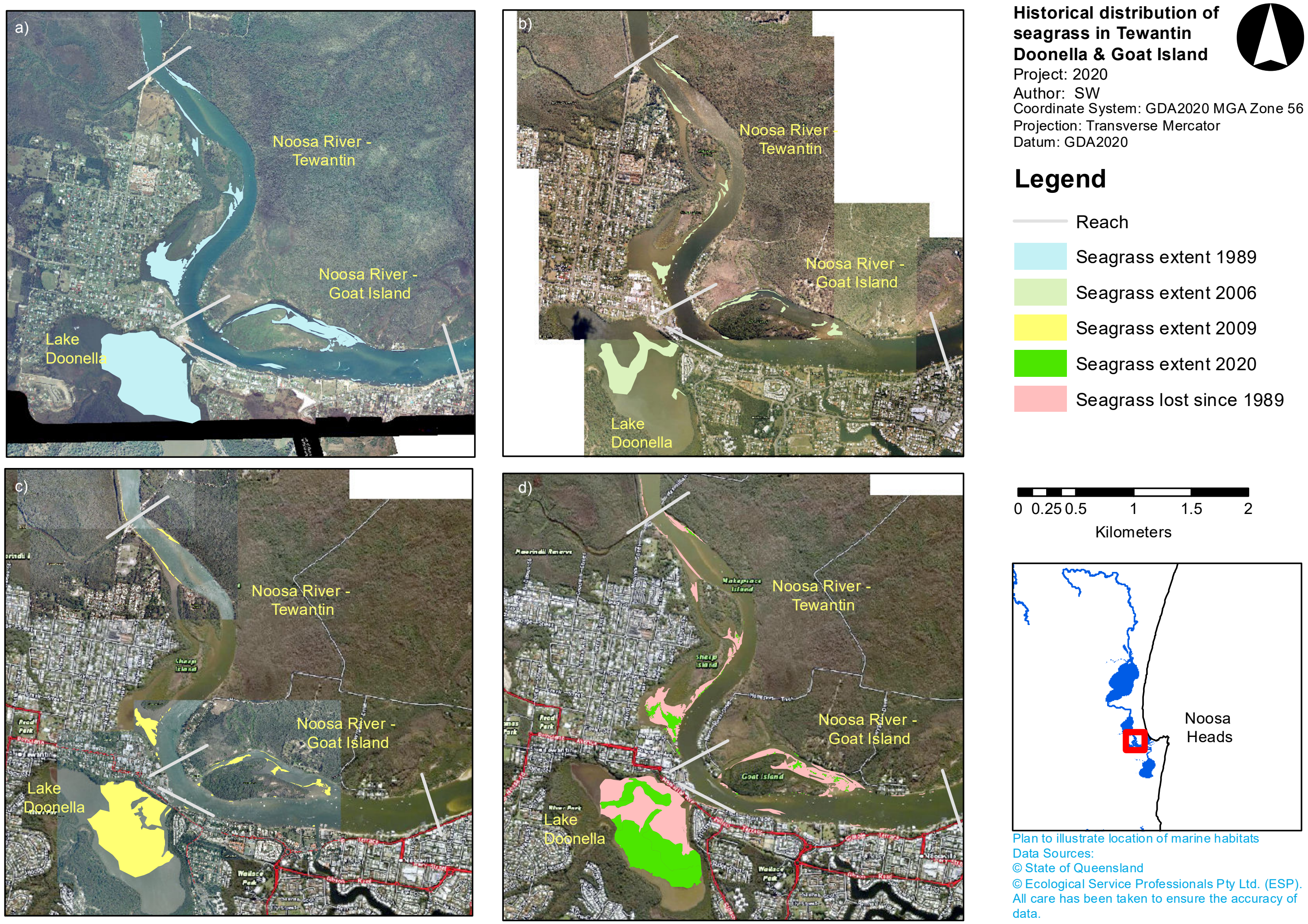

Figure 4.3 Historical distribution of seagrass in the Tewantin, Lake Doonella and Goat Island reaches in (a)1989, (b) 2006, (c) 2009 and (d) distribution in 2020 and area lost since 1989

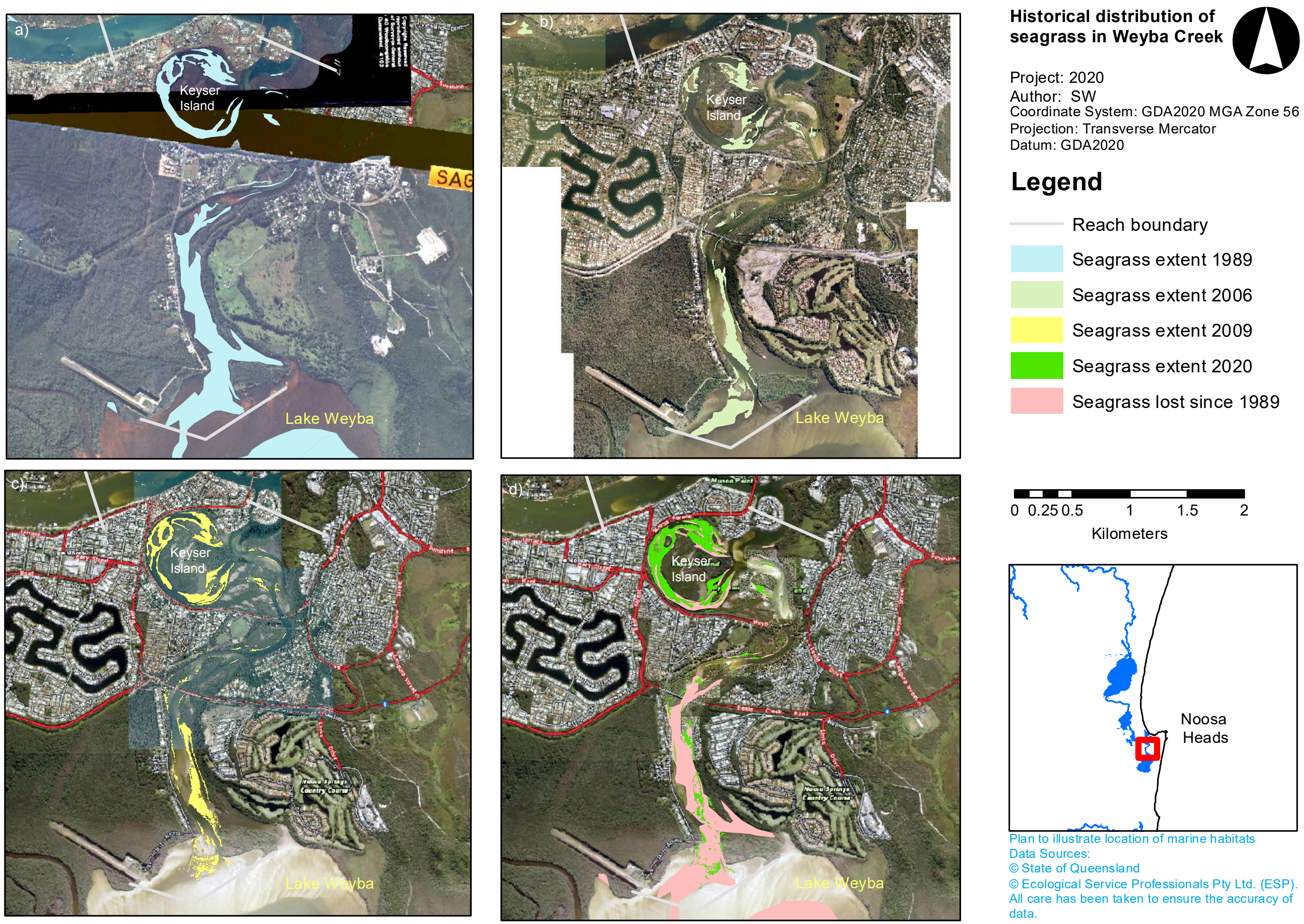

Figure 4.4 Historical distribution of seagrass in the Weyba Creek reach in (a)1989, (b) 2006, (c) 2009 and (d) distribution in 2020 and area lost since 1989

4.7 Influential Environmental Factors

Several factors may have contributed to the decline in the extent of seagrass in Noosa Estuary. In particular, flooding has resulted in substantial declines in seagrass elsewhere in the region at a similar time as observed here (Preen et al 1995; Campbell & McKenzie 2004). An assessment of available rainfall and riverine flow data was completed to determine if similar events contributed to the substantial declines observed in the Noosa Estuary.

The Noosa River flooded in 1992 (approximately 757 mm of rain fell over a two-day period in February 1992 recorded at Kiamba) (Figure 4.6), which may have been a trigger for substantial loss in seagrass extent due to mobilisation of sediment. This corresponds to a period of substantial loss of seagrass in several key areas, particularly in Lake Cooroibah and along the Main Noosa River channel. The impact of flooding on seagrass distribution is likely to differ depending on the reach, as the flood plume did not extend substantially up the Weyba Creek (Figure 4.5) and may have lessened the potential impact on light attenuation (duration and magnitude) and therefore seagrass survival.

Figure 4.5 Aerial image of the mouth of Noosa River on 24 February 1992 showing the majority of the flood plume bypassing Weyba Creek and Noosa Sound, and extending out into Laguna Bay (Source QLD Government 2021a)

4.7.1 Rainfall

The highest daily rainfall at the Kiamba Bureau of Meteorology (BOM) Station 040525[2] in February 1999 again exceeded a total monthly rainfall of 1012 mm of rainfall for the month with high daily rainfall in excess of 100 mm of rainfall occurring on the 1, 2, 8, 9 and 10 February 1999 (Kiamba BOM station 040525) (BOM 2021a) (Figure 4.6). Similarly high rainfall was recorded at Boreen Point on the banks of Lake Cootharaba of 1012 mm of rainfall for the month with high daily rainfall in excess of 100 mm of rainfall occurring on the 1, 2, 8, and 9 February 1999 (Boreen Point BOM station 40756) (BOM 2021b).

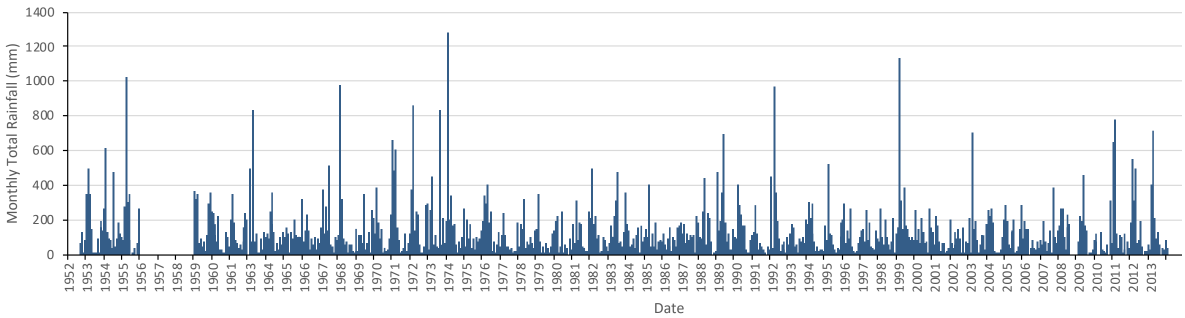

Figure 4.6 Monthly total rainfall (mm) measured at Kiamba BOM station from 1952 to 2014

4.7.2 Riverine Flow

Total river discharge measures at Teewah Creek at Coops Corner (QLD Gauging Station 140002A[3]) (QLD Government 2021b) generally reflects the rainfall in the area, with several peak monthly flood flows occurring since records began in 1972 following periods of high rainfall. In particular, the highest recorded monthly flow occurred in February and March 1992 with a total monthly flow of 25813 ML and 15980 ML respectively for each month (Figure 4.7). In contrast, the long-term average monthly flow is 2858 ML, more than 80% lower than recorded during those peak flood flows. The total monthly flow recorded in February 1992 was the highest on record for this gauging station. Other period of prolonged flows occurred from February to June 1999 and flow exceeding 10000 ML per month in August and September 2007, January and February 2008, December 2010, January 2011, March 2012, February 2013 and February 2020 (Figure 4.7). Peak flows in the upper catchment and subsequent flooding can be cause substantial mobilisation of sediment from the upper catchment, along creeks and rivers to Laguna Bay.

[2] The Kiamba Bureau of Meteorology (BOM) Station 040525 is approximately 26 km to the west of Tewantin, and is the closest weather station that was operational in 1992 and 1999.
[3] Flow has been recorded from May 1972 until present.

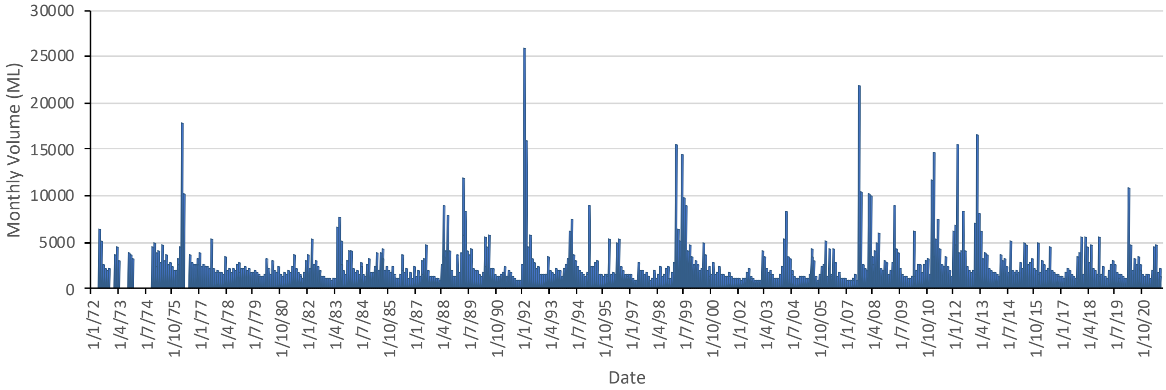

Figure 4.7 Total volume of water discharged at Teewah Creek gauging station between 1972 and 2021

5 Discussion

Seagrasses are highly sensitive to changes in environmental conditions and declines in water quality (particularly high turbidity), and are therefore considered indicators of environmental degradation and anthropogenic stressors (Heck et al. 2008; Waycott et al. 2009). Large scale seagrass loss has occurred in the past in Australia and across the globe (Short & Wyllie-Echeverria 1996), with the most significant and substantial extent of loss in Southern Queensland usually following a major flood or cyclonic event (Preen et al 1995; Campbell & McKenzie 2004). Minor or local scale impacts to seagrass occur due to human disturbances such as physical damage from propeller scaring, anchoring (Millazo et al. 2004), boat mooring (Walker et al. 1989; Hastings et al. 1995), boat wash (Bishop 2008), and pollution from oil spills, herbicide runoff and inputs from stormwater (Short & Wyllie-Echeverria 1996; McMahon et al 2005; Waycott et al 2009). The rate of seagrass loss recorded across the globe between 1879 and 2006 has been estimated at approximately 27 km^2 per year (i.e. a total of 3370 km^2) (Waycott et al 2009). More recently attention has focussed on assessing the potential for recovery following catastrophic changes in the face of climate change (Waycott et al. 2009; Kendrick et al. 2019).

The Noosa River flooded in 1992 (approximately 757 mm of rain fell over a two-day period in February 1992, recorded at Kiamba BOM station 040525; refer Section 4.7.1), which may have been a trigger for substantial loss in seagrass extent. At a similar time in Hervey Bay, more than 1,000 km^2 was reported as being lost following two major floods and a cyclone in a 3-week period (Preen et al. 1995). The loss of seagrass was thought to be due to light depravation due to turbid waters (Preen et al. 1995), and points to the need to manage terrestrial runoff and protect water quality (and in particular water clarity) to support a thriving seagrass community in an estuarine system. Recovery of seagrass meadows in deeper water (greater than 10 m) of Hervey Bay took more than 2 years post disturbance, due in part to seed germination from the existing seed bank (Preen et al. 1995). Recovery in shallow water meadows took even longer, with suspected burial of the seed bank due to redistribution of sediment thought to be a primary factor for the prolonged recovery in some areas (Preen et al 1995).

Based on analysis of historical imagery, there was no substantial recovery of seagrass in some parts of the Noosa Estuary once it was lost, likely due to smothering of the existing seedbank by fine sediment and destabilisation of the channel sediment, particularly along the main channel and at the mouth of Lake Cooroibah. The smothering of seagrass seedbanks can prevent reestablishment of seagrass, particularly in shallow habitat, where sediment is continually resuspended (Preen et al. 1995).

A further loss of seagrass occurred in Great Sandy Strait following flooding of the Mary River in February 1999, with more than 90% of intertidal seagrass lost (Campbell & McKenzie 2004). Recovery of seagrass took at least 3 years and was primarily achieved through natural seed germination.

Urbanisation of the foreshore, increased vessel traffic (boat wash), and increased anchoring and mooring of vessels in the river, particularly in the lower estuary, may have contributed to direct physical damage to seagrass or changes in water quality and hydrodynamics, particularly close to the river mouth, which may alter the way that sediment is transported out into Laguna Bay during flood flows or is retained in the estuary. Further work is required to understand the impact of this change on the potential suitability of habitats for seagrass, particularly in Weyba Creek and along the main river channel.

Seagrass meadows around the globe are sentinels for change in the environment. They are primary producers, capable of engineering the environment by converting sunlight, nutrients and carbon from the environment to stabilise soft sediments and create structured complex habitats that support high biodiversity including fish and invertebrates of commercial importance (Jelbart et al 2007; Nagelkerken et al. 2008; Waycott et al. 2011). The loss of seagrass in Lake Cooroibah and along the Noosa River at Tewantin and around Goat Island significantly decreases the potential ecological functions that seagrass can provide, including filtering water and sequestering carbon in the Noosa Estuary. The loss of biological filtration habitats such as seagrass, saltmarsh, mangrove and oyster reef habitats is not new in Noosa, with the substantial loss of habitat occurring at Hays Island in the early 1970s. This dramatic change to the mouth of Weyba Creek (Figure 5.1) may have altered water movement and created conditions that favoured the persistence of seagrass in some areas, and the decline in others. The loss of seagrass, particularly the large extent of loss from within the lakes may have contributed partly to the reported the declines in availability and therefore total catch of prawns in the estuary (Thurstan 2015); however, further work is required to assess the links between loss of seagrass and declines in prawn catches in Noosa. Elsewhere, seagrass beds are known to have a significant role as a nursery habitat for prawns in estuaries and embayments (Skilleter et al. 2005).

a)

b)

Figure 5.1 Aerial imagery from (a) June 1972 and (b) November 1974, showing the change in estuarine habitat due to urban development at the mouth of the Noosa Estuary (Source QLD Government 2021a)

6 Conclusions

The Noosa estuary is dominated by bare sand and mud habitats with occasional dense seagrass beds, rocky reefs and shellfish-dominated reef habitats. In 2020, seagrass covered a total of 56 Ha throughout the estuary, with the largest continuous remnant patches occurring at the entrance to Lake Weyba, along Weyba Creek (including around Keyser Island), in Lake Doonella and along the small bay off the main river channel at Tewantin. Notable declines in the area of seagrass beds have occurred within the Noosa Estuary, particularly in Lake Weyba and Lake Cooroibah, with approximately 80% of the total area of seagrass lost between 1987 and 2020.

Due to the nature of the Noosa River Catchment, different sub-catchments present a good comparative opportunity to assess the cause of declines in seagrass extent and likely impact of management actions. For example, impacts in along the main river channel are likely due to broader scale impacts from the upper catchment, including runoff from catchment clearing as well as boating activity. In contrast, seagrass in the smaller sub-catchments in Lake Doonella and Lake Weyba are likely responding to changes in the hydrodynamic regime, with seagrass in Weyba Creek being particularly susceptible to shifting sand banks.

Further assessment of the potential resilience of seagrass meadows to resist environmental changes in the Noosa Estuary are considered necessary to understand where to invest in future management actions for maximum gains. Consideration should also be given to the potential for natural recovery or assisted restoration of seagrass meadows once key triggers for past change are known and potential negative inputs have been managed.

Given that the cause of major changes to the extent of seagrass was most likely physical disturbance during a natural disaster, suitable management of the estuarine habitats in Noosa should consider an adaptive approach that examines and implements measures that maximise the resilience of seagrass beds, including the ability to respond to future natural disasters and human pressures that are predicted to increase in the future.

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Appendix A Value of seagrass to fisheries

Table 7.1 Criteria used to determine the fisheries habitat value of seagrass based on review of available literature[4]

Seagrass Patch Characteristic / Feature	**Criteria Score**			
	1	2	3	4
Meadow extent	Patchy <5m2 of seagrass bed surrounded by bare substrate (no other seagrass bed within 5m of the patch)	Patchy bed either intertidal or subtidal areas only (patches separated by more than 5m)		Continuous bed extending from intertidal to subtidal areas
Proximity to another structural habitats (based on wetland proximity score - Price et al 2007)	Poorly connected to other structural fish habitat (Intertidal seagrass proximal to mangroves, subtidal seagrass, macroalgae rocky reef, coral reef, or another structured habitat) No natural structural ecosystem merged with meadow boundary. (i.e. >1000m to another structural habitat and surrounded by bare habitat)	Moderately connected to other structural fish habitat (Intertidal seagrass proximal to mangroves, subtidal seagrass, macroalgae rocky reef, coral reef, or another structured habitat) Structural ecosystem merged with up to 25% of meadow boundary or within 1000m of other structural habitat	Well connected to other structural fish habitat (Intertidal seagrass proximal to mangroves, subtidal seagrass, macroalgae rocky reef, coral reef, or another structured habitat) Structural ecosystem merged with 25 to 50% of meadow boundary or Within 100m of other structural habitat	Well-connected up- and down-shore to other known structural fish habitats (Intertidal seagrass proximal to mangroves, subtidal seagrass, macroalgae rocky reef, coral reef, or another structured habitat). Structural ecosystem merged with >50% of meadow boundary or within 100m of other structural habitat within 100m of other structural habitat
Proximity to nearest continuous	>1km	200 to 1000m		<200m

seagrass bed (>3000m2)				
Proximity to deep water channels	Deepest edge of seagrass bed is < 0.3 m		Deepest edge of seagrass bed is 0.3 – 2m OR Water is > 0.3 m deep at deepest point with seagrass growing to deepest point estuary, lake or lagoon	Deepest edge of seagrass >2m depth OR Water is < 2m deep at deepest point, with seagrass growing to deepest points of estuary, lake or lagoon
Seagrass Condition Index (as defined by the metrics below)	Poor (Condition Index <4)	Moderate (Condition Index 5 to 8)	Moderate to Good (Condition Index 9 to 13)	Good to very good (Condition Index 14 to 16)
Meadow mosaic size (patches within 5m considered the same meadow)	Small bed area (>930m2) available for fish at high tide	Small bed area (930-2300m2) available for fish at high tide	Moderate bed area (3000 - 5000m2) available for fish at high tide	Large bed area (>5000m2) well connected and available for fish use at high tide
Total Score	**<8**	**9 to 12**	**13 to 18**	**19 to 24**
Fisheries Value	**Poor**	**Fair**	**Good**	**Very Good**

Table 7.2 Seagrass condition index criteria

Seagrass Condition Index	Criteria Score			
Score	1	2	3	4
Structural Complexity	Low structural complexity (i.e. max length of seagrass blades <10cm, depending on dominant species present)	Moderate structural complexity (i.e. max length of seagrass blades 10 to 20cm; depending on dominant species present)	High structural complexity (i.e. max length of seagrass blades 20 to 30cm depending on dominant species present)	High structural complexity (i.e. max length of seagrass blades >40cm depending on dominant species present)
Coverage of epiphytic algae	Low or very high cover of epiphytic algae (<20% or >80%)	High cover of epiphytic algae >60% of seagrass blades OR low cover of epiphytic (<20%)	Moderate cover of epiphytic algae (20-30%)	Moderate cover of epiphytic algae (30-40%)
Presence of cyanobacterial mats	Presence of dense cyanobacterial mats (Lyngbya).	Sparse coverage of cyanobacterial mats (Lyngbya).		Cyanobacterial mats such as Lyngbya absent
Coverage of seagrass	Sparse coverage of seagrass (<10%)	Sparse coverage of seagrass (10 to 30%)	Moderately dense coverage of seagrass (30-60%)	Dense coverage of seagrass (>60%)
Seagrass Condition Index (as defined by the metrics below)	**Poor**	**Fair**	**Good**	**Very Good**
Total Condition Index Score	**<4**	**5 to 8**	**9 to 13**	**14 to 16**