NIWA
Taihoro Nukurangi

Seagrass in the Eastern Bay of Islands: past and present abundance, threats and management options

NIWA Client Report: HAM2010-043
May 2010

NIWA Project: ELF10229

Seagrass in the Eastern Bay of Islands: past and present abundance, threats and management options

Fleur Matheson
Sanjay Wadhwa
Aleki Taumoepeau
Joshua Smith

NIWA contact/Corresponding author

Fleur Matheson

Prepared for

Northland Regional Council

NIWA Client Report: HAM2010-043
May 2010

NIWA Project: ELF10229

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Contents

Reviewed by:	*Approved for release by:*
Rohan Wells	Mary de Winton

Formatting checked

Executive Summary

This report describes an investigation into the loss of seagrass meadows from the Eastern Bay of Islands area. The project aimed to quantify the loss of seagrass in this area by comparison of historical and recent aerial images, identify factors that may have contributed to seagrass decline and recommend options to protect remaining seagrass and rehabilitate denuded areas.

The extent of seagrass meadows in the Eastern Bay of Islands area was delineated from historical and recent aerial photographs. Field visits in November 2009 and February 2010 were used to ground-truth the photograph analysis and to assess selected sites for seagrass condition and relevant environmental parameters. Six sites were assessed including three on offshore islands (Cooks Cove, Waiiti Bay and Otiao Bay) and a further three sites, two on the mainland, considered to have suffered seagrass loss (Urupukapuka Bay, Hauai Bay and Kaingahoa Bay).

The aerial photograph analysis showed that the extent of seagrass meadows in the mainland bays near Rawhiti (Kaimarama Bay, Hauai Bay and Kaingahoa Bay) had decreased substantially between 1961 and 2005-6. There were approximately 32 ha of seagrass in these bays in 1961 but less than 1 ha remained in 2005-6. Our field visits in 2009-10 confirmed that only small patches persist in these bays. In contrast, there has been minimal change to seagrass meadow extent on the offshore islands. Otiao and Urupukapuka Bays harboured approximately 17 ha between them in both 1961 and 2005-6.

Analysis of current seagrass condition showed that plant biomass was substantially higher at offshore island sites, particularly Cooks Cove, compared to the mainland sites. On the offshore island sites, seagrass meadows were extensive and found in water depths up to 4.5m. At the mainland sites, seagrass patches were confined to shallower water depths (<2-3m). All seagrass meadows in the Eastern Bay of Islands area are subtidal, growing permanently submerged below the low tide water mark.

Analysis of environmental parameters including underwater light availability, sediment particle size and seawater phytoplankton biomass, indicated that conditions may be at times be less suitable for seagrass growth at the mainland sites compared to the offshore island sites. Higher seawater phytoplankton biomass was recorded at the two mainland sites during summer and data loggers deployed from November 2009 to February 2010 indicated the highest reductions in light availability due to epiphytic algal growth at the two mainland sites. Enhanced phytoplankton and epiphytic algal growth in these bays may be linked to nutrient enrichment from septic tank leachate, stream and stormwater inflows, water currents moving contaminants from the inner Bay of Islands, and boat effluent and grey water (which often contains phosphorus) discharges. Particle size analysis revealed that the sediments at mainland sites also had a significantly higher quantity of fine sand size particles (125-250 µm) than sediments from the offshore island sites. This suggests that seagrass in these bays

may have been detrimentally affected by activities such as land clearance and development in surrounding catchments that have accelerated fine sediment runoff and deposition in these bays.

There are up to 1500 vessels operating in the Bay of Islands area during summer. Boating and watercraft activities and structures in the shallow, sheltered bays occupied by seagrass have the potential to physically damage these meadows. Only limited information was available to assess the potential contribution of boating activities to seagrass decline in the Eastern Bay of Islands. However, examining the location of existing moorings suggests that these structures have not had a significant detrimental impact on seagrass meadows. At Cooks Cove a large denuded area in the seagrass zone in front of the jetty indicates a localised impact arising from boat use of this jetty. The impact of inshore boat anchoring, trampling and watercraft use is unknown but potentially significant and we recommend that this be investigated.

To protect and rehabilitate seagrass meadows in Eastern Bay of Islands a number of actions are recommended to mitigate coastal pollution and minimise physical damage. These include: (1) riparian planting of stream margins on land cleared for agriculture and forestry to trap and filter diffuse contaminants; (2) ensuring septic tanks comply with operational guidelines and move towards reticulating sewage or more efficient treatment systems where possible (3) ensuring compliance of consented point source discharges and require consent holders to work towards improvements in the quality of discharges over time; (4) encourage boat users to discharge effluent and grey water to treatment facilities at marinas or offshore (5) encourage landusers to minimise fertiliser use; and (6) site any new moorings or coastal structures (e.g., boat ramps, jetties) away from areas occupied by seagrass.

This study has shown that large areas of seagrass have been lost from the mainland bays of Kaimarama, Hauai and Kaingahoa in the Eastern Bay of Islands. Some remnant patches remain in these bays. If conditions are suitable for seagrass growth in the mainland bays, meadows may regenerate from these remnant patches in the future. Our limited measurements of water and sediment quality suggest that conditions are less favourable for seagrass growth at the mainland sites relative to offshore island sites at particular times (i.e., summer); however the results are not conclusive. Seagrass transplantation has been used successfully in Whangarei Harbour to assist rehabilitation of seagrass to a former site. Seagrass transplantation could usefully be trialled at a small scale in the mainland bays of the Eastern Bay of Islands to test the current potential for enhancing seagrass recolonisation of these areas.

1. Introduction

In November 2008, Kuia from Ngati Kuta/Patukeha contacted NIWA and Northland Regional Council concerned about loss of seagrass meadows from areas in the Eastern Bay of Islands. A consultancy report commissioned by Ngati Kuta/Patukeha highlighted a potentially significant loss of seagrass from Urupukapuka Bay on one of the offshore islands since 1991 (Ngati Kuta ki Te Rawhiti Charitable Trust 2008). In addition, Kaumatua and Kuia recall extensive meadows of seagrass in some of the mainland bays which have now all but disappeared.

Seagrass meadows are an important ecological resource in coastal areas. In New Zealand, our sole seagrass species, *Zostera muelleri*, grows in shallow, sheltered coastal waters and provides habitat and food for an abundance of marine organisms, particularly crustaceans and fish. Seagrass meadows, particularly subtidal ones, are an important nursery for juvenile fish, including snapper and parore (Morrison et al. 2007; Morrison 2009). Unfortunately, significant loss of seagrass has been reported for many locations around the New Zealand coastline (Inglis 2003), including Tauranga and Whangarei harbours (Park 1999, Reed et al. 2004). This is a global issue (there are around 60 seagrass species worldwide) and declines are often attributed to impacts from human activities in the coastal zone (Orth et al. 2006).

This report describes an investigation into the loss of seagrass meadows from the area of concern in the Bay of Islands funded by the Foundation for Science, Research and Technology's (FRST) Envirolink programme. The project objectives were to:

- quantify the loss of seagrass in the Eastern Bay of Islands area by using historical and recent aerial photographs;
- identify the likely factors that have contributed to the seagrass decline;
- recommend options to protect remaining seagrass and rehabilitate denuded areas.

2. Methods

2.1 Aerial photograph analysis

Aerial photographs of the Eastern Bay of Islands in 1961 (NZ Aerial Mapping No. 1223; No. 2607/1, 17 March 1961), showing most of the area from Moturua Island to Rawhiti Point (see Figure 1 for overview map), were provided by a local resident (John Booth) and digitised. Recent aerial images (2005-6) for the same area were obtained from Land Information New Zealand. Historical and recent images were geo-rectified in ArcGIS and potential areas of seagrass were delineated. Field visits in November 2009 and February 2010 were used to ground-truth this analysis. All areas identified as potentially occupied by seagrass were checked for presence and cover using an underwater camera (DropCam) and/or by snorkel or scuba diving.

An additional set of historical aerial images of the area from 1977 were supplied by Northland Regional Council. Unfortunately the clarity of these photos was generally not sufficient to enable clear identification of seagrass meadows except for the area of Waiiti Bay.

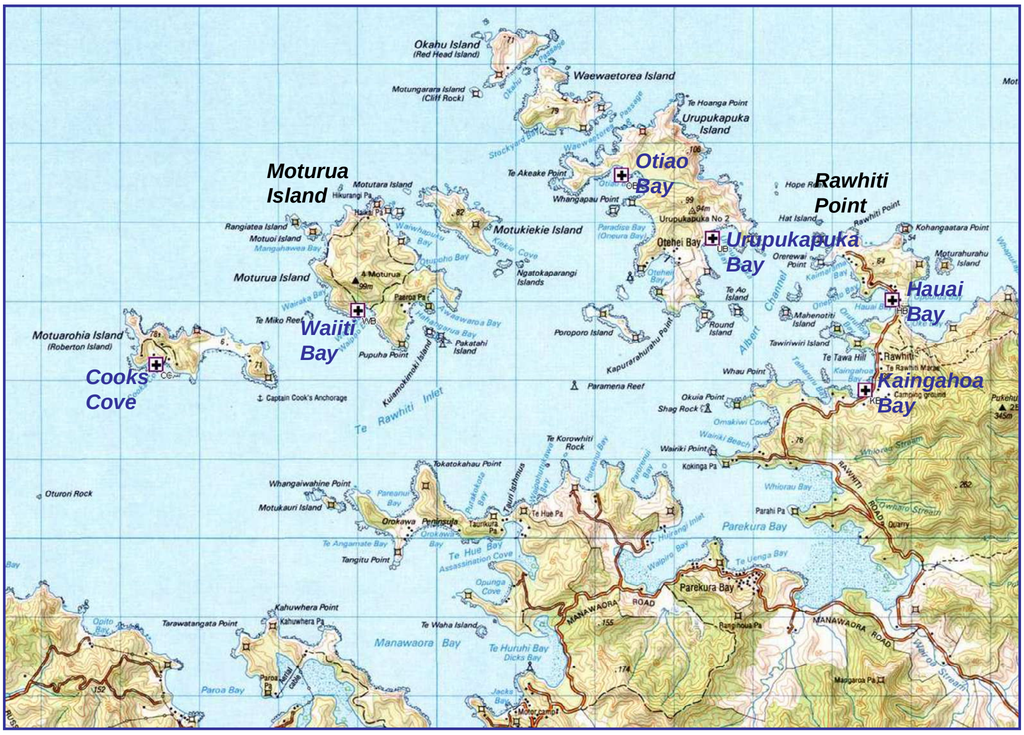

Figure 1: The Eastern Bay of Islands area showing the location of sampling sites (⊞).

2.2 Field sampling

Six sites were selected for assessment of current seagrass condition and key environmental variables (Figure 1). These sites included four on offshore islands (Cooks Cove, Waiiti Bay, Otiao Bay and Urupukapuka Bay) and two on the mainland (Hauai Bay and Kaingahoa Bay). The first three sites (Cooks Cove, Waiiti Bay and Otiao Bay) had extensive existing seagrass meadows. The remaining three sites (Urupukapuka Bay, Hauai Bay and Kaingahoa Bay) were thought to have suffered significant seagrass loss in recent decades.

At each site, divers took underwater photographs of replicate quadrats (0.5 m x 0.5 m) of the seagrass for plant cover analysis. Divers also collected core samples (8 cm diameter x 10 cm depth) for quantification of seagrass biomass and analysis of sediment organic matter content and particle size. Divers deployed underwater light/temperature loggers (Hobo® pendant) to assess light availability and water clarity over a period of several months. Water samples were collected on each visit for analysis of salinity (YSI® SCT meter), turbidity (Hach 2100P turbidimeter) and phytoplankton biomass (chlorophyll *a*).

2.3 Laboratory analysis

In the laboratory, water samples were analysed for chlorophyll *a* content by acetone pigment extraction and spectrofluorometry. The organic matter content of sediments was analysed by loss on ignition (4h/450°C) in a muffle furnace. Sediment particle size was analysed by a combination of wet sieving (particles >250 um) and automated particle size analysis (particles <250 um, EyeTech ToT Laser Machine – CIS100). Seagrass biomass was extracted from cores and separated into above- and below-ground fractions and dried (70°C) to constant weight. Solar radiation data for the study period were obtained from the nearest weather station (Kerikeri).

3. Results

3.1 Past and present abundance

The overall extent of seagrass meadows in the Eastern Bay of Islands area from Moturua Island to Rawhiti Point in 1961 compared to 2005-6 is illustrated in Figure 2. More detailed images for specific areas are provided later. The areas of Waiiti Bay and Cooks Cove (on Moturohia Island, west of Waiiti Bay) were not covered by the 1961 aerial images.

Seagrass meadows in the Eastern Bay of Islands are all subtidal (i.e., occurring below the low tide water mark). The aerial photograph analysis shows that while there are still extensive seagrass meadows in bays on the offshore islands, the expansive seagrass meadows present in mainland bays near Rawhiti (Kaimarama, Hauai and Kaingahoa Bays) in 1961 have been reduced to small remnant patches.

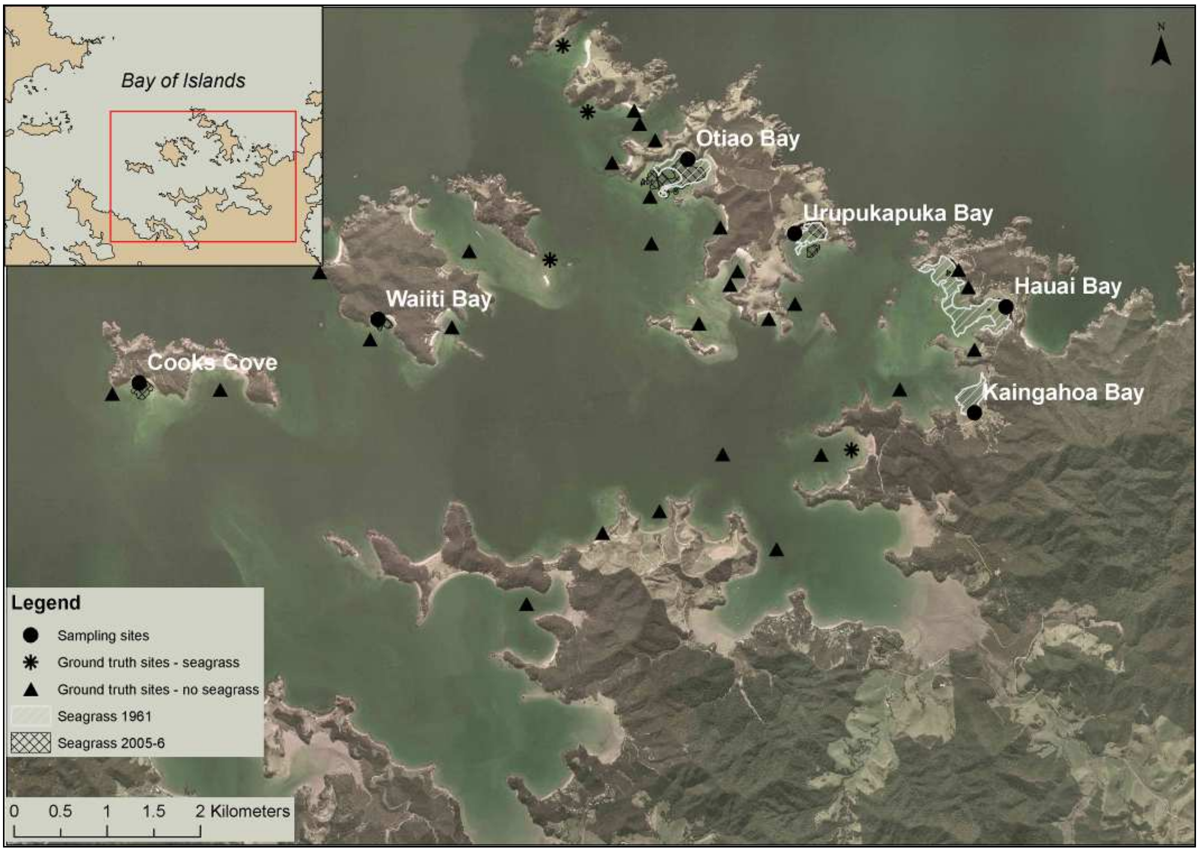

Figure 2: Areas of seagrass in the Eastern Bay of Islands in 1961 and in 2005-6. NB. The 1961 aerial images did not cover Waiiti Bay or Cooks Cove.

Table 1 and Figures 3 to 5 compare seagrass extent in 1961 and 2005-6 for specific areas. In Urupukapuka Bay there has been minimal change in seagrass extent between 1961 and 2005-6 (Table 1, Figure 3). There has also been minimal change in Otiao Bay (Table 1, Figure 4). However, in Kaimarama, Hauai and Kaingahoa Bays near Rawhiti on the mainland, there has been a marked reduction in seagrass extent (Table 1, Figure 5). For the five bays that we were able to compare in our analysis, total seagrass extent has declined by 73% from 49.3 hectares in 1961 to 18.4 hectares in 2005-6 (Table 1). The 1977 images indicated a comparable area of seagrass in Waiiti Bay in 1977 and in 2005-6 (~1.9 ha). There was approximately 2.8 ha of seagrass in Cooks Cove in 2005-6.

Table 1: Seagrass extent in specific areas of the Eastern Bay of Islands in 1961 compared to 2005-6.

Location	Area of seagrass (ha)	
	1961	**2005-6**
Otiao Bay	12.2	12.8
Urupukapuka Bay	5.2	4.7
Kaimarama Bay	9.7	0.4
Hauai Bay	15.2	0.5
Kaingahoa Bay	7.0	0.0
Total	**49.3**	**18.4**

Our field visits in the spring-summer of 2009-10, found slight differences in seagrass extent to those observed in 2005-6. This is not unexpected as seagrass meadows are dynamic habitats and their precise distribution can fluctuate through time. Notably, in 2009-10 compared to 2005-6, seagrass meadows were found to be even more extensive in Otiao and Urupukapuka Bays, and seagrass patches were detected in Kaingahoa Bay (none were evident in the 2005-6 aerial images). The location of our sampling sites (blue dots) in these Bays outside of the delineated seagrass areas highlights these differences. At Otiao Bay, seagrass meadows extended inshore of the 2005-6 distribution to the low tide water mark. At Urupukapuka Bay, the seagrass meadows in 2009-10 extended across most of the Bay (Figure 6). Hayward (1981) reported that most of the floor of Urupukapuka Bay (0.5-3 m deep) was covered by a thick mat of seagrass in 1981. At Kaingahoa Bay in 2009-10 a number of small patches were located close to the low tide water mark.

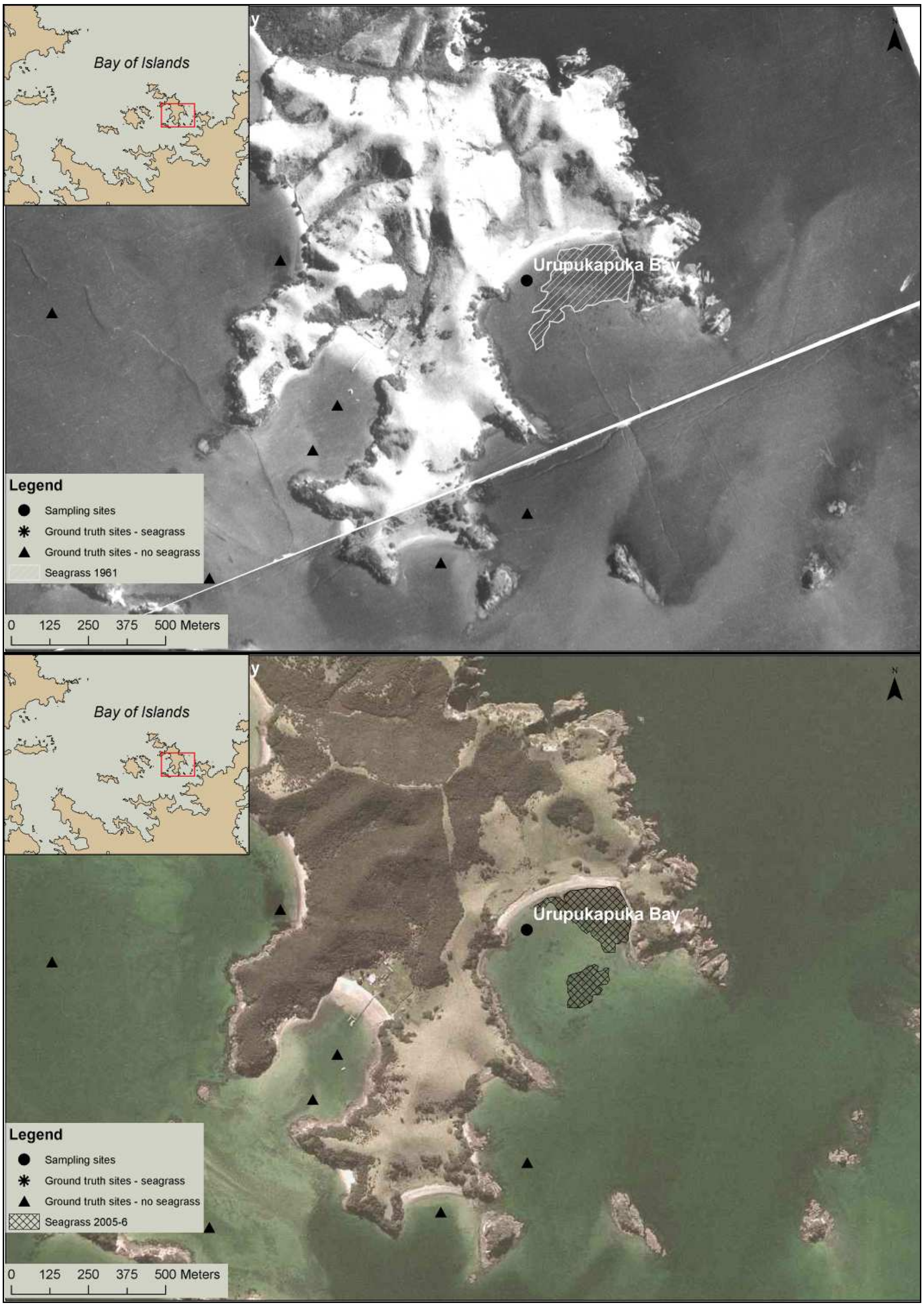

Figure 3: Area of seagrass in Urupukapuka Bay in 1961 (top) compared to 2005-6 (bottom). Ground truth and sampling sites are indicated.

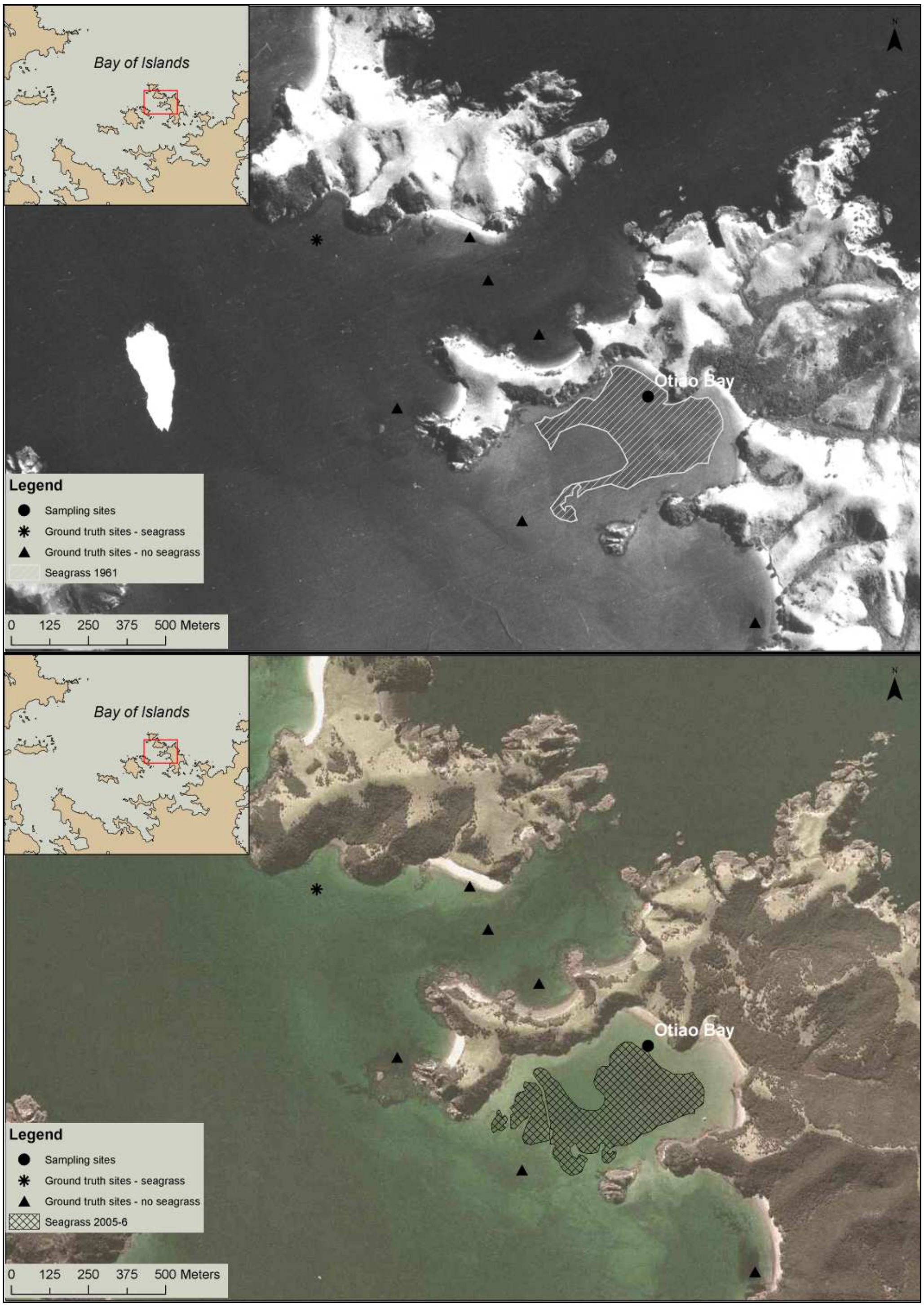

Figure 4: Area of seagrass in Otiao Bay in 1961 (top) compared to 2005-6 (bottom).

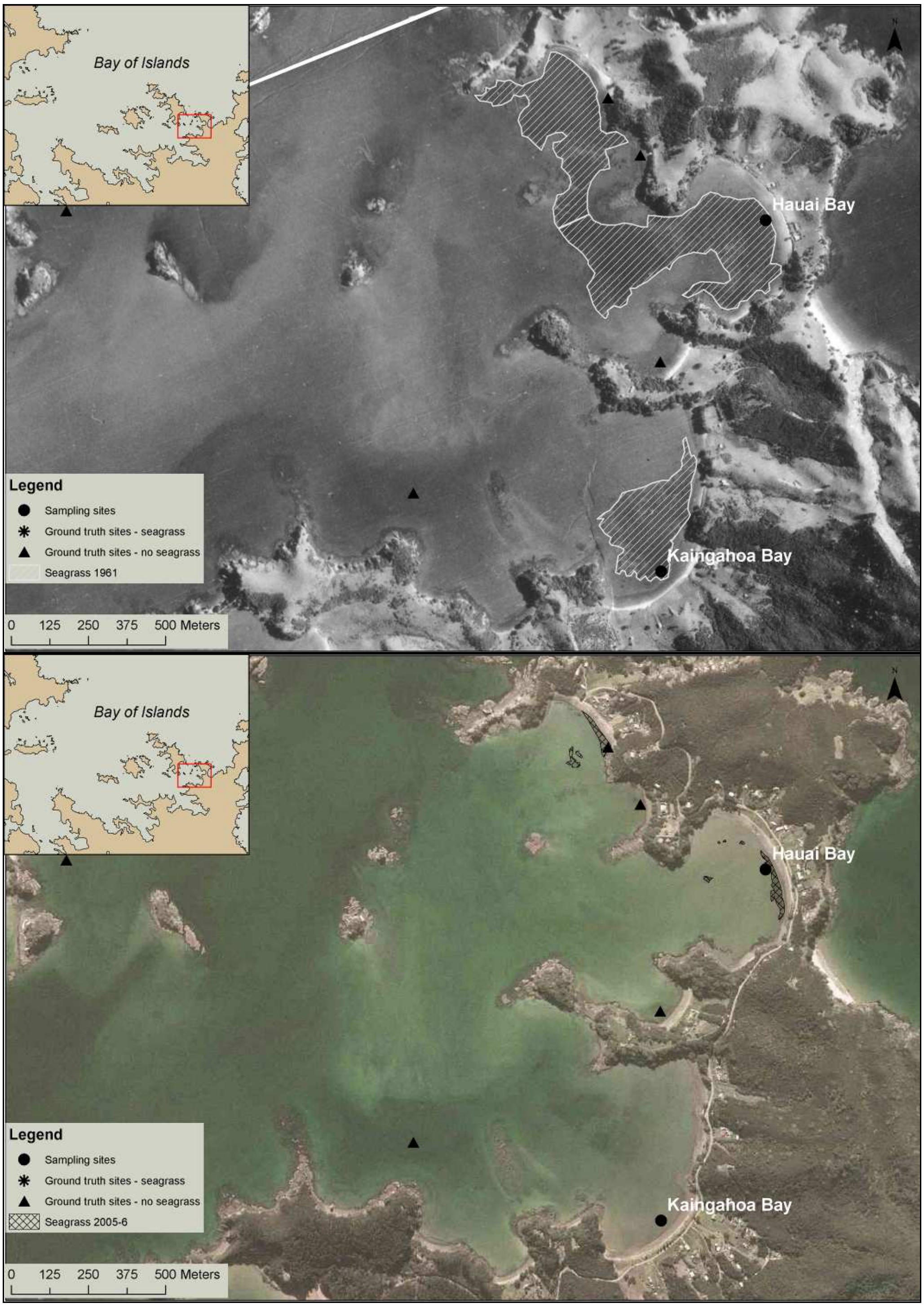

Figure 5: Area of seagrass in Kaimarama, Hauai and Kaingahoa Bays in 1961 (top) compared to 2005-6 (bottom).

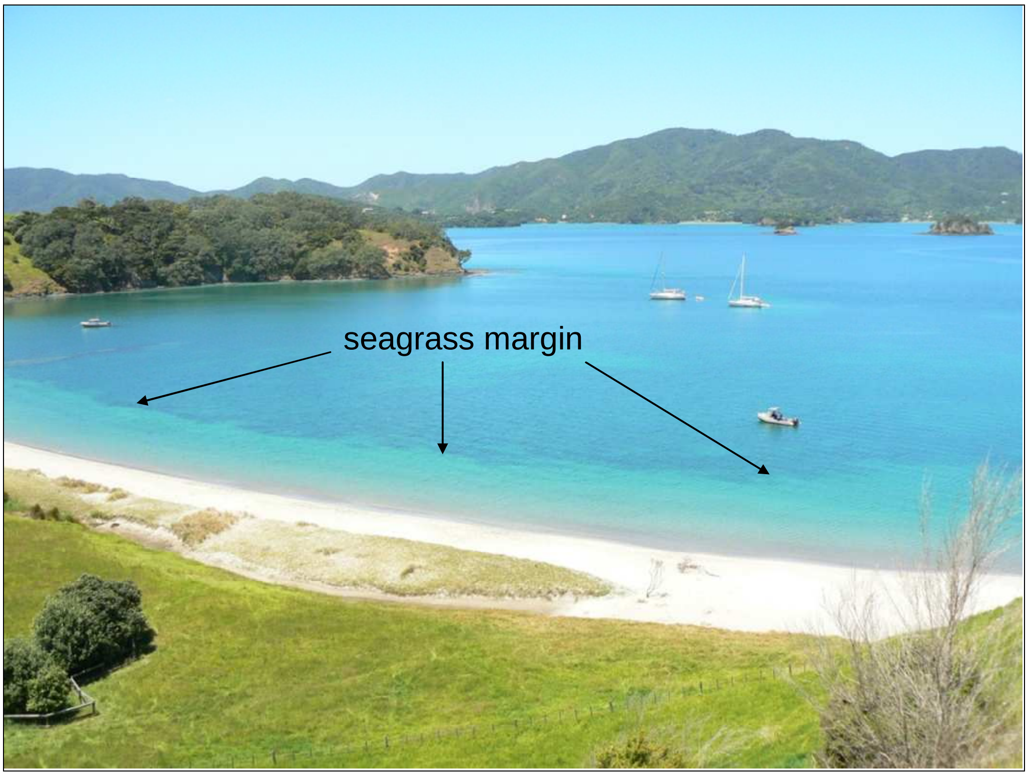

Figure 6: Seagrass meadows (dark areas) extending across Urupukapuka Bay in November 2009 (Photo: R. Griffiths/J. Hampson, NRC).

3.2 Site assessment results

Six sites were targeted for assessment of seagrass condition and environmental parameters in the summer of 2009-10. The results are summarised in Tables 2 and 3.

3.2.1 Seagrass condition

Extensive meadows of seagrass were found at the four offshore island sites (Cooks Cove, Waiiti Bay, Otiao Bay and Urupukapuka Bay, but only isolated patches occurred at the two mainland sites (Hauai and Kaingahoa Bays). Seagrass condition was generally best at Cooks Cove and worst at the two mainland sites (Table 2). Cooks Cove had the highest seagrass biomass and Kaingahoa Bay had the lowest. The seagrass patches in the mainland bays had relatively dense seagrass cover. In contrast, the seagrass cover was sparser at Otiao and Urupukapuka Bays, but seagrass formed meadows and occupied a much more extensive area. A high root biomass and a high root to shoot ratio are also indicators of robust seagrass meadow condition. The highest root to shoot ratio was found at Otiao Bay and the lowest at Hauai Bay.

Table 2: Summary of seagrass condition results for six sites in the Eastern Bay of Islands[1].

Parameter	Cooks Cove	Waiiti Bay	Otiao Bay	Urupukapuka Bay	Hauai Bay	Kaingahoa Bay
Extent	Meadow	Meadow	Meadow	Meadow	Patches	Patches
Depth limit (m)	4.5	3.3	4.5	>3.5	<3	<2
Cover (%)						
Spring	75 (6)	55 (10)	29 (3)	46 (8)	63 (9)	38 (4)
Summer	94 (3)	73 (10)	57 (5)	64 (11)	74 (5)	73 (4)
Total biomass (kg/m^2)	1.3 (0.5)	0.9 (0.3)	0.9 (0.4)	0.9 (0.2)	0.5 (0.1)	0.4 (0.1)
Root to shoot ratio	7.6 (2.8)	5.7 (1.0)	8.1 (2.8)	7.7 (1.2)	3.4 (0.3)	6.2 (3.2)

[1] Data from November 2009 (spring) only unless indicated otherwise. Where replicate samples were collected the mean (± standard error, n=3) is shown.

The depth limit for plant growth is an indicator of water clarity and underwater light availability. Greater depth limits usually indicate more favourable conditions. The depth limits for seagrass observed at our six sites ranged from 4.5 m at Otiao Bay and Cooks Cove to less than 2-3 m at the two mainland sites.

One of the biomass samples from Otiao Bay in November contained a single seagrass flowering shoot (inflorescence) (Figure 7). This is a positive sign, suggesting that seagrass meadows in this area may be able to reproduce and regenerate from seeds in addition to vegetative propagation from rhizome runners.

Figure 7: A seagrass flower (inflorescence) found in a biomass sample from Otiao Bay in November 2009.

3.2.2 Environmental parameters

The organic matter content of sediments within seagrass meadows reflects the primary productivity of these habitats and the contribution of seagrass detritus to sediments. Organic matter content was notably higher at Cooks Cove and Waiiti Bay, and lowest at Kaingahoa Bay on the mainland (Table 3). Kaingahoa Bay lacked seagrass patches in 2005-6 so the low organic content of seagrass sediments here may reflect the former absence of seagrass in this bay.

Table 3: Summary of sediment organic content and seawater analysis results for six sites in the Eastern Bay of Islands[1]**.**

Parameter	**Cooks Cove**	**Waiiti Bay**	**Otiao Bay**	**Urupukapuka Bay**	**Hauai Bay**	**Kaingahoa Bay**
Organic content (%)	3.1 (0.1)	3.0 (0.1)	1.5 (0.1)	1.6 (0.0)	1.6 (0.2)	0.9 (0.1)
Chl *a* (mg m^{-3})						
Spring	0.8	0.9	0.6	1.4	0.8	0.9
Summer	1.7	1.4	1.5	1.5	2.2	2.8
Salinity (ppt)						
Spring	35.2	35.5	35.1	34.9	35.8	35.4
Summer	35.3	35.0	35.2	35.3	35.1	35.5
Turbidity (NTU)						
Spring	1.30	0.88	0.82	0.91	1.33	0.68
Summer	0.56	0.66	0.51	0.39	1.16	0.69

[1] Data from November 2009 (Spring) only unless indicated otherwise. Where replicate samples were collected the mean (± standard error, n=3) is shown.

Seawater chlorophyll *a* concentrations are an indicator of phytoplankton (free-floating algae) biomass. We detected higher concentrations at all our sites in summer than in spring which probably reflects warmer sea temperatures more favourable for growth at this time of year. In summer concentrations were notably higher at the two mainland sites compared to the offshore island sites, particularly at Kaingahoa Bay. However, there were no clear differences between mainland and offshore sites in spring. High phytoplankton biomass in seawaters can be detrimental to seagrass as this reduces water clarity and underwater light availability. Chlorophyll *a* levels at the two mainland bays in the Eastern Bay of Islands during summer exceeded the levels found for Whangarei Harbour seagrass sites (0.5-1.9 mg m^{-3}; Matheson et al. 2009).

Salinity was close to standard seawater strength (35 ppt) at all sites suggesting that there were no major freshwater or stormwater inflows affecting the sites at the time of sampling. Seagrasses are generally tolerant of a wide range of salinity; however at salinities less than 10 ppt, overseas research suggests that they may suffer loss of biomass and a lack of leaf production (Hemminga and Duarte 2000).

Seawater turbidity is a measure of the amount of suspended particulate matter. This particulate matter, which includes phytoplankton but also inorganic particles (e.g., fine silts and clays) can also affect underwater light availability. Seawater turbidity readings were generally lower in summer than in spring. Turbidity can be elevated by stormy conditions, strong winds and swells stirring up sediments and by rainfall generating sediment erosion and runoff from land. The lower readings in summer may reflect the settled weather conditions and lack of rain in Northland in the summer of 2009-10. The highest turbidity readings on both sampling occasions were detected in Hauai Bay. However, in spring, the turbidity reading at Cooks Cove was almost equally as high. Turbidity levels measured at the Eastern Bay of Islands sites were generally less than mean levels found for Whangarei Harbour seagrass sites (1.5-2.0 NTU; Matheson et al. 2009).

Underwater light availability at each site was measured from November 2009 to February 2010 and above water (surface) light availability (irradiance) data was obtained for the same period from the Kerikeri weatherstation. For the entire 11 week deployment, underwater light availability (as photosynthetically available radiation, PAR) was highest at Cooks Cove and lowest at Urupukapuka Bay (Table 4). At all sites PAR values declined over the 11 week deployment as a result of epiphytic algal growth on the loggers. The decline in PAR between the first and last week of the logger deployment was greatest at the two mainland sites (95%), indicating a higher propensity for epiphytic algal growth (Table 4). However, the decline in PAR was almost equally as high at Waiiti and Otiao Bays (91-92%) (Table 4). Data from the first week of deployment reflects the underwater light availability in the absence of any substantial epiphytic interference. At this time PAR was highest at the two mainland sites (Table 4) which probably reflects the comparatively shallow depth (<2m) at which the seagrass patches here (and loggers) were located compared to other sites (>3m). Underwater light availability ranged from 5-11% of surface irradiance during the first week of logger deployment.

Table 4: A summary of the underwater light results as photosynthetically available radiation (PAR µmol m^{-2} s^{-1}) and percentage change between Weeks 1 and 11 for six sites in the Eastern Bay of Islands and for surface readings at the Kerikeri weatherstation [1]

Time interval	Kerikeri (surface)	Cooks Cove	Waiiti Bay	Otiao Bay	Urupukapuka Bay	Hauai Bay	Kaingahoa Bay
Overall (26 Nov – 10 Feb)	1207	49 (3)	25 (2)	23 (2)	18 (2)	24 (3)	36 (3)
Week 1 (26 Nov - 9 Dec)	1028	72 (14)	77 (14)	52 (10)	79 (13)	111 (21)	88 (19)
Week 6 (31 Dec – 6 Jan)	1351	57 (11)	12 (3)	35 (6)	2 (1)	15 (4)	26 (5)
Week 11 (4 Feb – 10 Feb)	1174	18 (4)	7 (2)	4 (1)	9 (1)	6 (1)	4 (1)
% change (Week 1-11)	+14%	-75%	-91%	-92%	-88%	-95%	-95%

[1] PAR values are means (± standard error).

Figure 8 highlights periods of declining underwater light availability linked to events of reduced water clarity. Where surface irradiance increased and underwater light irradiance decreased but subsequently recovered, this indicates a period of reduced water clarity. Such events are evident at Waiiti Bay from the 10 to 17 December, at Urupukapuka, Hauai and Kaingahoa Bays from the 31 December to the 6 January, and for Urupukapuka Bay on the 17 to 24 December. These reduced water clarity events may be linked to disturbance and resuspension of bottom sediments from boating activities especially given the timing of these events in the peak holiday period.

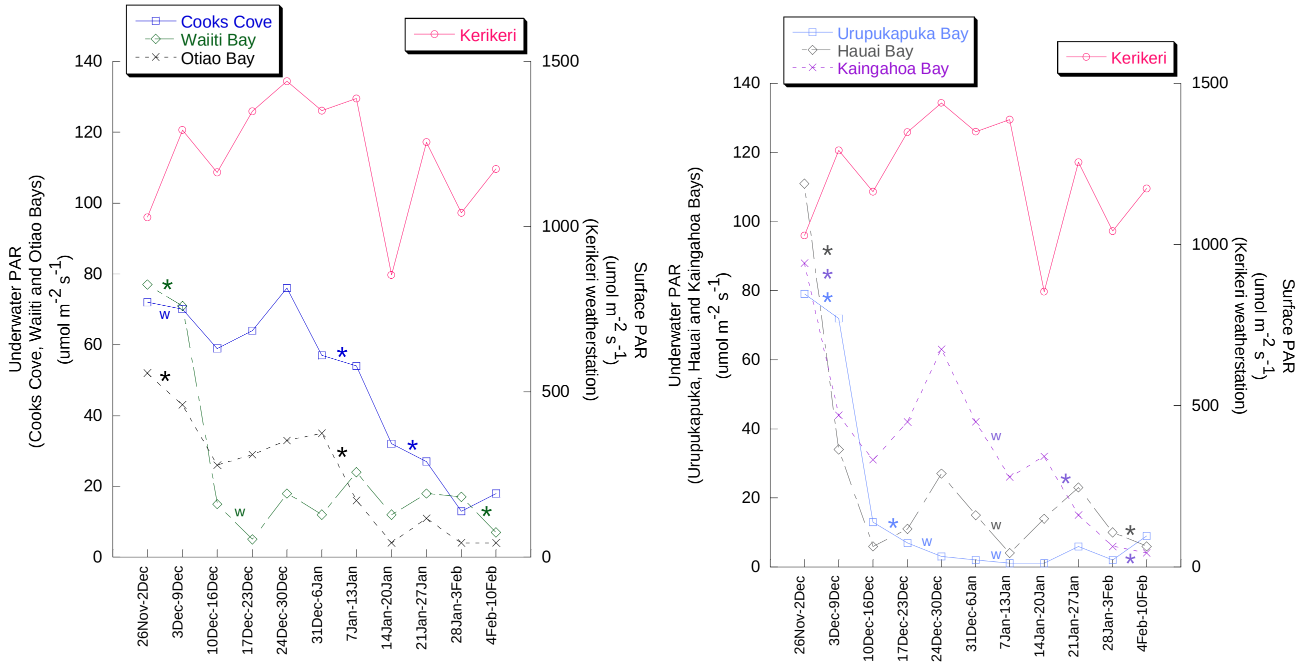

Figure 8: Light availability as photosynthetically available radiation (PAR) for the six sites and the Kerikeri weatherstation from November 2009 to February 2010. Graphs show weekly mean values. Asterisks (*) indicate a period of declining underwater light availability at a site coinciding with a period of improving surface light availability at Kerikeri. This indicates epiphytic algal growth on the loggers or a reduced water clarity event. In those instances (w) where light availability later improves this clearly indicates a reduced water clarity event as opposed to epiphytic algal growth.

Sediment particle size composition reflects the degree to which a site is exposed to physical forces such as currents and waves (more exposed sites generally have coarser sediments) but can also be a useful indicator of excessive fine sediment deposition detrimental to seagrass meadows. A summary of the sediment particle size data for each site is shown in Table 5.

The data show few significant differences between the two mainland sites from which seagrass meadows have declined and the four offshore island sites, particularly for very fine sediments in the silt and clay size classes (<62.5 µm and <3.9 µm, respectively). The only clear difference detected was for the fine sand size class (125 to 250 µm), quantities of which were significantly higher at the two mainland sites. This size class dominated sediment composition at all six sites.

Table 5: A summary of the sediment particle size data as percentage of sample volume in size classes for six sites in the Eastern Bay of Islands.[1]

Wentworth particle size class (µm)	Cooks Cove	Waiiti Bay	Otiao Bay	Urupukapuka Bay	Hauai Bay	Kaingahoa Bay
0.0-3.9	0.01 [b]	0.00 [ab]	0.00 [a]	0.00 [ab]	0.00 [a]	0.01 [b]
3.9-7.8	0.06 [bc]	0.02 [ab]	0.00 [a]	0.02 [ab]	0.01 [a]	0.09 [c]
7.8-15.6	0.14 [a]	0.11 [a]	0.04 [a]	0.09 [a]	0.03 [a]	0.29 [b]
15.6-31.2	0.24 [ab]	0.29 [ab]	0.14 [a]	0.44 [b]	0.13 [a]	0.49 [bc]
31.2-62.5	1.90 [a]	3.20 [ab]	1.91 [a]	4.71 [b]	1.94 [a]	2.96 [ab]
62.5-125.0	25.38 [ab]	27.81 [ab]	29.42 [ab]	24.81 [ab]	20.24 [a]	34.33 [b]
125.0-250.0	39.69 [ab]	31.51 [a]	40.62 [ab]	43.61 [b]	63.89 [c]	60.39 [c]
250-500	17.09 [bc]	19.62 [c]	15.27 [bc]	25.07 [c]	8.00 [ab]	1.00 [a]
500-1000	9.70 [c]	10.53 [c]	6.66 [bc]	0.93 [a]	3.35 [ab]	0.32 [a]
1000-2000	5.79 [bc]	6.88 [c]	5.36 [bc]	0.32 [a]	2.43 [ab]	0.12 [a]

[1] Different alphabetic superscripts indicate significant differences between sites (ANOVA, post-hoc Tukey test, $p<0.05$).

3.2.3 Other sites

In November 2009 we also visited Kaimarama Bay, Omakiwi Cove and Te Uenga Bay. Kaimarama Bay had a few patches of seagrass on otherwise bare sediment in water depths of around 3 m. Seagrass patches were also found in Omakiwi Cove at water depths of 2-3 m. No seagrass was recorded in Te Uenga Bay despite anecdotal reports of seagrass being abundant in this Bay in 1995 (Mike Kelly, resident, pers. comm.). Seagrass was not detectable in this Bay or in Omakiwi Cove in the 1961 aerial photographs.

In February 2010, 32 sites were visited to ground-truth the aerial photograph analysis. In addition to the sites mentioned above, a low, patchy cover of seagrass was detected at three additional sites; near Ngatokaparangi Island, in Okahu Passage and in Stockyard Bay (locations are shown in Figures 1 and 2).

4. Discussion

4.1 Threats to seagrass

Worldwide seagrass meadows are threatened by human activities in the coastal zone and contributing catchments. In the Eastern Bay of Islands the greatest threats to seagrass fall into two categories: (1) pollution of coastal waters with fine sediments, nutrients and toxic chemicals and (2) physical damage associated with recreational and commercial marine structures and activities.

4.1.1 Coastal pollution

Our results suggest that water clarity and underwater light availability at the mainland sites in the Eastern Bay of Islands where seagrass meadows have declined in recent decades may be less favourable at times relative to the offshore island sites where seagrass continues to flourish. Notably, summer time phytoplankton biomass (chlorophyll *a*) was much higher at the two mainland sites (2.2-2.8 mg m^{-3}) than the offshore island sites (1.4-1.7 mg m^{-3}) which could indicate nutrient enrichment of the mainland bays driving phytoplankton growth and detrimental shading of seagrass plants. These chlorophyll *a* levels are higher than those found for Whangarei Harbour seagrass sites (0.5-1.9 mg m^{-3}; Matheson et al. 2009). However, it should be noted that our water sampling was very limited with only two spot samples collected at each site, one in spring and one in summer. Nevertheless, the light logger data support this hypothesis as epiphytic algal growth reduced light availability during logger deployment by the greatest percentages at the two mainland sites over the summer period.

The most likely nutrient sources within the mainland bays are septic tank leachate, stream and stormwater inflows, water currents moving contaminants from the inner Bay of Islands, boat effluent and grey water (which often contains phosphorus) discharges.

Recent monitoring of the inner Bay of Islands coastal waters by Northland Regional Council suggests that nutrient concentrations are generally elevated above water quality guideline levels. McDiarmid et al. (2009) reported mean ammoniacal-nitrogen (NH_4-N) concentrations (0.090-0.096 g m^{-3}) that exceeded ANZECC water quality guideline low-effect trigger levels (0.015 g m^{-3}). A summary of the latest data supplied by Northland Regional Council supports this finding (Table 6). This summary also shows that nitrate plus nitrite (NO_x-N; NO_3-N+NO_2-N) and dissolved reactive phosphorus (DRP) concentrations in the Bay of Islands area are generally elevated above low-effect guideline levels. The nutrient concentrations measured in the inner Bay of Islands waters also exceed those found for seagrass sites in Whangarei Harbour (Table 6; data from Matheson et al. 2009). However, nutrient concentrations were not measured specifically for seagrass sites in the Eastern (outer) Bay of Islands.

Table 6: Mean nutrient, salinity and turbidity concentrations in Bay of Islands coastal waters. Data from 2008-10 (Raw data supplied by NRC). ANZECC low-effect trigger levels and Whangarei Harbour seagrass site data (Matheson et al. 2009) is also shown. Bold values indicate trigger levels met or exceeded.

Site	NO_xN ($g\ m^{-3}$)	NH_4-N ($g\ m^{-3}$)	TKN ($g\ m^{-3}$)	DRP ($g\ m^{-3}$)	TP ($g\ m^{-3}$)	Salinity (ppt)	Turbidity (NTU)
Opua Basin	**0.028**	**0.030**	0.38	**0.011**	0.027	29.1	7.4
Paihia - In front of toilets	**0.032**	**0.037**	0.34	**0.009**	0.022	32.9	**12.0**
Paihia - Te Haumi River	**0.031**	**0.038**	0.34	**0.010**	0.022	32.7	**13.0**
Paihia - NW Headland	**0.039**	**0.030**	0.36	**0.009**	0.024	29.0	7.7
Waitangi River - Waitangi Bridge	**0.082**	**0.044**	0.35	**0.009**	0.023	25.1	7.7
Kerikeri Inlet - Waipapa Entrance	**0.175**	**0.033**	0.22	0.001	0.019	14.3	5.6
Kerikeri Inlet - Kerikeri Entrance	**0.244**	**0.040**	0.25	0.003	0.022	15.0	6.7
Kerikeri Inlet - Wainui Island	**0.045**	**0.048**	0.38	**0.010**	0.024	28.3	6.1
Kerikeri Inlet - Winsor Landing	**0.037**	**0.034**	0.35	**0.009**	0.022	30.5	5.0
Kerikeri Inlet - Doves Bay Marina	**0.034**	**0.030**	0.40	**0.008**	0.018	30.4	3.2
Bay of Islands -Middle North Moorings	**0.037**	**0.033**	0.35	**0.011**	0.022	29.0	5.7
Bay of Islands Moorings - Tapu Point	**0.023**	**0.027**	0.35	**0.011**	0.025	28.2	7.8
Russell Foreshore	**0.021**	**0.026**	0.33	**0.006**	0.027	30.1	4.0
Waikare Inlet	**0.026**	**0.022**	0.32	**0.012**	**0.033**	28.1	9.4
Upper Te Puna Inlet	**0.015**	**0.027**	0.32	**0.007**	0.021	32.0	6.1
Upper Kawakawa River	**0.049**	**0.021**	0.35	**0.013**	**0.036**	22.6	**14.1**
All sites	**0.057**	**0.032**	0.34	**0.009**	0.024	28.9	9.0
ANZECC low-effect trigger level	0.015	0.015	-	0.005	0.030	-	0.5-10.0
Whangarei Harbour seagrass sites	0.003-0.005	0.019-0.027	-	0.005-0.007	-	28.0-29.2	1.3-2.0

Fine sediments washed from developed land can detrimentally affect seagrass meadows. Fine sediments can smother seagrasses, are easily resuspended so affect water clarity and can affect oxygen transport through sediments. The absence of seagrass meadows from parts of Tauranga harbour has been linked to higher percentages of fine sediment size classes (i.e., silt and clay) (Park 1994). For the Eastern Bay of Islands seagrass sites we found no conclusive evidence that seagrass decline in the mainland bays is linked to deposition of silts and clays. The mainland sites had a comparable quantity of silt and clay size class sediments to offshore island sites. However, the mainland sites did have a significantly higher quantity of the fine sand size class and this may still indicate a fine sediment impact. In the higher energy environment of the Eastern Bay of Islands, currents may transport the very fine sediment particles (i.e., silts and clays) offshore.

Other toxic chemicals that can detrimentally affect seagrass meadows include terrestrial herbicides washed into water, antifouling biocides used to clean boat hulls, petrochemicals (e.g., boat oil and fuels) and heavy metals. Northland Regional Council has investigated contamination of high-density boat mooring areas in the Bay of Islands (Doves Bay and Opua) with antifouling biocides (diuron and irgarol) and heavy metals (zinc, copper and lead). Heavy metals were found to be present at levels below ANZECC low-effect trigger levels, diuron was present at levels well below the New Zealand Environmental Exposure limit and irgarol was below the minimum detection limit (McDiarmid et al. 2009). It is therefore unlikely that these compounds are a threat to the seagrass meadows in the Eastern Bay of Islands area which is less densely populated and has less boat mooring pressure.

In the Eastern Bay of Islands there is only a single consented contaminant discharge. This is located in Kaimarama Bay and is for use of lime to clean algae from a boat ramp. This activity is considered to have a less than minor effect on the surrounding marine environment (Jacquie Reed, NRC, pers. comm.).

4.1.2 Coastal structures and activities

A comprehensive investigation of the impact of coastal structures and activities on the seagrass meadows in this area was beyond the scope of this study. However, given the high recreational use of the Bay of Islands area there is potential for boating activities to damage seagrass meadows. During the peak summer holiday season there are up to 1500 vessels in the Bay of Islands area (Jacquie Reed, NRC, pers. comm.). In particular, boat anchoring is a concern due to the high numbers of small recreational boats operating in the Bay of Islands area, particularly during summer, and the tendency for the areas most popular for anchoring to coincide with those occupied by seagrass meadows (i.e., shallow waters in sheltered bays). The setting, retrieving and dragging of anchors can rip out and break plants, generating bare patches or scars within seagrass meadows. Overseas research on the seagrass *Posidonia oceanica*, suggests that high levels of anchoring activity can lead to meadow fragmentation, lower seagrass cover and shoot density (Francour et al. 1999). There is no quantitative data for anchoring activity in the Eastern Bay of Islands; however Northland Regional Council records note Hauai and Otiao Bays to be amongst the most popular anchoring spots (Jacquie Reed, NRC, pers. comm.).

Moorings located in the sheltered bays of the Eastern Bay of Islands area also have the potential to detrimentally affect seagrass meadows. Where moorings are located in areas suitable for seagrass, heavy chain attached to moorings but lying loose on the seabed can drag across the seagrass and damage plants. In Australia swing moorings (a single anchor and chain) have been shown to produce circular scours in seagrass meadows averaging 39 m^2 but up to 300 m^2 where longer lengths of heavy chain were used (Walker et al. 1989). The same study showed that ‘cyclone’ moorings (three anchors and a swivel) were much less damaging to seagrass meadows producing scours of only 3m^2.

There are a total of 202 swing moorings in the Bay of Islands (Jacquie Reed, NRC, pers. comm.). However, only a small number are located in the Bays where this study documents historical and present day seagrass. There are no swing moorings in Waiiti, Otiao or Urupukapuka Bays but there are three in Cooks Cove, five in Hauai and Onepoto Bays and one in Kaingahoa Bay (Jacquie Reed, NRC, pers. comm.). However, closer examination of the locations of the moorings suggests they are unlikely to have had a significant detrimental impact on seagrass meadows. In Kaingahoa Bay the single mooring is located in the northern part of the bay; an area not occupied by seagrass in 1961. In Hauai and Onepoto Bays the moorings are located on the margins of the areas historically occupied by seagrass. The three moorings in Cooks Cove are located within the present day seagrass zone but the available images (only recent ones) show no large areas devoid of seagrass in the vicinity of these moorings (Figure 9).

Other structures that can be detrimental to seagrass meadows include wharves and jetties. These structures when located in areas occupied by seagrass meadows can shade seagrass growing beneath or adjacent to them, reducing or preventing growth (Shafer 1999). There are few of these structures in the Eastern Bay of Islands and in the areas where we have documented seagrass meadows. However, there is a jetty at Cooks Cove and a large area in the seagrass zone in front of this structure is devoid of seagrass suggesting a localised impact from boats using this jetty (Figure 9).

Seagrasses in the Eastern Bay of Islands may also be damaged by small boat use and trampling in very shallow water i.e., near the low tide water mark close to shore. Seagrass can be damaged when small boats or non-motorised craft (e.g., kayaks, row boats) are dragged on to shore or when propellors contact the seabed.

Figure 9: Cooks Cove showing the location of the three moorings amongst the seagrass meadows (dark area) and the area devoid of seagrass in front of the jetty (Photo: Northland Regional Council).

4.2 Management options

4.2.1 Protection strategies

Seagrass meadows in Eastern Bay of Islands would benefit from actions that seek to mitigate coastal pollution and minimise physical damage to the seagrass meadows.

For mitigation of coastal pollution, particularly nutrients and fine sediments, in the Eastern Bay of Islands but also the wider Bay of Islands area, the following actions are recommended:

- riparian planting of stream margins on land cleared for agriculture and forestry to trap and filter diffuse contaminants;
- ensuring septic tanks comply with operational guidelines and move towards reticulating sewage or more efficient treatment systems where possible;

- ensuring compliance of consented point source discharges and require consent holders to work towards improvements in the quality of discharges over time;

- encourage boat users to discharge effluent and grey water to treatment facilities at marinas or well offshore;

- encourage land users to minimise fertiliser use.

To minimise physical damage to seagrass meadows from commercial and recreational marine structures and activities the following action is recommended:

- site any new moorings or coastal structures (e.g., boat ramps, jetties) away from areas occupied by seagrass.

Given the lack of information available on anchoring, trampling and inshore watercraft use in the Bay of Islands, we also recommend that the potentially significant impacts of these activities on seagrass meadows be investigated in the future.

4.2.2 Rehabilitation of denuded areas

This study has shown that large areas of seagrass have been lost from the mainland bays of Kaimarama, Hauai and Kaingahoa in the Eastern Bay of Islands. Some remnant patches remain in these bays. If conditions are suitable for seagrass growth in the mainland bays, meadows may be able to regenerate from these remnant patches in the future. Our limited measurements of water and sediment quality suggest that conditions are less favourable for seagrass growth at the mainland sites relative to offshore island sites at particular times (i.e., summer), however the results are not conclusive and warrant further study. The comprehensive Oceans 20/20 Bay of Islands Coastal Project, due for completion in 2010, is anticipated to provide more detailed information on factors affecting water and sediment quality in the Bay of Islands (McDiarmid et al. 2009, Morrison et al. 2010).

Seagrass transplantation has been used successfully in Whangarei Harbour to assist rehabilitation of seagrass to a former site (Matheson et al. 2009). Additionally, seagrass transplantation could usefully be trialled at a small scale to test the current potential for seagrass rehabilitation in the mainland bays of the Eastern Bay of Islands.

5. Acknowledgements

We thank Helen Mountain Harte from Ngati Kuta/Patukeha for instigating this project with Northland Regional Council and NIWA. A number of people have provided information and assistance to this project particularly Jacquie Reed (Northland Regional Council) but also Richard Griffiths and Jon Hampson (NRC), Vince Kerr (Department of Conservation), Bay of Islands residents David Clarkson, John Booth, Mike Kelly, Penny Brothers, Bob Cathcart and NIWA staff Apanui Skipper, Virginie Dos Santos and Ron Ovenden. We also thank Rohan Wells (NIWA) for reviewing this report.

6. References

Francour, P.; Ganteaume, A.; Poulain, M. (1999). Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (north-western Mediterranean sea). *Aquatic Conservation: Marine and Freshwater Ecosystems 9*: 391–400.

Hayward, B.W. (1981). Foraminifera in the nearshore sediments of the Eastern Bay of Islands, Northern New Zealand. *Tane 27*: 123–134.

Hemminga, M.A.; Duarte, C.M. (2000). *Seagrass Ecology*. Cambridge University Press.

Inglis, G. (2003). Seagrasses of New Zealand. *In:* Green, E.P.; Short, F.T. (eds). *World atlas of seagrasses: present status and future conservation*, pp. 148–157. University of California Press, Berkeley.

Matheson, F.; Reed, J.; Dos Santos, V.; Cummings, V.; Mackay, G.; Jordan, M. (2009). Seagrass restoration in Whangarei Harbour: results of a small-scale transplantation trial. NIWA Consultancy report for Northland Regional Council. HAM2008-063. 25 p.

McDiarmid, A.; Chiswell, S.; Zeldis, J.; Palliser, C.; Maas, E.; Taylor, P.; Torres, L.; Nodder, S.; Hewitt, J.; Julian, K.; Hancock, N.; D'Archino, R.; Francis, M.; Sturman, J.; Sutton, P.; Stewart, C.; Schwarz, J.; Harper, S.; Stevens, C.; Thompson, D.; Bostock, H.; MacKay, K.; Halliday, J.; Baird, S.; Neil, K.; Sim-Smith, C.; Leathwick, J. (2009). OS2020 Bay of Islands Coastal Project Phase 1 Desktop Study. NIWA Consultancy Report for Land Information New Zealand WLG2009–3. 385p.

Morrison, M.; Lowe, M.; Spong, K.; Rush, N. (2007). Comparing seagrass meadows across New Zealand. *Water & Atmosphere 15(1)*: 16–17.

Morrison, M. (2009). Baby snapper all grew up in one big nursery. NIWA Media Release, March 2009.

Morrison, M.; Ching, N.; Mitchell, J.; Maas, E.; Hewitt, J.; Nelson, W.; Farr, T.; Willis, T.; Parsons, D.; Bowden, D.; Jones, E.; Nodder, S.; Swales, A.; Gibbs, M.; Chiswell, S.; Wood, B. (2010). Oceans Survey 20/20 Bay of Islands Coastal

Project Phase 2 – Biodiversity and Sediment Survey Interim Progress Report. NIWA Consultancy Report for Land Information New Zealand WLG2010–19. 17 p.

Ngati Kuta ki Te Rawhiti Charitable Trust (2008). Te Kupenga Manawahuna Customary Fisheries Project Final Report.

Orth, R.; Carruthers, T.J.B.; Dennison, W.B.; Duarte, C.M.; Fourqurean, J.W.; Heck Jnr. J.L.; Hughes, A.R.; Kendrick, G.A.; Kenworthy, W.J.; Olyarnik, S.; Short, F.T.; Waycott, M.; Williams, S.L. (2006*). A global crisis for seagrass ecosystems. Bioscience 56*: 987–996.

Park, S.G. (1994). Tauranga Harbour regional plan environmental investigations – Ecology of Tauranga Harbour. Environment BOP Environmental Report 94/8, Whakatane.

Park, S.G. (1999). Changes in abundance of seagrass (*Zostera* spp.) in Tauranga harbour from 1959–1996. Environment Bay of Plenty Environment Report 99/30. Whakatane. 19 p.

Reed, J.; Schwarz, A.-M.; Gosai, A.; Morrison, M. (2004). Feasibility study to investigate the replenishment/reinstatement of seagrass beds in Whangarei Harbour – Phase 1. NIWA Consultancy Report for Northland Regional Council AKL2004-33. 20 p.

Shafer, D.J. (1999). The effects of dock shading on the seagrass *Halodule wrightii* in Perdido Bay, Alabama. *Estuaries 22*: 936–943.

Walker, D.I.; Lukatelich, R.J.; Bastyan, D.; McComb, A.J. (1989). Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany 36*: 69–77.