A review and current understanding of Neptune's necklace *(Hormosira banksii)* in Tauranga Harbour

Bay of Plenty Regional Council
Environmental Publication 2023/06

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ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

Acknowledgements/He Mihi

Thank you to Chris Rix and Laura Boucher for support in the field surveys.

Publishing information/ Mōhiohio Pānuitanga

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Peer Reviews/Ngā Arotake Aropā

Reviewer	Description of change	Date
Stephen Park Senior Environmental Scientist, Bay of Plenty Regional Council	**Review**	**12/06/2023**
Leigh Stevens Principal/Senior Scientist, Salt Ecology	**Review**	**26/10/2023**

Recommended citation

Crawshaw & Shailer 2023. A review and current understanding of Neptune's Necklace (*Hormosira banksii*) in Tauranga Harbour. Bay of Plenty Regional Council Environmental Publication 2023/06

Executive summary/ Whakarāpopototanga Matua

A brown algae, *Hormosira banksii* (Neptunes necklace) typically found on rocky shores but known to form different ecotypes, has been found in several estuarine areas in Tauranga Harbour in conjunction with the ecologically valuable seagrass (*Zostera muelleri*) habitat. There is little current information available about the prevalence of *H. banksii* across Tauranga Harbour, or its presence in estuarine, soft sediment habitats, typically being associated with rocky shore habitats.

This report aims to provide a summary of existing scientific knowledge around *H. banksii* occurrence in estuarine habitats and reports on field surveys at two locations in Tauranga Harbour (Waipu Bay and Bowentown) where expansive habitats have been identified.

The survey identified large *H. banksii* beds across seagrass habitats in Tauranga Harbour. The morphology of the algae is consistent with previously reported ‘estuarine’ forms in the literature. This algae type has multivariate branching, no attachment structures, limited reproductive structures and does not float. The two species appear to be co-existing with limited negative impacts observed, with the exception of when *H. banksii* cover becomes higher than 80%, resulting in a decline in seagrass % cover and sediment oxygen depletion observed at some locations.

Historical surveys in Tauranga Harbour have identified the presence of *H. banksii* however there was limited documentation on its prevalence. The use of historical imagery has provided insights into the occurrence of *H. banksii* in Tauranga Harbour back as early as the 1950’s. The cover of *H. banksii* appears to be increasing to the current day, with distributions associated predominantly with seagrass habitats near the harbour entrances.

The scientific literature to date identifies that it is unlikely *H. banksii* is a sign of eutrophication, or increased nutrient inputs, however further investigations are needed to understand why it is increasing in cover within Tauranga Harbour and the potential flow on effects (positive or negative) to estuarine ecology. It appears to be a relatively unique algae assemblage in New Zealand soft sediment estuaries.

Contents/Rārangi Upoko

Introduction/Kupu Whakataki

A brown algae, *Hormosira banksii* (Neptunes necklace) typically found on rocky shores but known to form different ecotypes, has been found in several estuarine areas in Tauranga Harbour previously dominated by ecologically valuable seagrass (*Zostera muelleri*) habitat. Its presence has been reported at these sites before (Barker & Larcombe, 1976, Park & Donald, 1994), but not regularly or in great detail, and concerns have been raised that it could be or become a nuisance bloom with negative impacts on seagrass beds. In particular, two large areas have been identified at Waiau Estuary (near Waione Avenue, Athenree) and Waipu Bay that appear to be increasing in size. Based on these observations, there is concern that *H. banksii* presence could have a negative impact on the seagrass, smothering it and causing areas of sediment to become dark and anoxic.

This report is intended to provide a review on *Hormosira banksii* ecology and presence/adaptations to estuarine environments, and report results of field surveys in 2021 - 2022. This is a starting point to collate existing information and provide direction for future investigations.

Hormosira banksii (Neptunes Necklace) – a species introduction

Native to New Zealand and South-eastern Australia (Womersley (1967), *H. banksii* is the only species of the family Hormosiraceae (Osborn, 1948, Macinnis-Ng *et al.*, 2005), and the only intertidal species of the order Fucales found in the southern hemisphere (Neill *et al.*, 2016). *H. banksii* has a range of common names including Neptune's necklace, sea grapes, and bubble weed. It is abundant on intertidal rocky shores where it commonly forms extensive monotypic beds (Osborn, 1948), and is occasionally found under mangroves, entangled in pneumatophores (King, 1981).

Hormosira banksii is a distinctive brown macroalga, with variable morphology (Figure 1). The thallus consists of dichotomously branched chains of spherical vesicles about 10 mm in diameter, joined by thin constructions and attached by a small disc-shaped holdfast (Osborn, 1948, Macinnis-Ng *et al.*, 2005). It is a dull ochre to grey-brown colour, and exhibits considerable colour variation depending on the amount of light the plant receives (Osborn, 1948). Reproductive structures form visible raised pits on the vesicles (Osborn, 1948, Macinnis-Ng *et al.*, 2005, Neill *et al.*, 2016). In mangroves it has a smaller thallus and compact form with larger (up to 2 cm) golden beads, a close-set branching pattern, a softer texture, thinner construction and no holdfast (King, 1981, Bishop *et al.*, 2009, Bishop *et al.*, 2012, Coleman *et al.*, 2019).

A perennial, diploid, dioecious species, *H. banksii* releases eggs and spermatozoa on low tides. Male and female plants are distinguishable by orange sperm and olive-green eggs. Reproductive individuals can be found year-round, suggesting little seasonality (Osborn, 1948, Ralph *et al.*, 1998, McKenzie & Bellgrove, 2008, McKenzie & Bellgrove, 2009, Coleman *et al.*, 2019).

Like many fucoids, *H. banksii* has limited dispersal of propagules, probably restricted to <10 m, but the gas-filled vesicles are easily detached, can raft over long distances, and remain viable for extended periods of time (McKenzie & Bellgrove, 2008, Coleman *et al.*, 2019, Bellgrove *et al.*, 1997, Hawes, 2008, Hawes *et al.*, 2017). Populations amongst mangroves are hypothesised to result from detached fronds drifting from rocky shores into estuaries where they become trapped in pneumatophores (King, 1981, Bishop *et al.*, 2009, Bishop *et al.*, 2012, Coleman *et al.*, 2019). There are no reported cases of *H. banksii* growing amongst seagrass, and only one report of it growing in adjacent bands (Moore, 1950).

Hormosira banksii is an ecosystem engineer, facilitating diverse rocky intertidal communities. Its complex three-dimensional structure provides more microhabitats than abiotic substrates, so it is often associated with enhanced molluscan abundance and species richness (Bishop *et al.*, 2009). Dense intertidal algal canopies also reduce the amount of light reaching the understorey and this can have direct and indirect, positive and negative effects on other species (Schiel, 2004, Bellgrove *et al.*, 2017, Bishop *et al.*, 2009, Coleman *et al.*, 2019) .

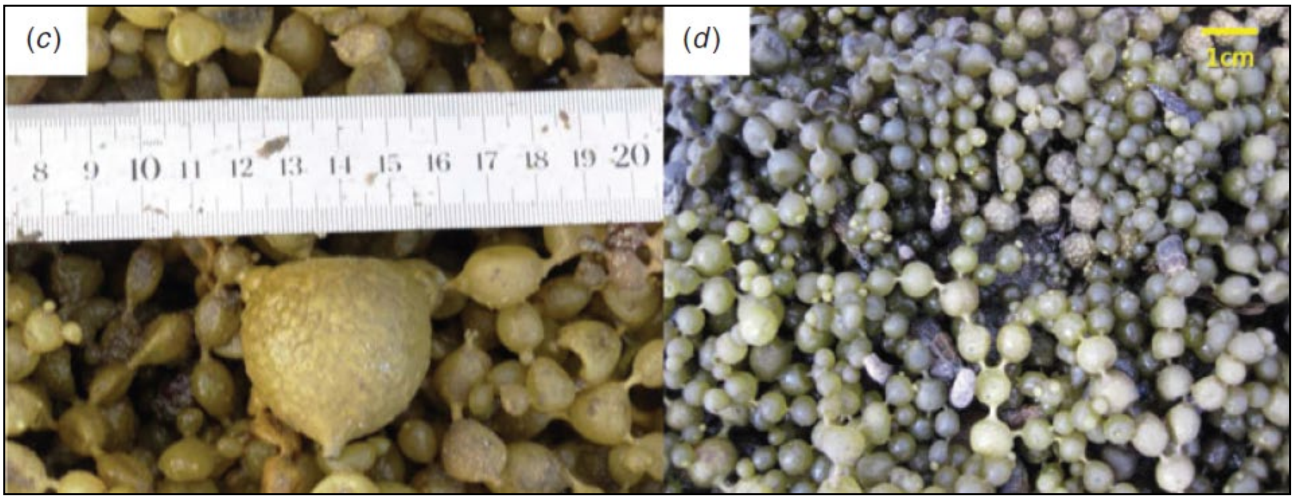

Figure 1 *Hormosira banksii morphology in (c) mangrove and (d) rocky shore habitats from Coleman et al. 2018.*

Hormosira banksii – environmental requirements

Although macroalgal growth is often a sign of increased nutrient inputs, *H. banksii* usually has a negative relationship with nutrient enrichment. Fucoid algae like *H. banksii* are very susceptible to disturbances such as sedimentation and eutrophication (Bellgrove *et al.*, 2017). They are particularly sensitive to sewage pollution, and generally decline or are absent within several kilometres of a wastewater discharge, where they are replaced by opportunistic and turf-forming green algae (Fairweather, 1990, Doblin & Clayton, 1995, Alestra & Schiel, 2014, Coleman *et al.*, 2019).

These effects are driven by displacement through increased competition, and by altered physical conditions which can inhibit zygote germination, retard embryo growth and increase embryo mortality (Kevekordes, 2001, Alestra & Schiel, 2014). In contrast, opportunistic algae species such as sea lettuce (*Ulva* spp.) showed very high recruitment and propagule densities at polluted sites (Bellgrove *et al.*, 1997, Alestra & Schiel, 2014). These opportunistic species quickly respond to nutrients and can impair the settlement and growth of *H. banksii* germlings through physical and chemical mechanisms (Doblin & Clayton, 1995, Bellgrove *et al.*, 1997, Alestra & Schiel, 2014, Bellgrove *et al.*, 2017, Parry, 2021).

Hormosira banksii – estuarine forms

There is limited observations of estuarine forms of *H. banksii* in New Zealand. Moore (1950) describes a "loose lying form" of *H. banksii* near Picton, New Zealand, and Bergquist (1959) a "derivative form, such as the mangrove swamp form". One report from Stewart Island also mentioned *H. banksii* which had washed in from the sea and formed a dense cover over 22 ha of an estuary (Stevens & Robertson, 2013). This may have been another estuarine population identified as wrack, although it was not a permanent population and had fluctuated in cover over repeat surveys (Stevens pers. comm). The population described by Moore (1950) was found in a tidal lagoon, partially enclosed by artificial structures, almost completely drained at low tides with a freshwater stream at the upper end. The firm gravelly bottom was covered in several inches of soft organic mud. Salinity varied and water movements were very gentle. *H. banksii* was scattered in a narrow belt around the low water neap, forming clumps up to 30 cm in diameter and 7 cm-10 cm deep. It was more abundant lower down, with "adjacent clumps merging over areas as big as 20 m^2". At the lowest tides most of the bed was exposed for about two hours, but at other times the highest parts were still covered by about 22 cm of water. Initially only scattered *Ulva* spp. was seen amongst the *H. banksii* but in later visits fragmented green thalli covered most of the area. Seagrass beds mostly occurred between bands of *Ulva* spp. and *H. banksii* but did overlap in a few places. The estuarine form described by Bergquist (1959) grew either as the “open swamp” form, amongst pneumatophores of mangroves, or the “shaded mud form” that grew on either hard or soft mud, where water lay for some of the intertidal period.

The estuarine alga was morphologically distinct from the typical rocky shore form (Figure 2) (Moore 1950). It lacked any holdfast yet remained stationary enough that healthy upper thalli could be distinguished from decaying lower ones. The branching of *H. banksii* is normally dichotomous, but in this form multiple branching was common, occurring at almost every segment. Incomplete division of segments gave rise to odd shapes, but there was no equivalent of the spirality seen in marsh fucoids (Moore 1950). Detached pieces continued to grow, at times showing bipolarity as young segments developed vegetatively from the broken ends. The vesicles contained watery mucilage. Only a few contained any gas, and they did not float. Most segments were within the usual size range for the species (6-13 mm), but some reached 25 mm. Conceptacles were small and few in number, visible on some but not all segments. The alga appeared to be sterile.

A few other studies have found considerable morphological variation in *H. banksii* correlated with local environmental conditions (Osborn, 1948). Populations were divided into two phenotypically distinct groups; those from exposed marine rock platforms, where thalli grow attached to rocks, mollusc shells, or other debris on tidal flats, and those from sheltered estuarine situations, such as free-living forms trapped among mangrove pneumatophores (Macinnis-Ng *et al.*, 2005). Differentiation was related mainly to size attributes. The vesicles of plants from estuarine habitats were reported to have a volume three to ten times those of marine plants (Ralph *et al.*, 1998). Environmental conditions such as wave action and degree of desiccation influence the physiology of *H. banksii* and correlate with morphological variation, and vesicle dimensions are likely linked to desiccation resistance (King, 1981, Macinnis-Ng *et al.*, 2005, Bishop *et al.*, 2009, Bishop *et al.*, 2012, Coleman *et al.*, 2019). Estuarine ecotypes are often genetically unique from nearby open coast populations, where the ecotypes are highly genetically structured with strong positive relationships to geographic distance, indicating limited gene flow (Coleman *et al.*, 2019). Estuarine populations showed higher levels of clonality relative to open coast populations which may result from their colonisation history and tendency toward vegetative reproduction (Coleman *et al.*, 2019).

A number of reports have noted *H. banksii* as being an occasional feature of soft shore estuaries, however there is limited detail available, although many note the *H. banksii* occurring among mangrove pneumatophores (Hare, 1992, Mead & Moores, 2005, Alfaro, 2006). This leads to the hypothesis that the alga in Tauranga Harbour could be a naturally occurring alternative estuarine form of *H. banksii,* rather than storm wrack from nearby rocky populations, or a nuisance bloom driven by pollution.

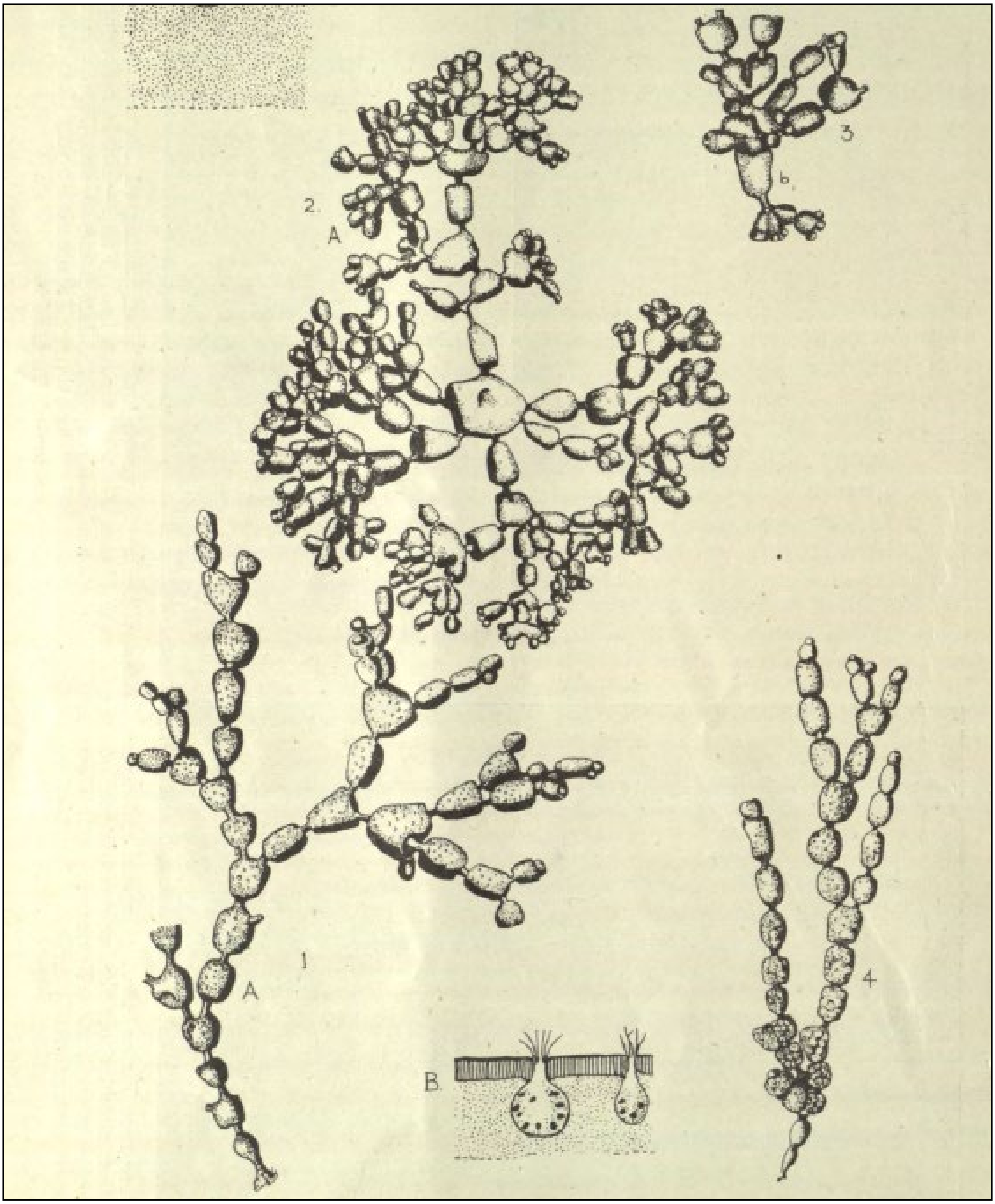

Figure 2 *Plate from Moore (1950) showing morphological differences between rocky shore (1,4) and estuarine (2,3) forms of H. banksii.*

Methodology/Huarahi

Field survey methods

Surveys were undertaken over the summer of 2022-2023 to investigate the presence, distribution and percentage cover of *H. banksii*. The surveys were undertaken in Waipu Bay and Athenree/Bowentown sandflats (Figure 3), following a visual survey for presence of *H. banksii* using oblique imagery from PhotoOblique.

Waipu Bay is a shallow intertidal dominated estuary located immediately south of Tauranga Airport and the Port of Tauranga (Figure 4). The bay is partially enclosed by rail and road bridges. It covers an area of 4.12 km^2, of which 94% is intertidal. There are saltmarsh areas on the northern and southern margins (Crawshaw *et al.*, 2022). The NZ Estuarine Trophic Index puts the open estuary in the A grade, indicating minimal eutrophication. Land use in the catchment includes industrial, residential and horticultural areas.

Athenree/Bowentown is an open intertidal area in the northern end of Tauranga Harbour, covering an area of 6.34 km^2, of which 96% is intertidal (Figure 5). The region contains mangroves and saltmarshes on the fringing edges (Crawshaw *et al.*, 2022). The NZ Estuarine Trophic Index puts the open estuary in the B grade, indicating moderate eutrophication (Crawshaw *et al.*, 2022). Land use in the catchment includes dairy, horticulture, exotic and native forest, and lifestyle blocks.

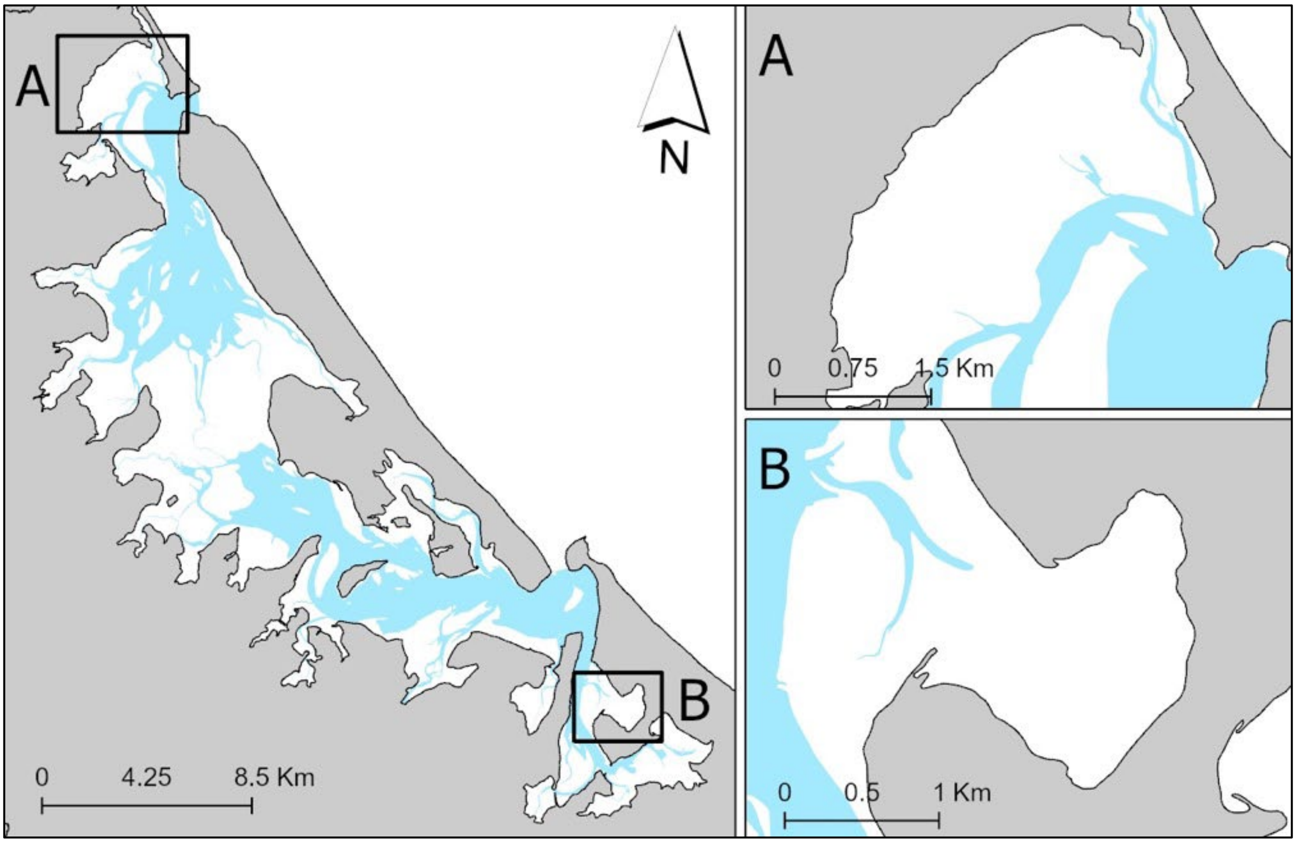

Figure 3 Left Panel: Tauranga Harbour with two site locations identified in black squares. A = Athrenree/Bowentown sandflats. B = Waipu Bay. Subtidal channels are shown in light blue.

Figure 4 *Aerial imagery of Waipu Bay in 2021 with dense accumulations of Hormosira banksii evident as brown-orange areas. Photo credit: PhotoOblique.*

Figure 5 *Aerial imagery of Athenree/Bowentown sandflats in 2021 with dense accumulations of Hormosira banksii evident as brown-orange areas. Photo credit: PhotoOblique.*

Waipu Bay survey

Transects were established prior to the survey, based on coverage of the estuary and overlapping with sites where aerial imagery indicated the presence of *H. banksii*. The transects ran from the low tide channel to the upper shoreline, with three points sampled along each, near the channel end, mid-point and shore end. At each of these points ten quadrats (0.25 m^2) were randomly sampled within a 20 m x 30 m block. Sampling was conducted either side of low tide in October 2022.

Each quadrat was analysed for *H. banksii* and seagrass cover (classified based on CSIG seagrass monitoring guide, Shannahan et al. 2023), algae entrainment into sediment, and redox potential discontinuity (RDP) depth. Where *H. banksii* was present on top of the seagrass, it was first quantified, then removed to allow seagrass cover to be established. A biomass sample was collected from one quadrat at each sampling location utilising a small quadrat (0.01 m^2). Wet-weight biomass was measured in the field before the sample was dried at 60 ºC for 96 hours before weighing again. The dried sample was sent for nutrient tissue analysis of TP, TN and TOC.

Athenree/Bowentown survey

Following the results of the first survey, an updated method was used to survey the Bowentown/Athenree sandflats in December 2022. A broadscale survey was conducted on foot, and sampling sites selected based on changes in the topography and density of *H. banksii*. At each site, three quadrats (0.25 m^2) were randomly sampled within a 20 m x 30 m block and quantified for *H. banksii* and seagrass cover (classified based on CSIG seagrass monitoring guide, Shannahan et al. 2023), algae entrainment into sediment, and wet weight of *H. banksii* (as described above). Notes were taken at each site on epifauna present. No dry measurements or tissue analysis was conducted at this location.

Quantifying current and historical distributions from aerial imagery

H. banksii has a bright ochre colour which can be distinguished from the darker green colour of seagrass beds and the light grey of bare sediment in high resolution aerial imagery.

H. banksii cover was digitised by tracing around areas visible in the imagery in ArcGIS Pro. For the most recent imagery, cover was divided into different density classes based on colour differences and verified with corresponding field samples and using recent oblique imagery from PhotoOblique. With the historical black and white imagery, it can be difficult to distinguish the *H. banksii*, therefore the estimates for historical extent (prior to 2003) are very conservative and are primarily intended to provide evidence of longevity of the species in the area.

Results/Ngā Otinga

Field observations

Hormosira banksii form

Two forms of *H. banksii* were evident across the surveys, the prevalent type identified is what appears to be an estuarine ecotype, and the normal rocky shore ecotype first described by Moore (1950) was less frequently observed. The first type represented the expected 'estuarine' type, with vesicles ranging from olive to dark olive in colour and smooth with no reproductive structures evident (Figure 6). Branching was prolific and multivariate. Vesicles were typically ≤ 7 mm in diameter, smaller than the typical rocky shore ecotype although there were sometimes a few larger, irregularly shaped segments present. Most clumps were small, the biggest around 10 cm in diameter. In the larger clumps, there was some differentiation from top to bottom. There was no sign of a holdfast, or attachment or entrainment to the sediment. Clumps could be broken apart easily, and the algae did not float.

Some fragments of the typical rocky shore type were found, often showing vegetative growth at both ends which showed more estuarine characteristics (Figure 7). This form was distinguished by the bright ochre colour, larger vesicles and visible reproductive structures.

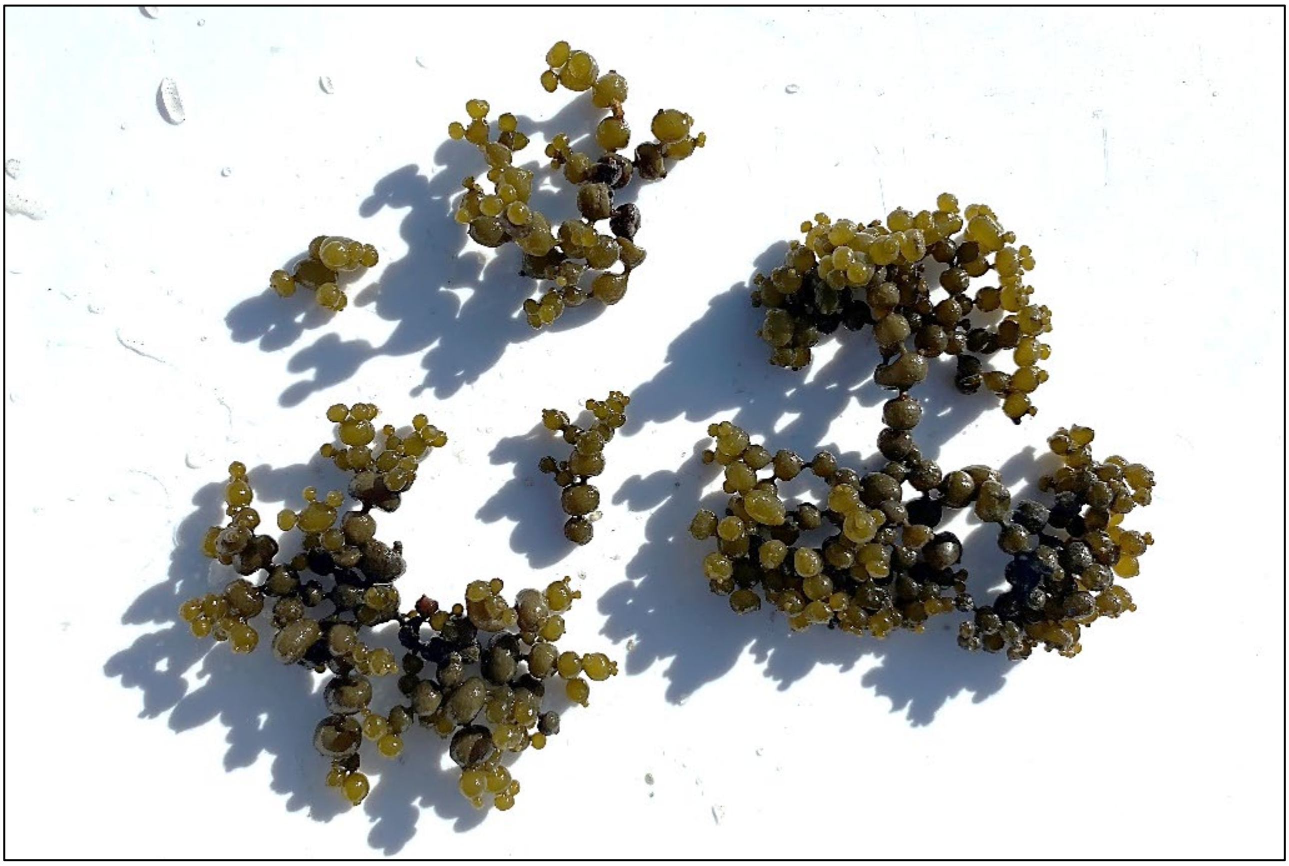

Figure 6 Small, smooth, olive-coloured vesicles, budding at almost every section, growing from both/all ends of fragments indicative of the estuarine ecotype.

Figure 7 Fragments of typical rocky shore type (large, bright ochre colour, visible reproductive structures) with vegetative growth at the ends showing more estuarine characteristics (smaller, smooth, darker colour, multivariate growth).

H. banksii was generally found in association with seagrass (Figure 8), rarely over bare sand, except in shallow depressions (likely formed by stingrays and waterfowl grazing) where it had sunk to the bottom amongst other debris, and at the end of larger subtidal channels in the upper shore line. The *H. banksii* was amongst but not attached to the seagrass. In some areas there were deep drifts (up to 14 cm) of many small fragments. No true attachment points or entrainment into the sediment was observed. Top fragments were generally a lighter colour than bottom fragments. It was not clear whether this change was due to recent desiccation or if it indicates stable piles differentiating over longer time periods as described by Moore (1950).

Figure 8 Hormosira banksii at Bowentown (left) and Waipu Bay (right) with distribution closely matching seagrass patches.

Macrofauna or epifauna were not directly surveyed, however, a number of species were found on and within the algae including mudflat whelk (*Cominella glandiformis*), cockle (*Austrovenus stuchburyi*), horn shell snail (*Zeacumantus lutulentus*), estuarine limpet (*Notacmea* spp.), mudflat topshell (*Diloma subrostrata*), top shell (*Cantharidus huttonii*) and high numbers of mud crabs (*Macrophthalmus hirtipes*) within dense *H. banksii* beds. Many bird species were observed feeding on the epifauna amongst the *H. banksii* beds.

Current distribution and density

The percentage cover of *H. banksii* was highly variable across Waipu Bay, however dense accumulations with higher percentage cover appeared closer to the estuary channel margins (Figure 9). Based on broad scale mapping from aerial imagery, supported by field observations and transect sampling, there was 27 hectares estimated of *H. banksii* cover in Waipu Bay, with 44% of that being complete cover (Table 1). The wet weight of *H. banksii* was measured at a number of sites, with the average weight being 5121 g/m^2, and a maximum recorded of 22,897 g/m^2 (Figure 9).

In Bowentown, the *H. banksii* accumulations were more difficult to map from aerial imagery due to poorer image quality, and thus digitising from imagery likely underestimates areas with sparse cover (Figure 10). The aerial imagery is also a year old, so distributions in the field at the time of sampling were different to that shown in Figure 10. Similar to Waipu Bay, *H. banksii* was typically associated with seagrass beds, with the exception of some regions where wave movements had created pockets of the algae on open sandflats. A total of 78 hectares of *H. banksii* cover was estimated for Bowentown, with the majority (49%) being sparse cover, with only 8% cover estimated to be complete cover (Table 1). The wet weight of *H. banksii* was measured at a number of sites at Bowentown, with the average weight being 2200 g/m^2, and a maximum recorded of 10,338 g/m^2 (Figure 10).

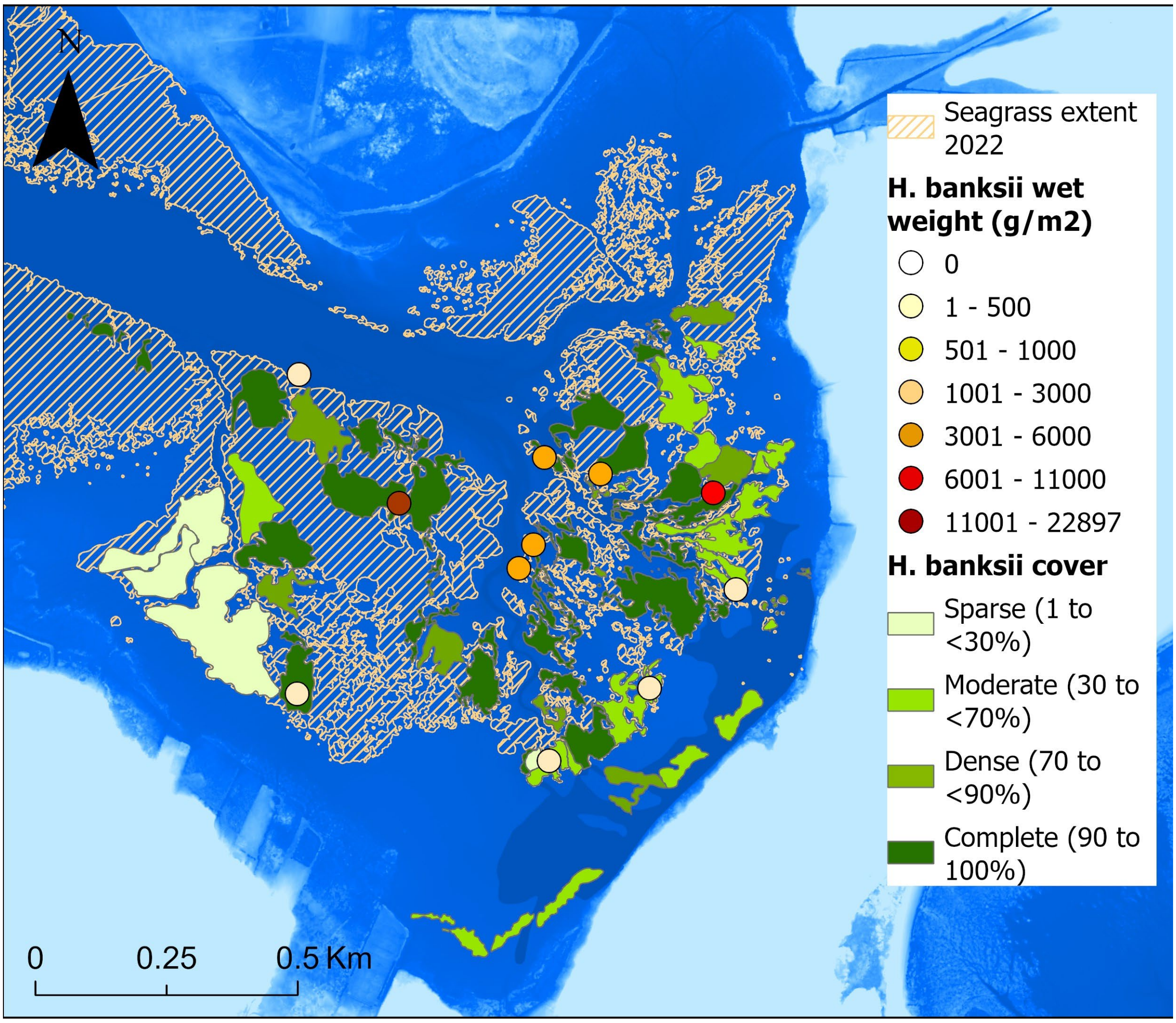

Figure 9 H. banksii cover classes in Waipu Bay in 2022, with H. banksii wet weight (g/m^2) from the 2022 field survey. Seagrass extent in 2022 is shown in peach hash. Base layer shows the LiDAR to highlight channels in blue.

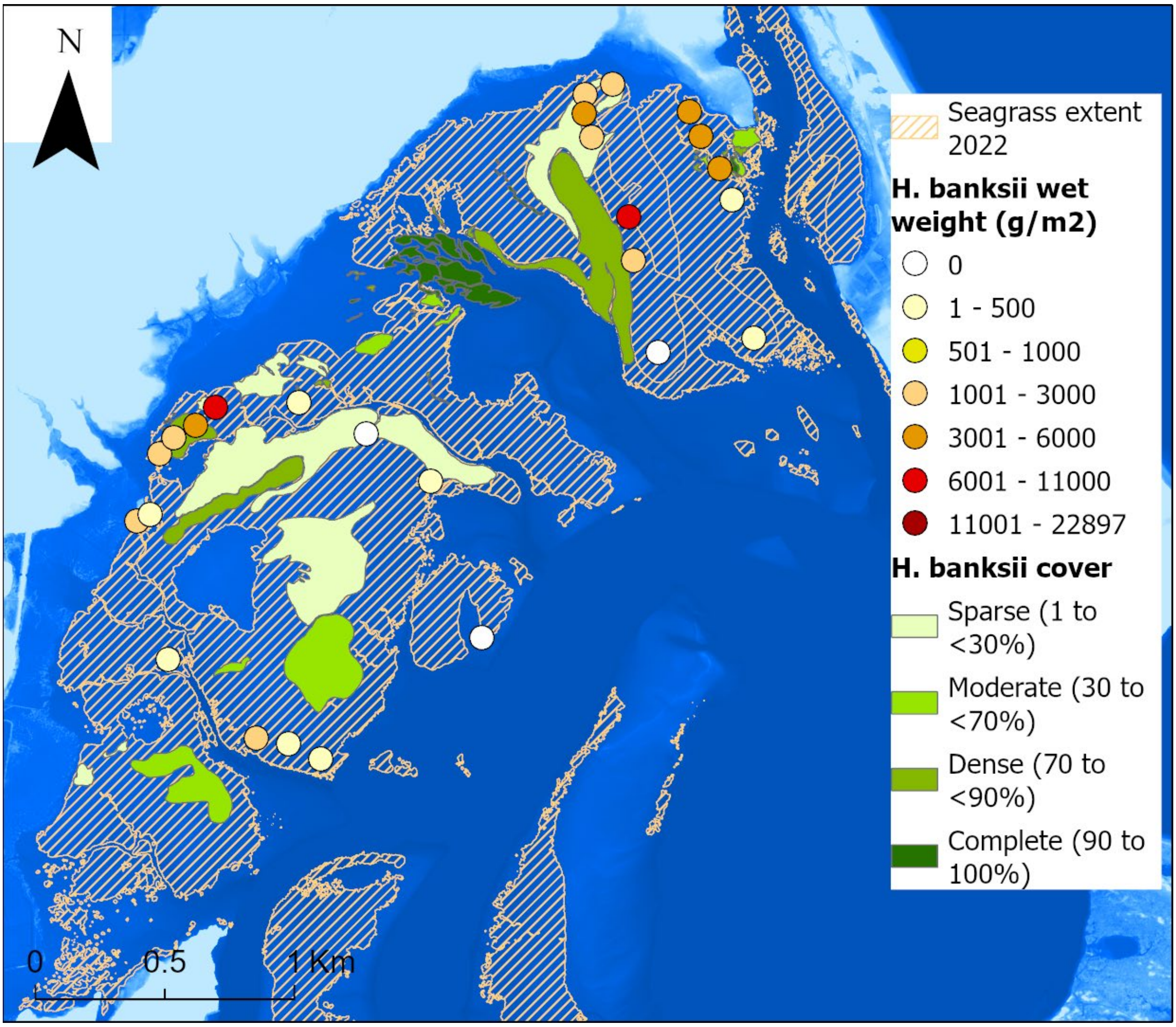

Figure 10 *H. banksii cover classes in Bowentown in 2021, with H. banksii wet weight (g/m²) from the 2022 field survey. Seagrass extent in 2022 is shown in peach hash. Base layer shows the LiDAR to highlight channels in blue. Note that due to time differences (1 year) between available imagery and field sampling the wet weight measurements do not align with the mapped regions.*

Table 1 *Total area of each H. banksii cover class in hectares, and percentage of total cover in each cover class for Waipu Bay and Athenree.*

	Waipu Bay		Athenree	
***H. banksii* Cover Class**	**Area (hectares)**	**% of total cover**	**Area (hectares)**	**% of total cover**
Sparse (1 to <30%)	5.4	20	38.4	49
Moderate (30 to <70%)	6.3	23	15.1	19
Dense (70 to <90%)	3.3	12	18.6	24
Complete (90 to 100%)	12	44	5.9	8
Sum	**27**		**78**	

There was generally a positive linear relationship between increasing *H. banksii* cover and wet weight (Figure 11), with the exception of one large outlier in Waipu Bay, which was a very dense accumulation.

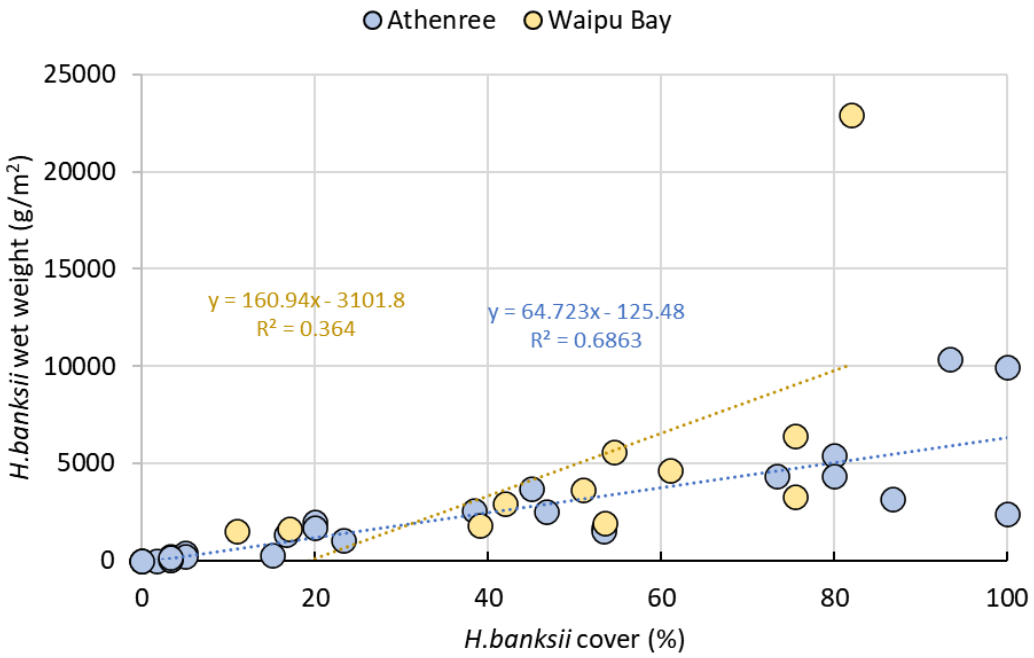

Figure 11 Relationship between H. banksii cover (%) and wet weight (g/m^2) for Athenree (blue) and Waipu Bay (yellow).

There was a strong linear relationship between the *H. banksii* wet and dry weight, and this is provided to allow for any future comparisons to literature values (Figure 12).

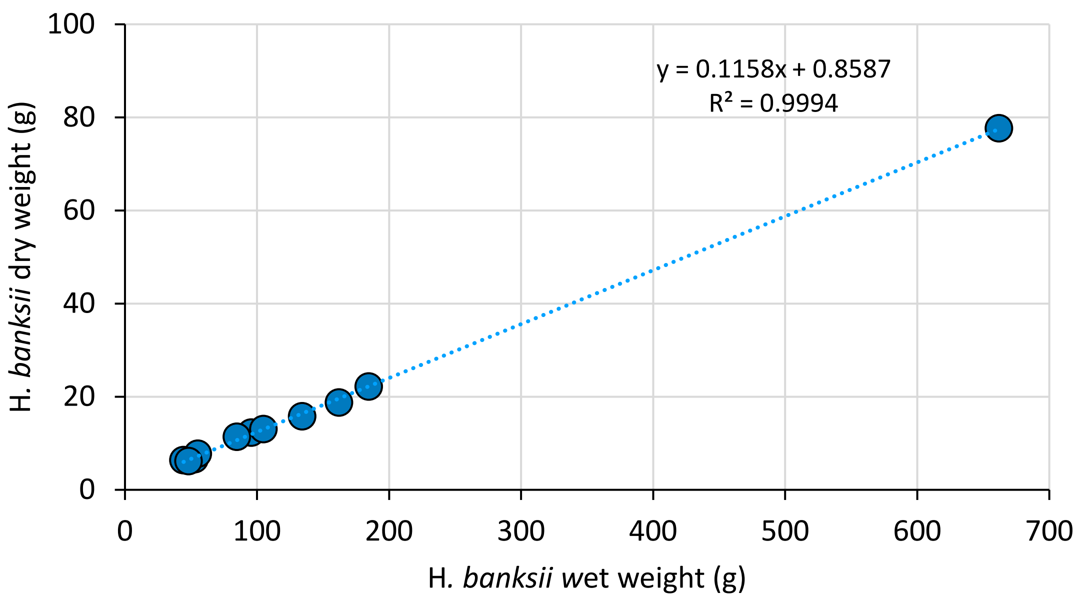

Figure 12 Relationship between H. banksii wet weight and dry weight from the Waipu Bay site to allow comparisons to literature.

Relationship with seagrass

The *H. banksii* presence was typically associated with seagrass beds, and at lower densities it did not appear to have an influence on the seagrass beds. At Waipu Bay, there appeared to be a decline in seagrass cover when *H. banksii* cover was greater than 60% (Figure 13). In Athrenree, there was less of an association, however at 100% cover of *H. banksii* seagrass cover was well below 10%. In the early 1990's there was large areas of *H. banksii* at high densities which had no seagrass present underneath (Park, pers. comm.).

The visual surveys indicated that in most instances, even as *H. banksii* cover was reaching 80%, the seagrass underneath appeared green and healthy, with clean oxygenated sediments, although occurring in a lower percentage cover. Only once *H. banksii* cover reached complete cover was there typically signs of dead seagrass or deoxygenated sediments.

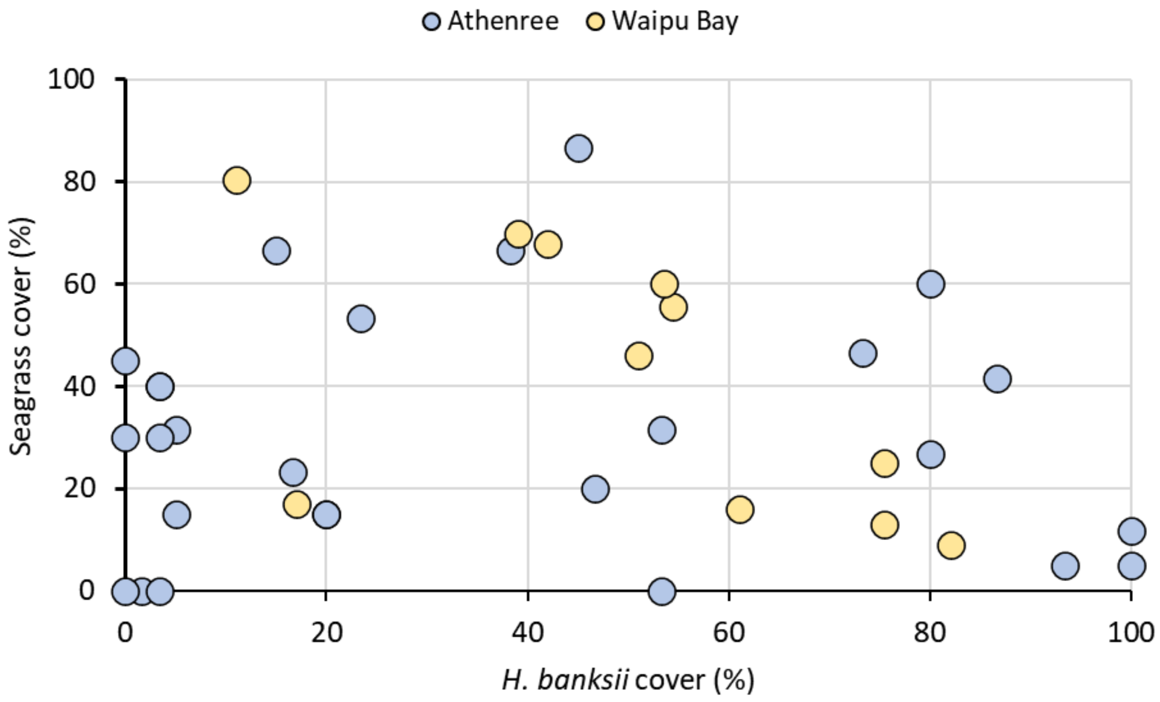

Figure 13 Relationship between the field sampled seagrass cover and H. banksii cover for Athenree (blue) and Waipu Bay (yellow).

Tissue nutrients

Tissue nutrients of *H. banksii* were collected at Waipu Bay, to provide a baseline sample and assessment against macroalgae nutrients from Tauranga Harbour. The average total nitrogen was 1.04 g/100 g dw (dry weight), and total carbon 28 g/100 g dw (Table 2). The average C:N ratio was 27, and the average phosphorus content 488 mg/kg dw.

In comparison to the long-term average for *Ulva* spp. (sea lettuce) in October, the mean TN was lower in *H. banksii,* however there was a large difference between the phosphorus content, which was higher in *Ulva* spp. than in *H. banksii.*

Table 2 H. banksii tissue nutrients from 11 samples at Waipu Bay in October 2022, compared to long term (1991 – 2020) sea lettuce tissue results at Grace Road (Crawshaw 2021).

H. banksii	Total nitrogen (g/100g)	Total carbon (g/100g)	C:N ratio	Phosphorus (mg/kg)
Min	0.98	26	24	390
Max	1.14	30	29	610
Average	1.04	28	27	488
Sea lettuce Grace Road (Crawshaw 2020)				
Mean	2.14	27	13	1100

Historical distributions

The first records of the ecology of Tauranga Harbour are reported in surveys from Bioresearchers in 1976 (Barker & Larcombe, 1976). They mention *H. banksii* (unattached form) as a species occuring locally within mangrove zones, and additionally as a species occuring within the seagrass zone. They provide images of *H. banksii* growing within seagrass beds in central Tauranga Harbour (Figure 14). *H. banksii* is also reported growing on hard substrates in the mid-tidal level, and was common in shaded areas.

Figure 14 Seagrass (Zostera muelleri) and H. banksii, central Tauranga Harbour (Barker & Larcombe, 1976).

Park & Donald (1994) surveyed algae and seagrass in the intertidal zones of Tauranga Harbour over the summer of 1990/91, covering over 85 locations. This was the first major broadscale survey of the harbour on record which quantified algae cover. Measurements recorded the percentage cover of each species in quadrats, following transects from the shoreline to the low tide mark. “Extensive high-density beds of unattached *Hormosira*” were noted as “an unusual feature” (as it is a species usually found attached to rocky shores, not free-living in open estuaries) and *H. banksii* was described as “very abundant” with an average cover across all sites of 2.38%. For comparison, the most abundant species were seagrass, with an average cover of 22.46% and sea lettuce (*Ulva* spp.) with 3.78%.

The historical transect data was transferred into GIS where *H. banksii* was reported when >1% cover (Figure 15). This indicated that the highest % cover *H. banksii* was found at Bowentown and Huntress Creek channel on Matakana Island.

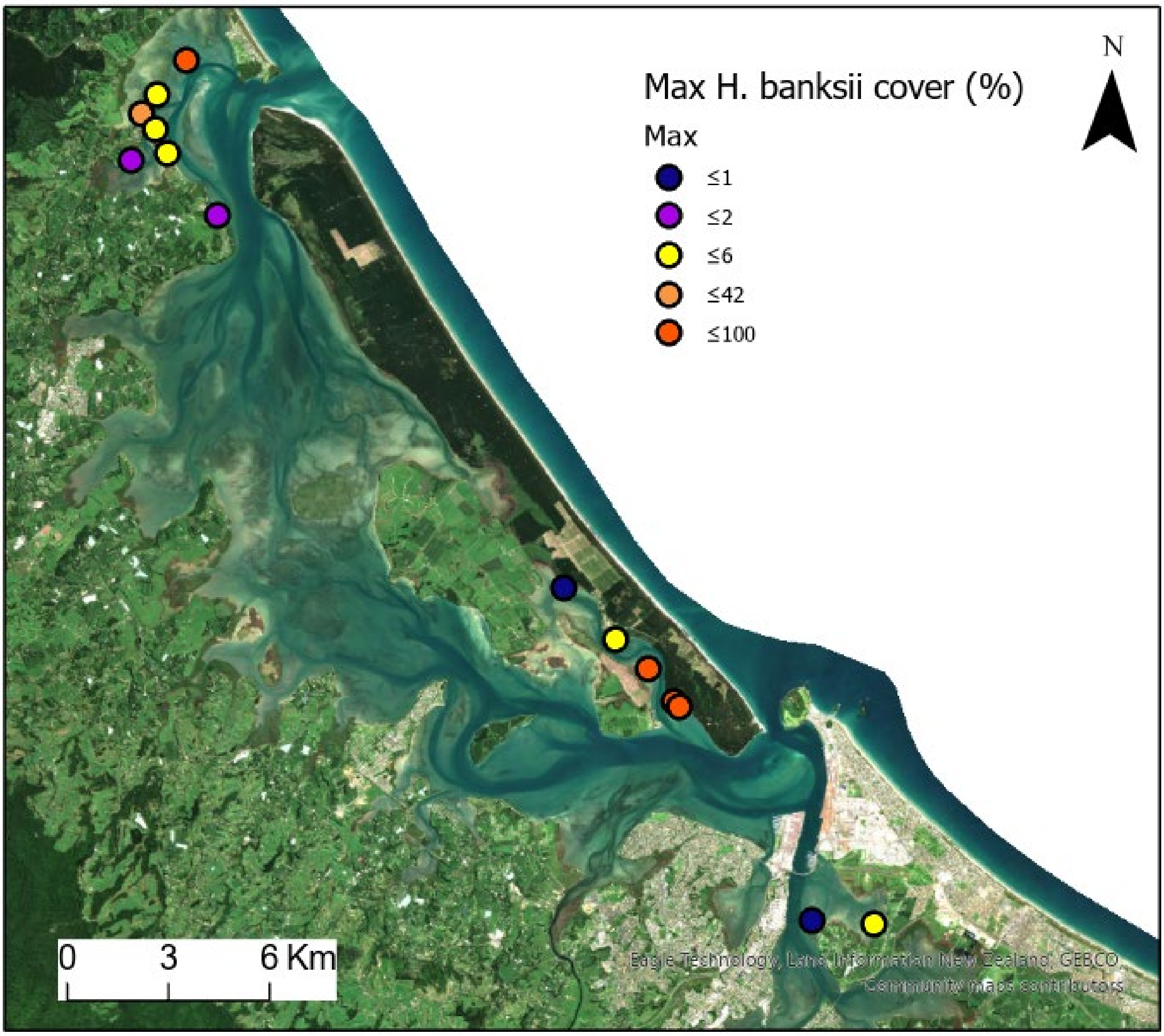

Figure 15 Historical presence and maximum reported % cover of H. banksii from a 1990/1991 survey of Tauranga Harbour algae cover by Park & Donald, 1994. Sites where H. banksii was not identified have not been plotted (over 85 odd sites) but can be seen in Park & Donald, 1994.

Mapping from aerial imagery identified that *H. banksii* was present in both Waipu Bay and Athenree back as early as 1942 – 1963 (based on the oldest available imagery). From these early images, it was distinguishable as dark patches with typical patterns of the algae shaped by water currents and, in newer imagery, colour was also able to be used to identify the algae (Figure 16).

Waipu Bay historically had large dense seagrass beds covering a large area of the intertidal zone, with small patches of *H. banksii* in the upper intertidal zone near Matapihi (Figure 17). Over time, it appears that the *H. banksii* has grown larger in aerial coverage from an initial estimate of 1.76 ha in 1963, to a current day extent of 27 ha (Figure 18).

In Athenree similarly seagrass beds covered the majority of the intertidal zone, with small accumulations of *H. banksii* evident at the top of drainage channels (Figure 19). The cover of *H. banksii* appeared to remain relatively stable between 1942 to 2014 below 10 ha, then an increase to 78 ha by 2021 (Figure 20). It is noted that there was no available historic imagery from 1990 when the last algae surveys were conducted (Park & Donald, 1994), and *H. banksii* abundances were much higher than is reported between 1982 and 2003 (Park, pers. comm).

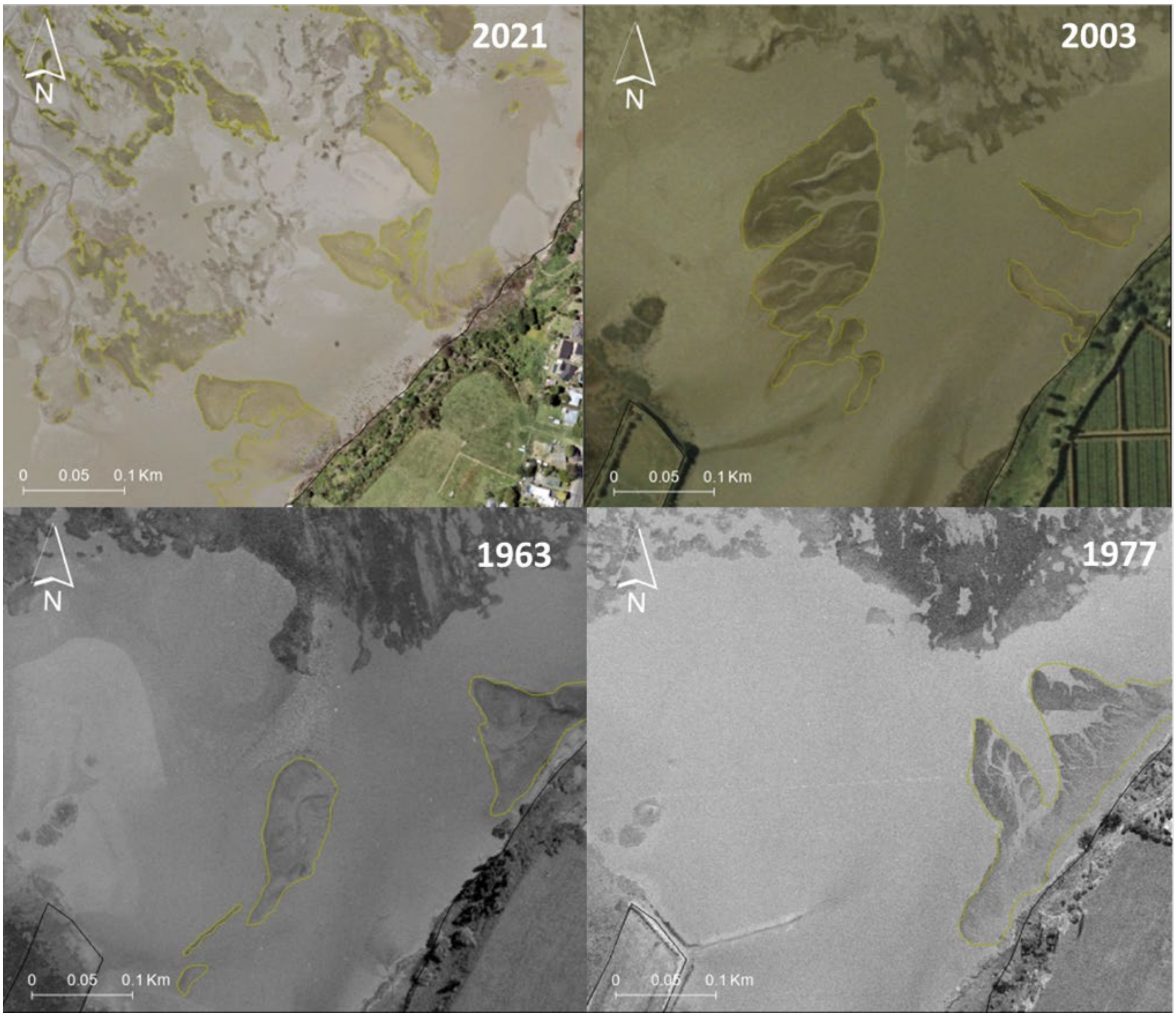

Figure 16 Examples of H. banksii mapped from historical aerial imagery in Waipu Bay.

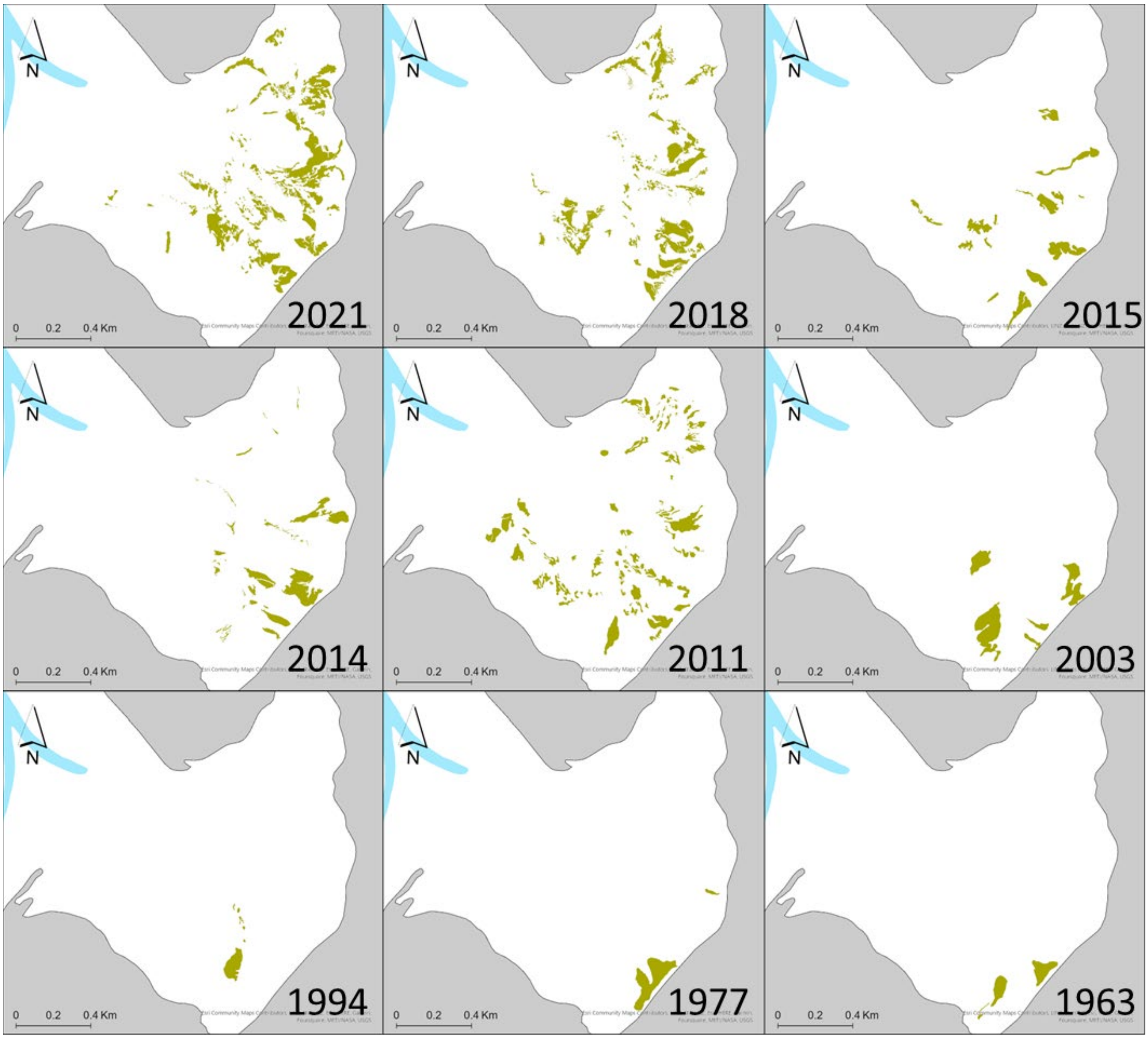

Figure 17 *H. banksii cover in Waipu Bay mapped from aerial imagery (green). Note in black and white images (pre 2003) it is difficult to identify H. banksii from seagrass and may be an underestimation of cover. Intertidal channels are shown in blue.*

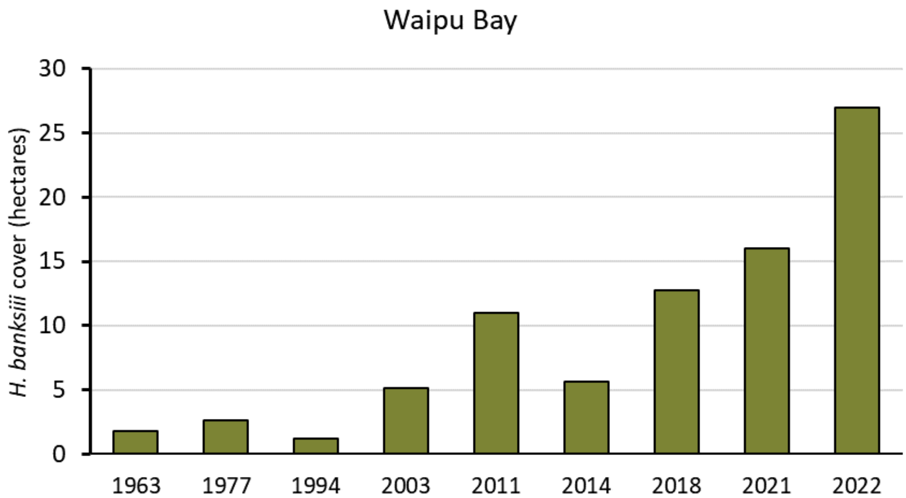

Figure 18 *Estimated H. banksii cover (hectares) in Waipu Bay mapped from aerial imagery.*

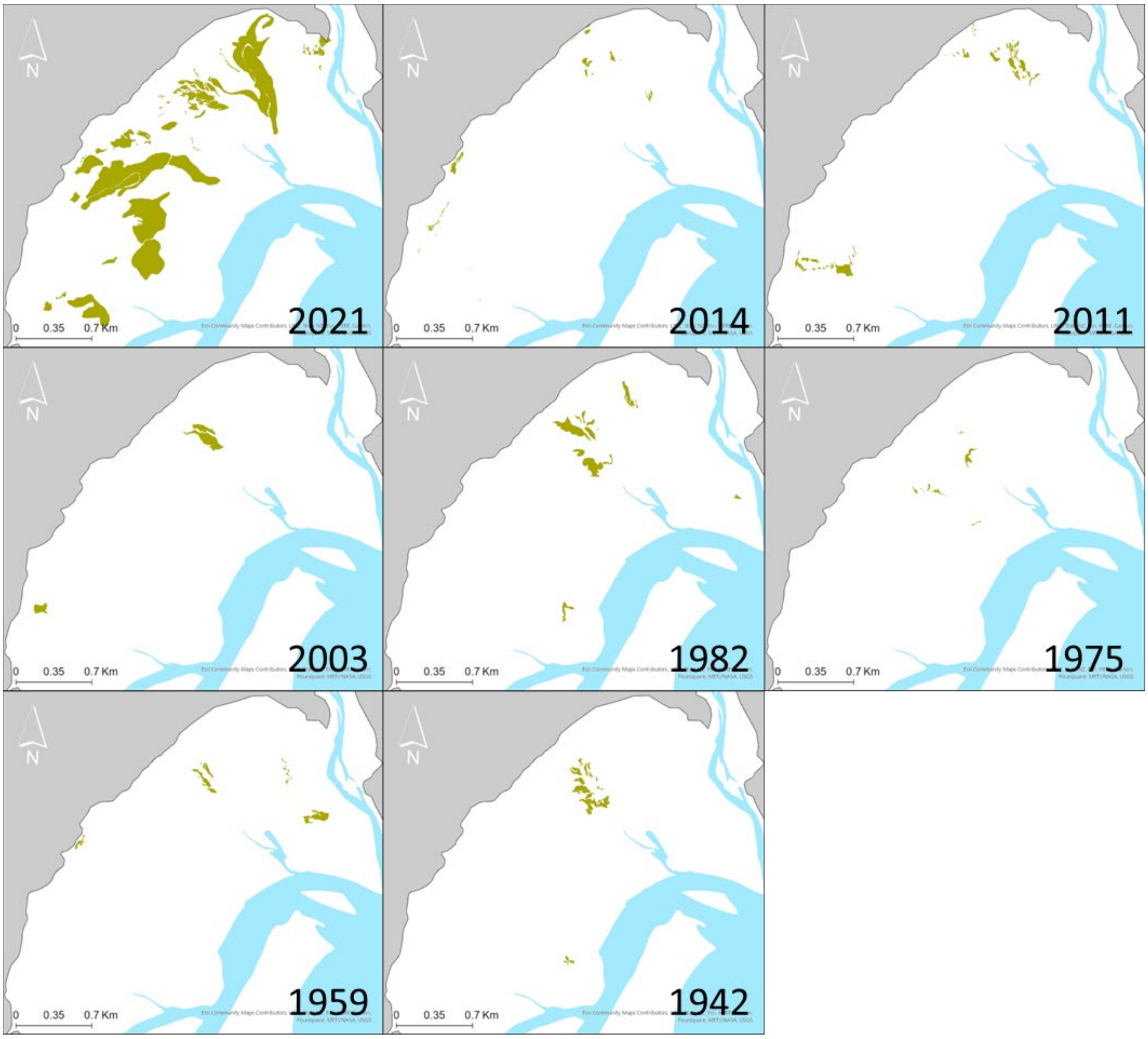

Figure 19 H. banksii cover in Athenree mapped from aerial imagery (green). Note in black and white images (pre 2003) it is difficult to identify H. banksii from seagrass and may be an underestimation of cover. Intertidal channels are shown in blue.

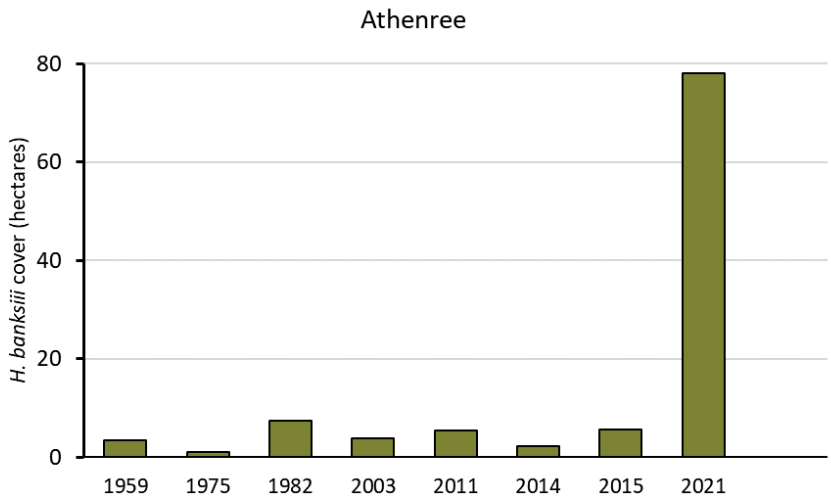

Figure 20 Estimated H. banksii cover (hectares) in Athenree mapped from aerial imagery.

Report discussion/Matapakitanga

Morphology

The algae found in Tauranga Harbour had similarities but also notable differences to the estuarine population described by Moore (1950). The clumps were much smaller and formed drifts made up of many small fragments rather than discrete large clumps. The algae had no attachment point and were not embedded in the substrate. Most of the survey identified well oxygenated sandy sediments, however, a few small, isolated patches of decay were found under high density and cover depositions. The smaller algal clumps in Tauranga may also be more mobile than the larger ones in Picton, and thus disturbed just enough by tidal flows or weather events to prevent complete settling. In summer there can be significant decay, when algae are pushed into the high upper-tidal zone by wind and currents, which has been observed in Bowentown.

Vesicles were smaller than usual, but did show prolific multivariate branching and some larger, irregular segments. Despite the text in Moore (1950) describing larger vesicles, the illustrations appear to show smaller vesicles as well, so the Picton and Tauranga populations may or may not have this in common. The Tauranga result was also different to descriptions of mangrove populations (mostly Australian) which consistently had larger vesicles and a lighter colour compared to rocky shore populations (King, 1981, Bishop et al., 2009). All estuarine descriptions agree on the lack of flotation and reproductive structures.

The presence of rocky shore ecotype fragments with estuarine type growth at the ends suggest drifting rocky shore fragments as one possible source of algal material, and rocky areas around the harbour entrances could support this theory, but the majority of fragments were entirely of the estuarine type. The number of fragments resembling the estuarine form rather than rocky shore form suggests most of the volume is coming from vegetative growth within the estuary rather than a constant supply of new material. Studies of genetic diversity in estuarine and open coast ecotypes of *H. banksii* in Australia identified clear genetic distinctions between populations and suggested the possibility of one large storm event establishing the estuarine populations from the rocky coastline, with limited gene flow since that event (Coleman et al. 2018).

Differences in environmental conditions such as tidal regime, salinity, temperature, light, trophic status, substrate, depth and water movements may explain some of the variation amongst different reported estuarine populations (Macinnis-Ng *et al.*, 2005, Mueller *et al.*, 2015). Waipu Bay, for example, is a relatively sheltered estuary, tidally exposed, with a narrow salinity range, firm sand and low nutrient levels. The exposure of *H. banksii* to air and desiccation stress has been discussed as a controlling factor on the *H. banksii* vesicle size (Bergquist, 1959, Mueller *et al.*, 2015). Additionally, the presence of increasing freshwater influence in estuarine environments has been shown to be a trigger for a morphological change from a rocky shore ecotype to an estuarine ecotype in various Fucaceae species (Gibb, 1957, Allender & Smith, 1978). Advanced changes in morphology are usually not reached for several years (Gibb, 1957), and once the new ecad form has been established it is usually maintained, even if moved to other environments (Gibb, 1957, Allender & Smith, 1978). This could explain the failure of short-term salinity transplant experiments, to induce a typical form of *H. banksii* to take on the characteristics of a loose-lying form (Moore, 1950). The chemical composition and physiological properties of fucoid tissues also change under reduced salinity, which may facilitate long-term adaptation and osmoregulation (Munda & Kremer 1977).

Overall, there are very limited studies in New Zealand investigating the morphology and environmental drivers of *H. banksii* in marine habitats (in particular the estuarine ecotype) and remains a research gap requiring further investigation.

Distribution

The Tauranga Harbour population surveyed was found almost exclusively on top of seagrass, following the same patterns of distribution, although not all of the seagrass was covered, whereas the Picton *H. banksii* (Moore, 1950) occurred in bands between seagrass and other algae. In Tauranga Harbour it appears that algal fragments can become entangled in seagrass, similarly to how they become trapped amongst pneumatophores in mangrove populations (Bishop et al., 2012). The lesser association in the Picton study may be due to reduced habitat for seagrass (steeper sided cobble shores) or physical factors (wave energy) that weren't examined. This close association between the two species highlights the importance of studying their interactions.

Because *H. banksii* is predominantly found on rocky shores rather than estuarine sandflats, there may be more estuarine sandflat populations than what has been documented, which have been dismissed previously as accumulated wrack. Stevens & Robertson (2013) mentioned a 22 ha patch of *H. banksii* in Freshwater Estuary (Stewart Island), which they described as wrack washed in from the sea, however it may be an example of another estuarine population, although this was reported to fluctuate between survey years (Stevens pers. coms). The *H. banksii* was sitting on dense seagrass, predominantly near the upper intertidal edge. Identifying and measuring more estuarine *H. banksii* occurrences, particularly around seagrass populations, may help to define the specific conditions under which this particular ecotype forms, and if there are consistent growth patterns across populations which could be used to predict its effects.

The extent of *H. banksii* is increasing over time in Tauranga Harbour and is spatially related to the presence of seagrass beds. There is no information to draw from as to why this interaction occurs, however it is likely that the seagrass helps to trap the *H. banksii* in place, related to the hydrography and physical characteristics of the intertidal flats.

Ecology

H. banksii is an important habitat for juvenile fish (Morrison *et al.*, 2009). In particular, *H. banksii* is known as an important nursery species for juvenile parore in north-eastern NZ estuaries, where juveniles settle directly onto these and other habitats on rocky reef forms of *H. banksii* (Morrison, 1990). The complex three-dimensional structure of *H. banksii* supports dense and diverse communities of invertebrates (Bishop *et al.*, 2013). The small size and above ground biomass of *Zostera muelleri* may not provide such a complex habitat at low tide, and the presence of *H. banksii* may facilitate higher or more diverse communities.

There appears to be minimal impacts on seagrass beds from *H. banksii* presence at low densities, however at higher densities (between 60 – 80% *H. banksii* cover) there was evidence that the seagrass beds were being smothered and responding by declining in percentage cover. There was some evidence of oxygen depletion in the sediments at high density *H. banksii* locations. This is a similar response to macroalgae blooms (such as sea lettuce) on seagrass beds, where macroalgae causes degradation by smothering and shading seagrass from sunlight. Blooming macroalgae can have a range of detrimental effects to coastal ecosystems, such as noxious odours, reduction in sediment oxygen conditions, displacement of seagrass and reduced benthic biodiversity by physical smothering and light reduction, fish kills, and nutrient release through the breakdown of decaying organic matter (Norkko & Bonsdorff, 1996, Teichberg *et al.*, 2010, Niemand, 2018). Although *H. banksii* is not considered a blooming algae species, it appears it may have similar impacts on the ecology of the estuarine environment when present at high density. Given the lack of reports of estuarine sandflat populations of *H. banksii* in New Zealand, it appears that Tauranga Harbour may be hosting a unique assemblage that requires further investigation. In Tauranga Harbour we have seen the decline of numerous estuarine habitats, including scallop and horse mussel beds (Park & Donald, 1994, Clark *et al.*, 2018), and coraline turf (*Coralline* spp.) associated with seagrass beds (Park & Donald, 1994, Morrison, 2012). Therefore, understanding the ecological significance of the *H. banksii* population, its relationships to seagrass beds and its environmental stressors will be important for management of the harbour.

Recommendations

The information collated in this report highlight that we still know very little about the role of *H. banksii* in estuarine habitats, and the previous data collection and monitoring has been opportunistic and not targeted to this species ecotype. Given the extensive ranges it now inhabits, a number of recommendations are provided to support future investigations and monitoring into this species.

- Mapping spatial cover and density of *H. banksii* over time using broadscale mapping techniques to track changes in relation to seagrass extents.
- Investigate the use of satellites to map *H. banksii* distributions to provide higher level of spatial variability and seasonality.
- Undertake assessments of epifauna and macrofauna associations with *H. banksii* in estuarine habitats.
- Support research into fish associations with estuarine *H. banksii* and the potential of it being a habitat of significance for fisheries (in collaboration with MPI).
- Investigate the environmental conditions required for *H. banksii* presence in Tauranga Harbour.
- Support research into genetic analysis to understand the wider population dynamics and if the estuary populations are stable/self-supporting, or regularly seeded from external sources.
- Investigate other populations of *H. banksii* across New Zealand habitats to understand growth forms and habitat preferences.

Conclusions

This report has provided a summary of current knowledge of estuarine forms of the brown algae *H. banksii* and reported on historical and current distributions across sites in Tauranga Harbour. The survey has confirmed that the *H. banksii* in Tauranga Harbour seagrass beds appears consistent with other reports of an estuarine ecotype, modified for life in a soft sediment estuarine environment, with multivariate branching and limited evidence of reproductive structures. There are very limited reports of this species in large quantities in other New Zealand estuaries, which signifies that it may be a unique habitat limited to few locations in New Zealand.

The historical mapping identifies the presence of the algae back to the 1950’s in Tauranga Harbour, however its distribution appears to be increasing to the current day (although this may relate to the increasing quality of aerial imagery availability). The large accumulations are predominantly associated with the presence of seagrass beds, although some shoreline /channel observations were also identified. The current locations are limited to near the harbour entrances, indicating water quality and flushing may be a driver of its current locations, or proximity to a rocky shore source that has colonised the soft sediment habitats.

There appears to be a negative impact of the *H. banksii* presence on seagrass beds at high densities, impacting the seagrass similarly to how other macroalgae has been reported to affect seagrass (smothering, light reduction and sediment deoxygenation). There is no information available to assess how the increase of this species may impact on estuary ecology, and further research is recommended to understand these unique assemblages in Tauranga Harbour.

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Appendix

Survey Photos – Waipu Bay

Figure 21 Hormosira banksii in Waipu Bay. Top left: deep drift of H. banksii. Top right: various shapes and branching. Bottom: drift of H. banksii over seagrass

Figure 22 Examples of quadrats surveyed in Waipu Bay with H. banksii on top of seagrass.

Survey Photos – Bowentown/Athenree

Figure 23 Drifts of H. banksii on top of seagrass beds in Bowentown.

Figure 24 Top left: large clumps of H. banksii typical throughout the survey.
Top right: example of quadrat showing colour variation in H. banksii.
Bottom: H. banksii clumps within mangrove pneumatophores.