NIWA
Taihoro Nukurangi

Macroalgae at Waipu, Northland

Waipu Macroalgae

Prepared for Northland Regional Council

June 2018

Prepared by:
Wendy Nelson

For any information regarding this report please contact:

Wendy Nelson
Programme Leader
Biodiversity
+64-4-386 0600
wendy.nelson@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No: 2018165WN
Report date: June 2018
NIWA Project: ELF18303

Quality Assurance Statement		
	Reviewed by:	Roberta D'Archino
	Formatting checked by:	P Allen
	Approved for release by:	Dr Alison MacDiarmid

Contents

Executive summary

The deposition of large quantities of macroalgae on Waipu beach in Northland has resulted in a range of negative impacts, including curtailing access to the beach and water for recreation, and producing unpleasant odours. The macroalgae have been deposited along the beach, swept into the neighbouring stream, as well as suspended in the water column and have been present in subtidal accumulations in the immediate offshore region.

This project was undertaken to assemble baseline data about the macroalgae at Waipu. Data have been assembled on the incidents reported over the past decade by Northland Regional Council, photographs taken by NRC staff and members of the public have been assembled, a questionnaire distributed to gather observations from affected members of the public to summarise local experiences and insights, and specimens from accumulations have been collected and identified. Over the 2017/2018 summer, observations have been made on the occurrence of macroalgal wrack on Waipu beach and further collections made to evaluate the species present.

Over the past eight years, the majority of the specimens collected are red algae, with a mixture of species characteristic of intertidal and subtidal habitats being found amongst the drift material. The wrack has included relatively few species of green algae, and the brown algae in the wrack are all typically found growing on rocky reefs in north eastern North Island areas. Certain red algae have been more frequently recorded than other species – *Spyridia filamentosa*, and several species of *Plocamium.* These are considered to be native to the region. Both *Spyridia* and *Plocamium* spp. appear to be able to grow while suspended in the water column or in submerged accumulations, and at certain times contribute the majority of the biomass.

1 Introduction

Statement of problem

In recent years, on a number of occasions, significant quantities of macroalgae have been washed ashore at Waipu in Northland. This has caused considerable concern among the public and Northland Regional Council (NRC) staff. This research project was initiated to gather information in order to better understand the causes of these events, and inform management to enable better planning for and responses to future incidents.

The project was planned to include three parts:

1) Species composition of the algae washed ashore: determining the main species present, whether native or invasive, and their characteristics; whether the species composition has changed over time and whether it changes during the main growing season (December to February); comparison of species assemblages in the local marine environment versus the species composition of algae cast ashore.

2) Investigation of potential causes for the increase in algae cast ashore over the last five years: involving an analysis of water quality data, hydrodynamic processes and climatic conditions.

3) Possible mitigation measures for Council to minimise the effect and better plan for incidents of drift accumulations of macroalgae.

By mid-summer 2017/18, it was apparent that the incidents which had occurred in the previous five summers were not occurring in this summer, and only modest accumulations of macroalgae were washed ashore at Waipu and nearby beaches. As a consequence, the project was reduced in size and modified to include the following components:

A) Baseline information: summary of the state of knowledge about drift accumulations of macroalgae in Waipu Cove and surrounding area, records of events, sources of environmental data they may provide context for interpretation of events, to include:

- Species composition of macroalgae sent to NIWA over the past 5 years and in 2017/2018 with a comparison of species composition and comparison the drift material with that of the local region,
- Records of events: Data from community and NRC, including responses to questionnaires, record of incident reports from NRC, and recent and historical photographs
- Wind data for years

B) Literature review: analysis of national and international literature concerning nuisance accumulations of macroalgae, including current understanding of factors driving these events, with discussion of the relevance to the situation in Northland, specifically Waipu and surrounding area.

2 Baseline data

At the beginning of this project community members and NRC staff established a plan for monitoring the timing and extent of events when macroalgae washed ashore (Appendix A). As the incidents of drift macroalgae were not as severe as in previous years, there were fewer observations made and the number of samples sent to NIWA were fewer than anticipated. However, there were images taken with fixed cameras and these images form an archive for future reference for NRC and the community.

Over the past 5 years NRC staff have corresponded with NIWA about nuisance quantities of macroalgae washed on beaches, and sent specimens of macroalgae for identification. Details of the species identified from the accumulations of cast macroalgae are provided in Appendix B, with species lists for the red, brown and green algae recorded and then lists by date and site of collections

Based on the samples received by NIWA, the species composition of the material washed ashore varies, although there are some species that predominate. In general, the mixture of species recorded is typical of species found on rocky shores in the north eastern North Island. Red algae predominate in the drift accumulations (as seen in the photographic record) and also reflected in the samples sent to NIWA. There have been very few green algae reported, and only some brown algae.

None of the species present are recognised as introduced species. Based on current data there is no reason to consider the species from Waipu are non-indigenous, and none are known to be toxic or harmful. Although most macroalgae require attachment to solid substrate for growth, some macroalgae are able to continue to grow if suspended in the water column, and some species are sufficiently buoyant to remain in suspension rather than sinking to the sea floor or being washed off shore. The depth of the water adjacent to Waipu and the water clarity in the area appears to enable photosynthesis and continued growth even by species that are not buoyant but present in subtidal drift accumulations.

Key species reported from the drift accumulations include the red algae *Spyridia filamentosa* and species of the genus *Plocamium*.

Spyridia filamentosa is native to northern New Zealand. This species is also widely distributed in warm to tropical waters worldwide. Recent research suggests that there is considerable variation in the species. The New Zealand specimens that have been studied are most closely related to strains also known from Hawaii, Western Australia and Japan (Zuccarello et al. 2002; Conklin and Sherwood 2012).

Figure 1: *Spyridia filamentosa*. A. Whole thallus (5 cm high) B. Microscope view of distinctive banding pattern on branches.

The individuals of *Spyridia filamentosa* can grow to 16 cm in height although often they are smaller. The thalli are densely and finely branched – and they have a very characteristic banding pattern on the branches that can be seen with a microscope (Figure 1A, B; also http://www.algaebase.org/search/images/). *Spyridia filamentosa* produces spores but is also able to grow vegetatively from fragments and forms balls or masses that are neutrally buoyant. This floating material can continue to proliferate at the sea surface or in the water column, and in the surf zone.

Spyridia filamentosa has been recorded in drift accumulations of seaweed in tropical and warm temperate coastlines (e.g. Benz et al. 1979; Norton & Mathieson 1983; Piñón-Gimate et al. 2009). Investigations of the sexual and asexual modes of reproduction in this species (West & Calumpong 1989) revealed a high frequency of spore production and germination, followed by rapid cell division rates in propagules (both sexual and asexual).

Spyridia filamentosa has been washed ashore in very large quantities at sites in Northland, the Hauraki Gulf, Manukau Harbour and Coromandel. In some cases, these accumulations break up quickly, but in other situations the accumulations persist, and are resuspended by tides and then deposited again in following tidal cycles.

Species of the red algal genus *Plocamium* are common and widespread in New Zealand. There are at least three species present in the north-eastern North Island that have been recorded from the drift at Waipu. Individual *Plocamium* thalli are usually less than 15 cm in height, and normally grow attached to rock. *Plocamium* species are not generally regarded at buoyant. They have a standard red algal reproductive cycle and are not known to reproduce vegetatively.

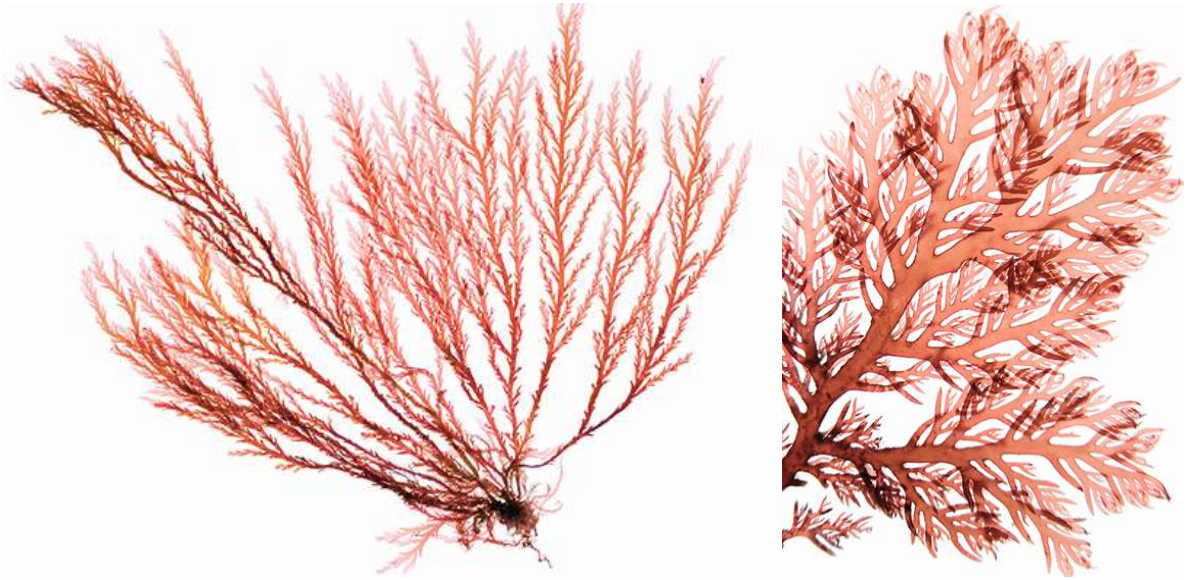


Figure 2. Example of *Plocamium* species. A. Whole thallus B. Branching pattern

The taxonomy of this genus is very challenging. Species of *Plocamium* have very distinctive branching which enables them to be placed in the genus readily, but the variation within species is still poorly understood, and further research is required to clarify diversity of New Zealand species. At present no names can be applied to the samples from Waipu given the state of the taxonomy of the genus in New Zealand.

The presence of *Plocamium* species in nuisance accumulations is not frequently reported, although there was an anecdotal report of large quantities of *Plocamium* in the upper Waitemata in the mid-1990s.

Additional baseline data on the frequency and extent of nuisance events have been drawn from questionnaires, enabling a compilation of the observations and perspectives of members of the local community (Appendix C). In addition, reports of incidents have been recorded by NRC staff, and a summary of the data provided is summarised in Appendix D, including a summary of incident reports by year and month in which reports have been made and the reasons for incidents to be reported to NRC staff. In Appendix E wind data from nearby recording stations have been assembled, providing information of the direction, frequency and intensity of wind between 2010 and 2016.

Photographic records, both historical and recently recorded, are presented in Appendix F. Some of these images of major deposition events have the wind data for the time period during the event.

Summary of experiences at Waipu

Incidents of quantities of drift algae being stranded on Waipu Beach have been occurring for decades, but the frequency and severity of these appear to have been increasing over the past five to ten years (Appendices C, D, F). In general, the incidents are more frequent in summer months (particularly from December through to March/April refer Appendices C, D), but there have also been incidents reported and/or photographed in winter and spring. The summary of incidents reported to NRC supplied as part of this project do not cover all events. There are images of large accumulations taken on dates when no reports have been recorded.

In the worst incidents the material has extended both along the beach, cast up towards the upper shore/dune area, and has also been swept into the neighbouring stream. Refer Appendix F for images of events. At the height of these events the use of the beach and amenities were severely curtailed with access to the beach, use of the beach for recreation, as well as the use of the water by swimmers, all being severely impacted.

In addition to the material being washed ashore, it seems also that there is a high degree of re-suspension with large quantities of macroalgae also apparent floating in the water. There are also observations of large accumulations of material subtidally in the nearshore area, and also aerial imagery supporting these observations, not only in summer but also in winter.

The annual wind characteristics for sites near to Waipu (Whangarei, Leigh) presented in Appendix E, give an indication of the prevailing conditions at the site. The wind data in the period accompanying specific incidents have compiled in Appendix F does not present a clear picture of specific conditions that are consistently associated with deposition events. At present there is no clear pattern of wind direction associated with the deposition of material on the beach or retention in the bay. It appears that the shape and the orientation of the beach relative to the predominant winds means that beach cast material is retained rather than dispersed. It seems highly probable that under certain conditions retention on the beach will be favoured rather than accumulations being resuspended with high tide and then being washed out to sea. The physical drivers are likely to be a combination of wind direction, intensity and duration, tidal conditions (neap vs spring, time of tide), and potentially local currents.

3 Literature

Natural processes such as local currents, tides, and weather and storm activities result in macroalgae being washed ashore. Macroalgal accumulations, often referred to as wrack, are natural phenomena and occur worldwide (e.g., Lastra et al. 2014). Usually the beach cast material originates from nearby intertidal or subtidal coastal assemblages and is usually multispecific, reflecting the local community. In some cases of nuisance scale outbreaks, a single species predominates. Macroalgae that are washed ashore are known to contribute to the availability and turnover of carbon and nitrogen in coastal systems, critical processes for cycling or nutrients and food in coastal ecosystems. In addition, drift algae provide habitat for sand-dwelling organisms, which in turn contribute to the breakdown of the macroalgal biomass and provide food for shore birds (e.g., Mews et al. 2006; Ince et al. 2007; Olabarria et al. 2010; Barreiro et al. 2011; Dugan et al. 2011; Gómez et al. 2013). Drift macroalgae make a very significant contribution to the export flux of carbon to unvegetated sediments and the deep sea (e.g. Krause-Jensen and Duarte 2016), an important component of the global carbon budget.

Research has been conducted on the deposition of wrack on beaches in other parts of the world. Orr et al. (2005) found that tidal dynamics, exposure and sediment characteristics of the beach and buoyancy of the species of macroalgae present interacted in shaping wrack deposition processes. Even on beaches where there is little or no tidal influence (e.g., Baltic Sea) there is high spatial and temporal variation in the dynamics of beach-cast wrack. Hammann & Zimmer (2014) found that over the course of one year, the amount of weekly deposited macrophyte wrack along the shoreline fluctuated from zero to 3000 g·m−1.

The fate of wrack is also complex and highly variable, with the rate of decay differing between species, and affected by temperature and moisture levels, and the bacteria and fauna present within the drift (e.g. Mews et al. 2006; Lastra et al. 2015; Conover et al. 2016). Mews et al. (2006) concluded *"the dynamics of nutrient fluxes within the marine–terrestrial ecotone depends not only on the spatial distribution and amount of beach-cast detritus, but also on its species composition".* Studies to date have shown that the fate of wrack is influenced by not only the position on the shore where it has been cast relative to the terrestrial environment, but also the vertical accumulation of wrack, desiccation, burial, in situ macrofaunal consumption, microbial degradation and export by tides and currents, as well as the fragmentation that occurs through abrasion with sediments and wave driven disturbance (e.g. Orr et al. 2005).

When large volumes of macroalgae are washed up on beaches or proliferate within confined bays, there are negative aesthetic and amenity impacts on recreation and tourism, impacts on marine installations such as blocking access to boat ramps, and effects on associated coastal businesses. As these accumulations of biomass degrade, the rotting material can result in areas where there is low oxygen (anoxia), and the production of hydrogen sulphide, with various follow-on impacts on associated biota, as well as unpleasant odours affecting local residents and visitors. Large quantities of drifting or submerged macroalgal blooms can also affect the abundance and diversity of benthic organisms, for example by shading sea grass and microalgae, smothering sea floor communities. These negative impacts of drift accumulations have been summarised for New Zealand (Nelson et al. 2015) and internationally (e.g., Charlier et al. 2007; Liu et al. 2013; Smetacek & Zingone 2013; Lyons et al. 2014).

There is evidence for increasing frequency and intensity of drift accumulations reaching nuisance or harmful bloom proportions and this is attributed to excess nutrients/eutrophication of coastal environments (e.g., Jeffrey et al. 1995; Lapointe & Bedford 2007; Teichberg et al. 2010, 2012; Kennish et al. 2011; Thornber et al. 2017), including nutrients entering the marine environment via groundwater (e.g. Kwon et al. 2017). As summarised by Smetacek & Zingone (2013)

> *"Sudden beaching of huge seaweed masses smother the coastline and form rotting piles on the shore. The number of reports of these events in previously unaffected areas has increased worldwide in recent years. These 'seaweed tides' can harm tourism-based economies, smother aquaculture operations or disrupt traditional artisanal fisheries. Coastal eutrophication is the obvious, ultimate explanation for the increase in seaweed biomass, but the proximate processes that are responsible for individual beaching events are complex and require dedicated study to develop effective mitigation strategies."*

The largest macroalgal harmful blooms have been composed of the green alga *Ulva*, sometimes referred to as 'green tides', particularly in China but also elsewhere globally, and also the brown alga *Sargassum*, particularly in the Caribbean but more recently on the coasts of Brazil and west Africa (Sissini et al. 2017). The extent and severity of impacts of some of these blooms has led to the application of various types of remote sensing techniques to map and quanitify the blooms e.g., Shen et al. 2014; Wang & Hu 2016). Piñón-Gimate et al. (2017) used nitrogen isotopes to characterise macroalgal blooms and to assess land-based nutrient enrichment in coastal waters, an approach that has also been used in New Zealand for *Ulva* blooms (Barr et al. 2012, 2013).

Thornber et al. (2017) conducted a detailed study in a eutrophic estuary that had been plagued by nuisance macroalgal blooms, and where efforts to manage nutrients had been instituted. They documented high variability in macroalgal abundance and diversity across "*month-groups, years, sites, and even within individual sites in a eutrophic estuary*". Thornber et al. (2017) noted that *"futher management efforts are required to decrease nutrient inputs from point sources (e.g. waste water treatment facilities) and non-point sources throughout coastal watersheds. Even with point source reductions, ecosystem recovery will take several years to decades and may not return to pre-eutrophication status due to shifting baselines and altered trophic interactions (Duarte et al., 2009; Greening et al., 2014).*", and "*Eutrophication management efforts should be coupled with continued long-term monitoring of water quality, macroalgal blooms, and other ecological indicators to conclusively determine the short- and long-term impacts of nutrient reduction on coastal ecosystems.*"

4 Summary

The frequency and severity of events where macroalgae are being washed ashore at Waipu, and drift accumulations are retained subtidally adjacent to Waipu, appear to be increasing. More baseline data on the physical conditions surrounding the nuisance scale events are required including data on water temperature, sea conditions, wind direction, intensity and duration and nutrients. There are examples of detailed monitoring programmes in the international literature, which indicate the complexity and variability of nuisance outbreaks. There is a consensus in the literature that both temperature and nutrients are the main contributing factors to bloom events, and the nutrients may result from both point source, and non-point source enrichment, including nutrient laden ground water. It is not possible to draw conclusions about the driving factors influencing events at Waipu at present.

5 Acknowledgements

This project was supported by both a MBIE Envirolink Medium Advice Grant as well as through additional funding from the Marine Macroalgae project of NIWA's Coasts & Oceans Marine Biological Resources Programme (COBR1801). Richard Griffiths and staff of the Northland Regional Council are thanked for providing data and images, and for liaising with the Waipu community. Waipu community members are thanked for their contributions, providing information, assisting with beach watch operations and for collection of specimens and providing images - particularly Roger King, Angus McCulloch, Rick Stolewerk, and Anton Trist. Andre La Bonte and Nick Shears are thanked for images.

6 References

Barr, N., Zeldis, J., Gongol, C., Drummond, L., Scheuer, K. (2012) Effects of the Canterbury earthquakes on Avon-Heathcote Estuary/Ihutai macroalgae. NIWA client report CHC2012e072, prepared for Environment Canterbury and Christchurch City Council. Christchurch, Environment Canterbury. Christchurch, NIWA. 33 p.

Barr, N.G., Dudley, B.D., Rogers, K.M., Cornelisen, C.D. (2013) Broad-scale patterns of tissue-δ15N and tissue-N indices in frondose *Ulva* spp.; developing a national baseline indicator of nitrogen-loading for coastal New Zealand. Marine Pollution Bulletin 67: 203–216.

Barreiro, F., Gómez, M., Lastra, M., López, J., and De la Huz, R. (2011) Annual cycle of wrack supply to sandy beaches: effect of the physical environment. Marine Ecology Progress Series, 433: 65–74.

Benz, M.C., Eiseman, N.J., Gallaher, E.E. (1979) Seasonal occurrence and variation in standing crop of a drift algal community in the Indian River, Florida. Botanica Marina, 22: 413–420.

Charlier, R.H., Morand, P., Finkl, C., Thys, A. (2007) Green tides on the Brittany coasts. Environmental Research, Engineering and Management, 3: 52–59.

Conklin, K.Y., Sherwood, A.R. (2012) Molecular and morphological variation of the red alga Spyridia filamentosa (Ceramiales, Rhodophyta) in the Hawaiian Archipelago. Phycologia, 51: 347–357.

Conover, J., Green, L.A., Thornber, C.S. (2016) Biomass decay rates and tissue nutrient loss in bloom and non-bloom forming macroalgal species. Estuarine, Coastal and Shelf Science, 178: 58-64

Duarte, C.M., Conley, D.J., Carstensen, J., Sánches-Camacho, M. (2009) Return to Neverland: shifting baselines affect eutrophication restoration targets. Estuaries and Coasts, 32: 29–36.

Dugan, J.E., Hubbard, D.M., Page, H.M., Schimel, J.P. (2011) Marine macrophyte wrack inputs and dissolved nutrients in beach sands. Estuaries and Coasts, 34: 839–850, DOI 10.1007/

Gómez, M., Barreiro, F., López, J., Lastra, M., and de la Huz, R. (2013) Deposition patterns of algal wrack species on estuarine beaches., Aquatic Botany, 105: 25–33,

Greening, H., Janicki, A., Sherwood, E.T., Pribble, R., Johansson, J.O.R. (2014) Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, Florida, USA. Estuarine and Coastal Shelf Science, 151: A1-A16.

Hammann, S., Zimmer, M. (2014) Wind-driven dynamics of beach-cast wrack in a tide-free system. Open Journal of Marine Science, 4: 68-79. http://dx.doi.org/10.4236/ojms.2014.42009

Ince, R., Hyndes, G.A., Lavery, P.S., Vanderklift, M.A. (2007) Marine macrophytes directly enhance abundances of sandy beach fauna through provision of food and habitat. Estuarine and Coastal Shelf Science, 74: 77– 86.

Jeffrey, D.W., Brennan, M., Jennings, E., Madden, B., Wilson, J.G. (1995) Nutrient sources for in-shore nuisance macroalgae: the Dublin Bay case. Ophelia, 42: 147–161.

Kennish, M.J., Fertig, B., Sakowicz, G.P. (2011) Benthic macroalgal blooms as an indicator of system eutrophy in the Barnegat Bay–Little Egg Harbor Estuary. Bulletin of the New Jersey Academy of Science, 56: 1–5.

Krause-Jensen, D., Duarte, C. M. (2016) Substantial role of macroalgae in marine carbon sequestration, Nature Geoscience, 9: 737–742, doi:10.1038/NGEO2790.
Kwon, H.K., Kang,H., Oh, Y.H., Park, S.R., Kim, G. (2017) Green tide development associated with submarine groundwater discharge in a coastal harbor, Jeju, Korea. Scientific Reports, 7: 6325, DOI:10.1038/s41598-017-06711-0
Lapointe, B.E., Bedford, B.J. (2007) Drift rhodophyte blooms emerge in Lee County, Florida, USA: Evidence of escalating coastal eutrophication. Harmful Algae, 6: 421-437.
Lastra, M., Rodil, I.F., Sánchez-Mata, A., García-Gallego, M., Mora, J. (2014) Fate and processing of macroalgal wrack subsidies in beaches of Deception Island, Antarctic Peninsula. Journal of Sea Research, 88: 1–10.
Lastra, M., López, J., Neves, G. (2015) Algal decay, temperature and body size influencing trophic behaviour of wrack consumers in sandy beaches. Marine Biology, 162: 221–233, DOI 10.1007/s00227-014-2562-z
Liu, D., Keesing, J., He, P., Wang, Z., Shi, Y., Wang, Y. (2013) The world's largest macroalgal bloom in the Yellow Sea, China: formation and implications. Estuarine, Coastal and Shelf Science, 129: 2–10.
Lyons, D.A., Arvanitidis, C., Blight, A.J., Chatzinikolaou, E., Guy-Haim, T., Kotta, J. et al. (2014) Macroalgal blooms alter community structure and primary productivity in marine ecosystems. Global Change Biology, 20: 2712–2724.
Mews, M., Zimmer, M., Jelinski, D.E. (2006) Species-specific decomposition rates of beach-cast wrack in Barkley Sound, British Columbia, Canada. Marine Ecology Progress Series, 328: 155–160.
Nelson, W.A., Neill, K.F., D'Archino, R. (2015) When seaweeds go bad: an overview of outbreaks of nuisance quantities of marine macroalgae in New Zealand. New Zealand Journal of Marine and Freshwater Research, 49: 472-491. DOI: 10.1080/00288330.2015.1064975
Norton, T., Mathieson, A. (1983) The biology of unattached seaweeds. In: Round F, Chapman D eds. Progress in phycological research, Vol. 2. Amsterdam, Elsevier. Pp. 333–386.
Olabarria, C., Incera, M., Garrido, J., Rossi, F. (2010) The effect of wrack composition and diversity on macrofaunal assemblages in intertidal marine sediments. Journal of Experimental Marine Biology and Ecology 396: 18–26.
Orr, M., Zimmer, M., Mews, M. and Jelinski, D.E. (2005) Wrack deposition on different beach types: spatial and temporal variation in the pattern of subsidy. Ecology, 86: 1496-1507. http://dx.doi.org/10.1890/04-1486
Piñón-Gimate, A., Soto-Jiménez, M.F., Ochoa-Izaguirre, M.J., García-Pagés, E., Páez-Osuna, F. (2009) Macroalgal blooms and d15N is subtropical coastal lagoons from the Southeastern Gulf of California: discrimination among agricultural, shrimp farm and sewage effluents. Marine Pollution Bulletin, 58: 1144–1151.
Piñón-Gimate, A., Espinosa-Andrade, N., Sánchez, A., Casas-Valdez, M. (2017) Nitrogen isotopic characterisation of macroalgae blooms from different sites within a subtropical bay in the Gulf of California. Marine Pollution Bulletin, 116: 130–136.
Shen, H., Perrie, W., Liu, Q., He, Y. (2014) Detection of macroalgae blooms by complex SAR imagery. Marine Pollution Bulletin, 78: 190–195.
Sissini, M.N. et al. (2017) The floating Sargassum (Phaeophyceae) of the South Atlantic Ocean – likely Scenarios. Phycologia, 56 (3): 321–328.
Smetacek, V., Zingone, A. (2013) Green and golden seaweed tides on the rise. Nature 504: 84–88.
Teichberg, M., Fox, S.E., Olsen, Y.S., Valiela, I., Martinetto, P., Iribarne, O. et al. (2010) Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Global Change Biology, 16: 2624–2637.
Teichberg, M., Martinetto, P., Fox, S.E. (2012) Bottom-up vs. top-down control of macroalgal blooms. In: Wiencke, C.B., Bischof, K. eds. Seaweed biology. Berlin, Springer. Pp. 449–467.

Thornber, C.S., Guidone, M., Deacutis, C., Green, L. Ramsay, C.N., Palmisciano, M. (2017) Spatial and temporal variability in macroalgal blooms in a eutrophied coastal estuary. Harmful Algae, 68: 82–96.

Wang, M., Hu, C. (2016) Mapping and quantifying *Sargassum* distribution and coverage in the Central West Atlantic using MODIS observations . Remote Sensing of Environment, 183: 350–367.

West, J.A., Calumpong, H.P. (1989) On the reproductive biology of *Spyridia filamentosa* (Wulfen) Harvey (Rhodophyta) in culture. Botanica Marina, 32: 379–387.

Zuccarello, G.C., Sandercock, B., West, J.A. (2002) Diversity within red algal species: variations in world-wide samples of *Spyridia filamentosa* (Ceramiaceae) and *Murrayella periclados* (Rhodomelaceae) using DNA markers and breeding studies. European Journal of Phycology 37: 403–417.

Appendix A Plan for monitoring

During October 2017 a plan was developed for monitoring Waipu beach, involving community members and NRC staff. Volunteers from the local community and Waipu Cove Campground undertook to make daily observations of seaweed on the beach, to provide accurate data about when drift accumulations first come ashore.

The beach was divided into sections (refer map below), and volunteers were provided with a format for recording the presence of any macroalgae, and estimations of percentage cover as the measure of quantity present (refer table below). In addition, a camera was installed at the surf club to take photos of the beach (Figs x & y)

The intention was to use the data from these sources as well as weather patterns and environmental data (e.g. water temperature) to try to identify what conditions cause the seaweed to wash ashore.

Council staff were also planning to collect regular samples of any algae washed ashore over the summer for identification, to determine if the algal community changes over the course of the summer and which species are most abundant, and if there are any unusual or exotic species present.

Figure A1. Waipu Beach with sections for monitoring marked in red

Table A1: Format for recording observations of macroalgae on Waipu beach

Name:

n/a	section not viewed
0	no seaweed
1	< 1% (present but small quantities)
2	2-10% (small amounts)
3	10-5-% (large amounts
4	>50% (loads)

Please record the time that you make the observation in comments
Seaweed at Shelly beach to be recorded in 'other' not in section 1 only if you make an observation

Date	Waipu stream	Section 1	Section 2	Section 3	Other	Comments
Example	3	0	0	n/a	0 - Shelly Beach	8:55am
26/10/2017						
27/10/2017						
28/10/2017						
29/10/2017						
30/10/2017						
31/10/2017						

Figure A2. Surveillance camera at Waipu

Figure A3. Image of Waipu beach taken with monitoring camera

Appendix B Macroalgae recorded from collections

The species most commonly occurring in the drift were red algae: *Spyridia filamentosa*, species of *Plocamium* and *Acrosorium ciliolatum*.

Red Algae (41)

Acrosorium ciliolatum	low intertidal to subtidal; small, finely branched, thin blades; this species is normally found in small amounts growing entangled in turf or epiphytically and never in large quantities on reefs
Callithamnion sp.	very fine filaments
Callophyllis sp.	divided red blades
Caulacanthus ustulatus	mid intertidal; small, turf-forming
Chondracanthus chapmanii	intertidal & upper subtidal; branched, grows close to rock substrate
Chondria sp.	thin, small blades
Cladhymenia lyallii	thin, branched blades
Cladhymenia oblongifolia	low intertidal to subtidal; thin, strap-like
Dasya sp.	very finely branched
Dasyclonium sp.	finely branched, usually growing as an eiphyte
Erythroglossum undulatissimum	small, finely branched, thin blades
Falkenbergia rufolanosa	Intertidal to subtidal; this is the alternative life history stage of *Asparagopsis armata*; very fine filaments, often forming fluffy balls /clumps
Gelidium caulacantheum	mid intertidal; small, turf-forming
'Gigartina' atropurpurea	large, thick, bladed species
Gigartina macrocarpa	intertidal; branched, grows close to rock substrate
Gigartina sp. (small, tufted)	intertidal; branched
Gracilaria truncata	strap-like, branched
Halymenia' sp.	subtidal; thin blades
Hymenena sp.	finely branched, thin blades
Hymenena variolosa ?	small, finely branched, thin blades
Jania sagittatta	geniculate coralline
Jania sp.	geniculate coralline
Laurencia sp.	small, branched red
Melanthalia abscissa	upper subtidal; wiry, branched
Plocamium (1 -fine)	intertidal to subtidal; finely branched, flattened; species of *Plocamium* normally occur in small patches in a range of open coast habitats, but not in large quantities. More research is required to determine the correct species names for NZ taxa.
Plocamium (2)	As above
Plocamium sp.	As above
Polysiphonia (4 pcc)	finely branched filaments
Polysiphonia (very fine)	finely branched filaments
Polysphonia sensu lato	finely branched filaments
Psilophycus alveatus	upper-mid intertidal
Pterocladia sp.	low intertidal to subtidal; robust, branched
Pterocladiella capillacea	low intertidal; wiry, branched
Rhodophyllis sp.	thin divided blades
Rhodymenia sp.	wiry, forked

'Sarcothalia'decipiens	intertidal & upper subtidal; branched, grows close to rock substrate
Sarcothalia marginifera	intertidal; branched, robust
Spyridia filamentosa	subtidal; very finely branched; often present drifting, buoyant as clumps or loose balls
Stenogramma interruptum	subtidal; strap-like divided blades
Stylonema alsidii	very fine thin filaments
Vidalia colensoi	subtidal, wiry, tough, zigzag appearance

Brown Algae (10)
Carpomitra costata
Carpophyllum angustifolium
Carpophyllum flexuosum
Carpophyllum maschalocarpum
Carpophyllum plumosum
Dictyota sp.
Ecklonia radiata
Sargassum sinclairii
Xiphophora chondrophylla
Zonaria turneriana

Green Algae (3)
Caulerpa flexilis
Cladophora sp.
Ulva sp. (blade)

Date	**Location**	**Species identified**
Mar-13	Uretiti	*Spyridia filamentosa*
	Waipu	*Spyridia filamentosa*
		Plocamium sp.
Apr-13	Ruakaka	*Spyridia filamentosa*
26-Nov-15	Waipu	*Spyridia filamentosa*
Jan-16	Waipu	
		Acrosorium ciliolatum
		Callithamnion sp.
		Callophyllis sp.
		Carpophyllum plumosum
		Caulerpa flexilis
		Dasya sp.
		Ecklonia radiata
		'Gigartina' atropurpurea
		Gigartina macrocarpa
		Gracilaria truncata
		'Halymenia' sp.
		Jania sagittata

		Jania verrucosa
		Laurencia sp.
		Plocamium sp.
		Psilophycus alveatus
		Rhodymenia sp.
		Sarcothalia marginifera
		Sargassum sinclairii
		Spyridia filamentosa
		Stenogramma interruptum
2-Nov-17	Waipu Area 1, section 1	*Carpophyllum plumosum*
		Caulerpa flexilis
		Plocamium (fine)
		Sargassum sinclairii
		Blades - ??
2-Nov-17	Stream & coast – Waipu Stream	*Acrosorium ciliolatum*
		Gelidium caulacantheum
		Hymenena?
		Plocamium (2)
		Small red blades –
13-Dec-17	Waipu Area 1	*Carpophyllum flexuosum*
		Plocamium (fine)
	Waipu Area 2	*Carpophyllum flexuosum*
		Carpophyllum plumosum
	Waipu Area 3	*Carpophyllum plumosum*
16-Jan-18	Waipu Area 1 – beach & water	*Plocamium*
		Spyridia filamentosa
20-Jan-18	Whangarei Harbour - in balls/clumps	*Polysiphonia* – 4 pcc
		Stylonema alsidii
22-Jan-18	Langs Beach – southern end	*Carpomitra costata*
		Carpophyllum angustifolium
		Carpophyllum maschalocarpum
		Caulerpa flexilis
		Cladhymenia oblongifolia
		Ecklonia radiata
		'Gigartina' atropurpurea
		Gigartina macrocarpa
		Melanthalia abscissa
		Plocamium sp.

		Polysphonia sensu lato
		Pterocladia sp.
		Pterocladiella capillacea
		Sarcothalia marginifera
		Ulva blade
		Xiphophora chondrophylla
		Mixed reds – very fine
		Fragments of delesserians
22-Jan-18	Waipu	*Carpophyllum maschalocarpum*
31-Jan-18	Waipu	*Plocamium*
		Spyridia filamentosa
25-Feb-18	Ruakaka surf/beach – all samples deteriorated – so discarded	*Plocamium*
	10 x 50m band free floating algae	*Spyridia filamentosa*
	10knit easterly (onshore) winds 0.5m wave height	*Polysiphonia* (very fine)
		Cladophora sp.
		Erythroglossum undulatissimum
27-Feb-18	Shelly Beach - water sample	*Spyridia filamentosa*
		Chondria lyallii
		Ecklonia radiata
		Erythroglossum undulatissimum
		Falkenbergia rufolanosa
		'Halymenia' sp.
		Plocamium sp.
		Polysiphonia (very fine)
27-Feb-18	Shelly Bay shore sample (many as small fragments)	*Carpomitra costata*
		Carpophyllum angustifolium
		Carpophyllum maschalocarpum
		Cladhymenia lyalli
		Dictyota sp.
		'Gigartina' atropurpurea
		Gigartina sp. (small, tufted)
		Gracilaria truncata
		Hymenena sp.
		Jania sp.

		Melanthalia abscissa
		Psilophycus alveatus
		Rhodophyllis sp.
		Rhodymenia sp.
		Sarcothalia marginifera
		'Sarcothalia' decipiens
		Vidalia colensoi
		Xiphophora chondrophylla
		Zonaria turneriana
		Seagrass fragments
17-May-18	Waipu Surf Club	*Acrosorium ciliolatum*
		Carpophyllum plumosum
		Chondracanthus chapmanii
		Dasya sp.
		Dasyclonium sp.
		Falkenbergia rufolanosa
		Jania sp.
		Jania sagittata
		Spyridia filamentosa
17-May-18	Waipu Stream	*Caulacanthus ustulatus*
		Falkenbergia rufolanosa
		Hymenena variolosa
		Plocamium sp.
		Spyridia filamentosa

Appendix C Questionnaires

Table B1. Questions and responses:

Question	Reponses		
When did you first notice large accumulations of macroalgae on the beach (please name which beaches you have observed this at), and over how many years?	2005 – 2017, mainly at Waipu Cove but depending on the wind/current direction the algae would also accumulate at: Shelly Beach (400m south of Waipu Cove), Ding Bay (2.5km south of Waipu Cove), Langs Beach (3km south of Waipu Cove)	December, 2012	January 2013, Waipu Cove
Do you recall any historic events (20+ years ago)?	I have been a surf lifeguard at Waipu Cove since 1978, in the early eighties there were several years of algal blooms but these tended to be offshore and extended in length for several kilometres.	No	I have been coming to Waipu Cove since 1977 and had not come across this weed or heard it referred to in that time. At times after severe storms there have been large accumulations of "ordinary" seaweed (neptunes necklace, kelp etc) over that time.
What time of year have these occurred (please be as accurate as possible but don't guess if you are not sure)?	Over the past 7 years these accumulations have not occurred before mid December and have carried on through January and often into February	December and gone by April	Generally early January 2013 prior to 09/01 2014 early Jan 2015 early Jan 2016 ~Boxing Day (2015) 2017 New Years Day 2018 Xmas eve (2017) One time the weed appeared in significant amounts in November but didn't finish up on the beach.
Have there been occasions when there are large quantities in the water but it hasn't come ashore?	this is the first time the algae has been very late in the summer and has NOT come ashore in any significant amount.	Yes, plenty of times	Yes there have been a several times a year when there have been patches in the water that never finished up on Waipu Beach sometimes disappearing towards Langs sometimes towards Uretiti

At what point do you consider that the drift accumulation is more than regular/natural drift coming ashore? When does it constitute a nuisance or beyond the normal range - is it the volume of the material, how far it stretches up the coast?	• When it interferes with swimming, surfing and other water activities • Yes it is very detrimental to all beach users, not only is it unsightly it gets stuck in peopls togs and is very hard to get out of your hair. • It is most definitely the density of the red algae that is damaging, it is disgusting and difficult to swim through	Volume and positioning, normally washes up on the beach right in the Cove in high beach usage area	When it clogs the Waipu stream, when people won't enter the water and avoid coming to the cove, when the smell of rotting pervades the beach and surrounds.
Have you notice accumulations at other beaches? If so, has this occurred at the same time or not?	• Because of the prevailing North - South ocean drift the algae normally ends up accumulating in the southern end of Bream Bay, Waipu Cove. It has been to Ruakaka Beach and as far north as Oakura Beach. it depends on the prevailing wind and the ocean currents at the time.	Waipu, Lang's and Shelley beach, often if conditions are right it moves down to Ruakaka	Langs Beach, Ruakaka, Uretiti sometimes occurring at the same but usually at different times.
Do the accumulations differ in appearance - have some been dominated by one type of seaweed or are they usually a mixture of different shapes/colours?	• The darkness of the algae is different at different times of the year and different years.Last year the algae was not as deep a red as the year before. There are many types of seaweed, greater than 10 varieties. They are different shades of dark red to light red to dar brown to light brown. Large leave algae to spindly leaves.	Mixture of species but majority is the red algae	The fine algal "bloom" constitutes the nuisance - at times the larger varieties seaweed get washed up at the same time. The larger varieties are nowhere near the same nuisance value they are easy to collect and are popular with gardeners
Do you have the impression that the accumulations are associated with particular weather conditions or sea state?	Yes. Until this year I believed it was thicker when the water temperature warmed up traditionally mid-December. This year the water was warmer much earlier but we had no algae. My observation from this year compared to earlier years is that if the water is exceptionally clear i.e. 'blue water' there is little or no algae. This was the case this year we had the warm blue water come in much earlier. In conclusion the dirtier the water, the algae increases dramatically. The water at Mangawhai Heads is very clear at the moment and there is no sign of algae - 12 km away.	Yes, wind and current if on-shore it seems to wash up	My impression is that periods of sunshine and warmth after it initially appears in non nuisance levels encourage rapid proliferation. Often a weather event will push it into the shallows and then small lapping waves and tide action deposit it on the beach. The mass may hang around and decompose, lingering for weeks or it can "disappear" from one tide to the next.

How often/ have you complained or contacted the council relative to the number of accumulation events that have occurred?	I did notify council several times and assisted with the clean up	We have removed from the beach approx. 8 - 10 times over the past 5 years with approval from NRC. WDC and NRC receive numerous complaints through their environmental hotline	4/5 of major accumulations
How long do the accumulations remain on the beach?	They remain until the next high tide or the next heavy on/off shore wind.	Depends on weather conditions, if constant will remain on beach for 7 – 10 days until conditions change	Days to weeks
Are there any weather conditions that help remove the algae from the beach?	Off shore winds have generally kept the algae approximately 3-400metres off the beach Any wind that blows from a southerly direction keeps the algae away from Langs Beach and Waipu Cove A N or NE blow tends to take the algae back out to sea.	Off shore winds and large swells + currents	Long-shore drift tends to concentrate the weed in the corner from the surf club to the little stream. Depending on tide wind and surf conditions it will then move around the corner or back up the beach towards the Waipu river
Do you have any sense of the impact of the accumulations - on the beach, water quality in the neighbouring beach (how far out to sea do algae float in the water before they are washed up), on people using the beach, businesses...Have there been any attempts (successful or otherwise) to remove material - if so, what has worked/not worked?	Local farmers have removed considerable quantities over the past summers. This has worked. The algae tends to sit offshore at certain wind/tide conditions and may not wash ashore unless conditions are right. I have seen the algae up to 6-700mm in depth extending 250m up the beach from the rocks to the surf lifesaving club. I regularly swim from Waipu Cove to Langs, and with the exception of this year, there has been algae on the ocean floor throughout the swim at approximately 6 metres of depth.	Yes it impacts local businesses (café, camping ground and dairy), beach users, surf club with how/where they position there flags, they often have to move far down the beach so people do not swim between flags as to far to walk. Algae removed from beach using local farmers with great success but large cost up to $15k for one removal (300 tonne)	The impact is immense on visitor numbers, beach usability, the surrounding residential area. The initial response was the WDC with a digger to release the decomposing material from the stream on the outgoing tide back to sea where it dispersed quite effectively. In subsequent years the Reserve Board has organised a bobcat to stockpile the material on the beach and diggers to load onto farm trailers to dump on local farmers land. Significant quantities were moved. At times the material has been removed by another weather event.

Appendix D NRC Incident reports

Data extracted from NRC reports provided a picture of the timing and frequency of incidents being reported to NRC staff by members of the public.

Most recorded reports have been since 2010, although there were reports in 1999, and 2001 (Figure D1). The majority of incidents occurred in summer from December, and tailing off by April (Figure D2).

The reasons for people to report events to NRC staff were categorized as: “odour; discolouration and foams/scums in water; other coastal incident; other water incident”. These figures do not give an indication of the severity of the event being reported.

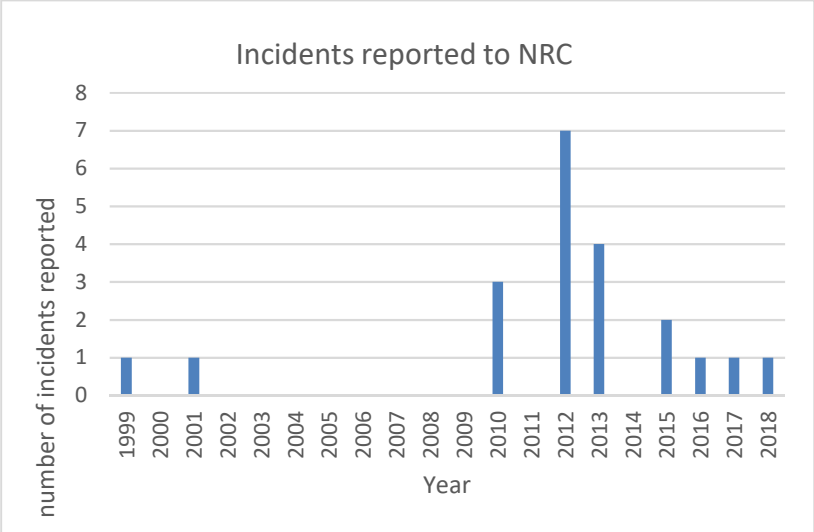


Figure D1. Number of incidents report by year

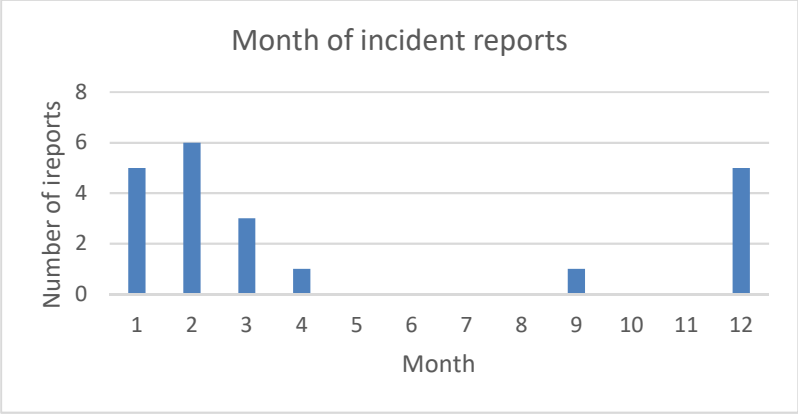


Figure D2. Number of incident reports by month

Appendix E Wind Data

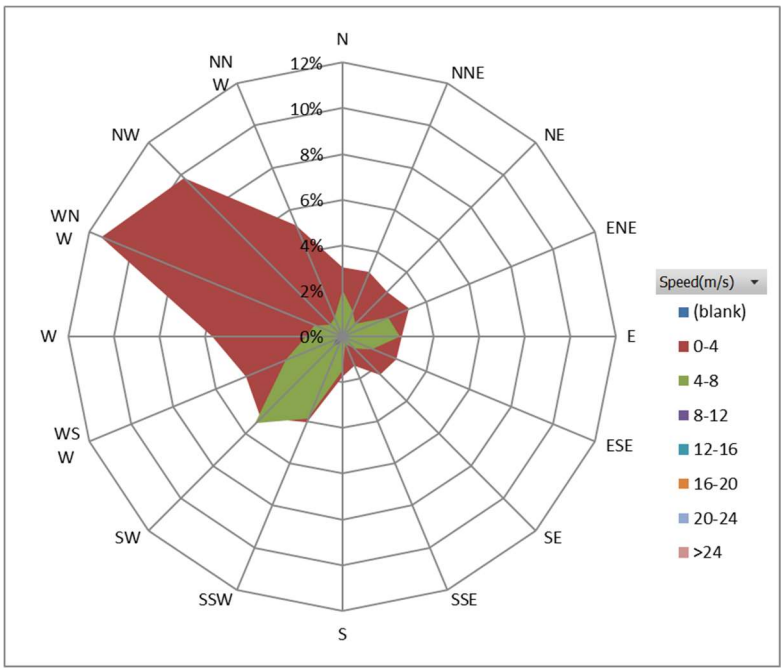


Figure E1. Whangarei Aero Aws Metservice – 1/01/2010 - 31/12/2010

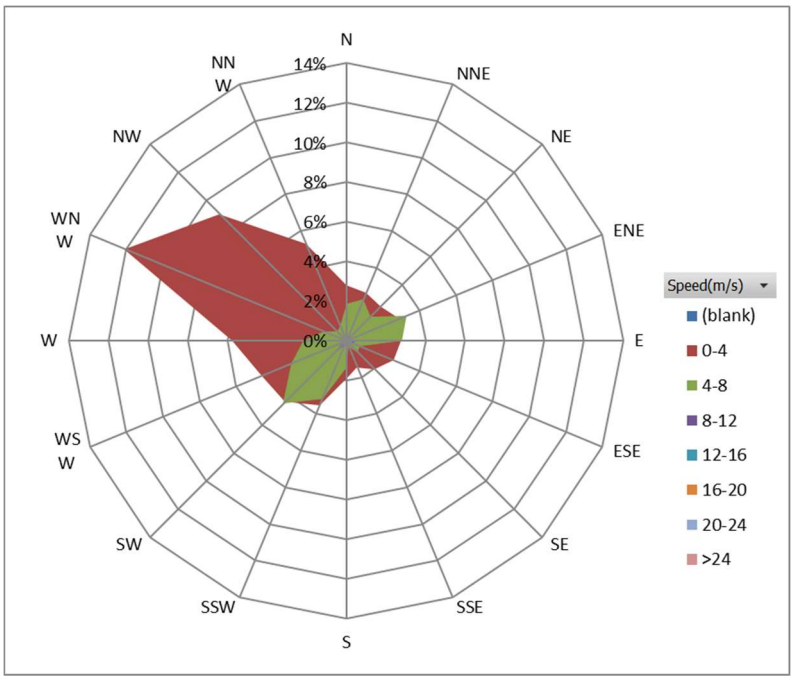


Figure E2. Whangarei Aero Aws Metservice – 1/01/2011 - 31/12/2011

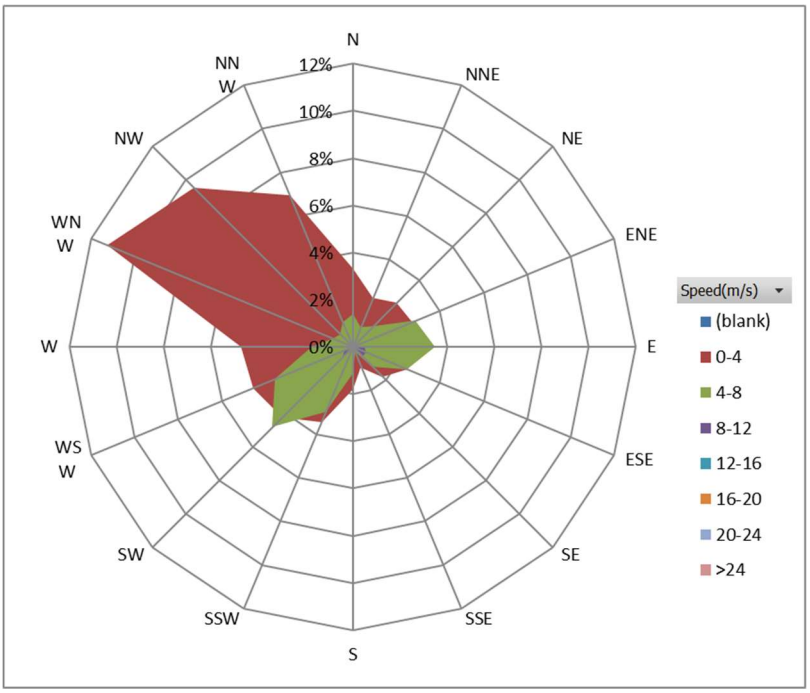


Figure E3. Whangarei Aero Aws Metservice – 1/01/2012 - 31/12/2012

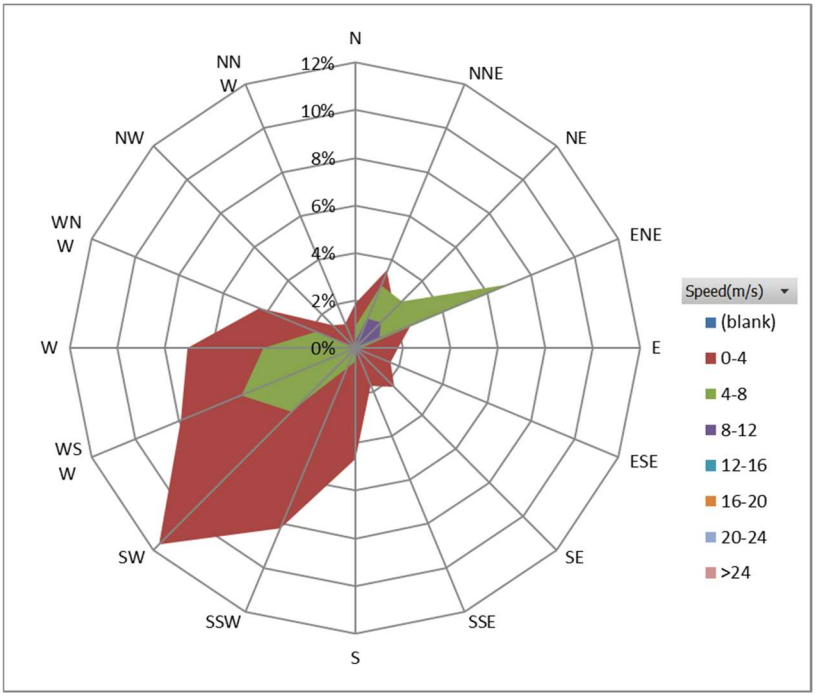


Figure E4. Leigh 2 Ews - 1/01/2013 - 31/12/2013

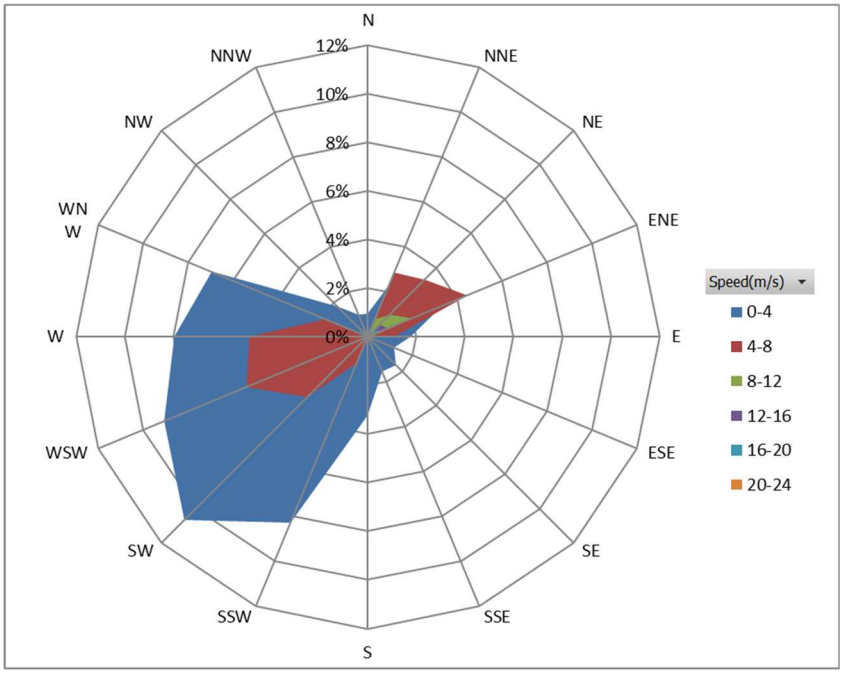


Figure E5. Whangarei Ews NIWA – 1/01/2014 - 31/12/2014

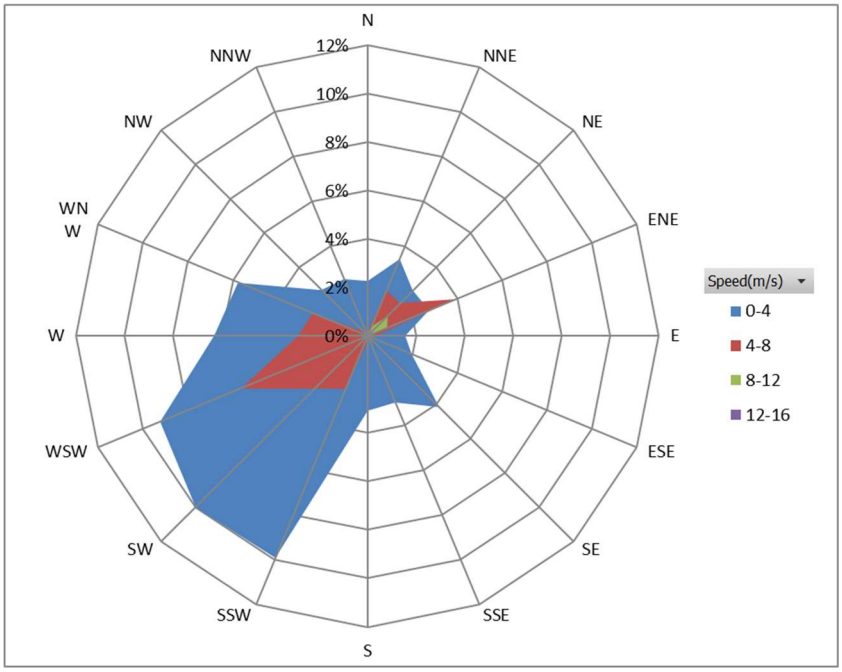


Figure E6. Whangarei Ews NIWA – 1/01/2015 - 31/12/2015

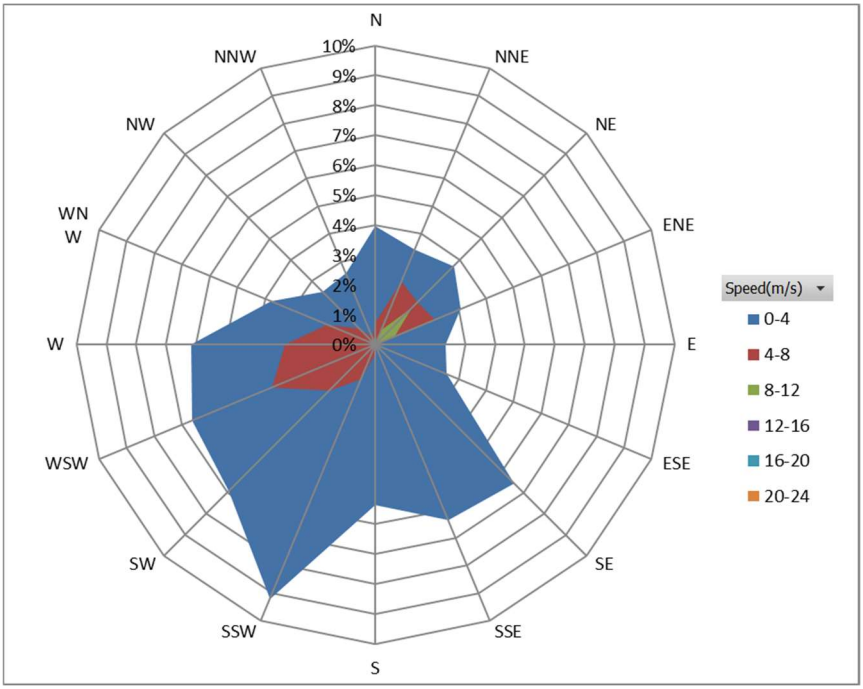
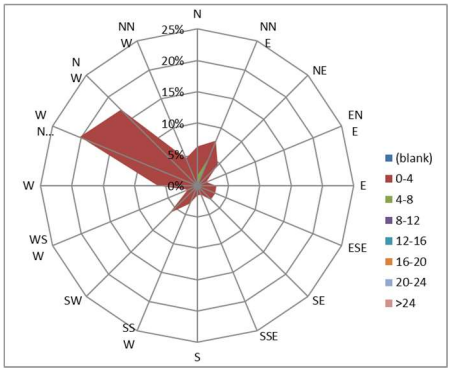


Figure E7. Whangarei Ews NIWA – 1/01/2016 - 31/12/2016

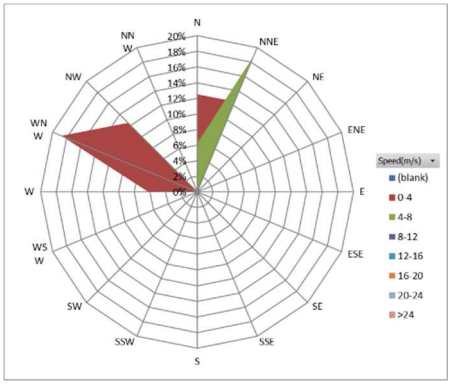
Appendix F Photographs

21 February 2012 - NIB visit, Black/Grey water near the outlet onto the beach.

Whangarei Aero Aws Metservice – 14-21 Feb 2012



Whangarei Aero Aws Metservice - 20/02/2012 - 21/02/2012

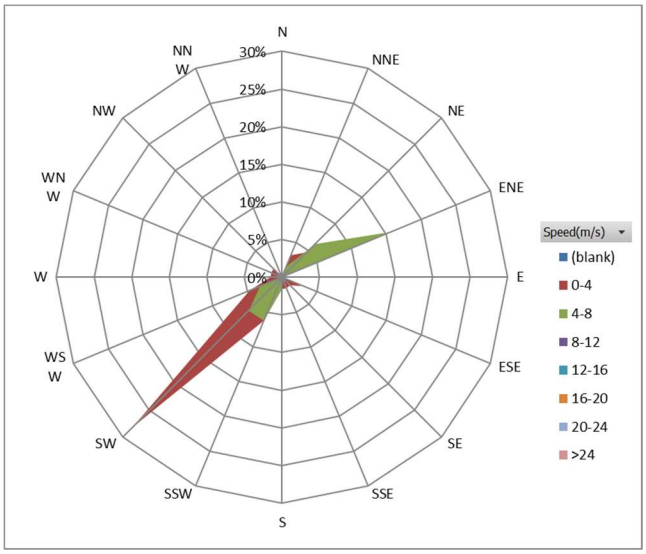


20 February 2013 – Joey McKenzie - Seaweed on beach looking south – note bleaching on top of seaweed mat

20 February 2013 – Seaweed on beach looking north

20 February 2013 –Inside seaweed matt

Leigh 2 Ews - 13/02/2013 - 20/02/2013



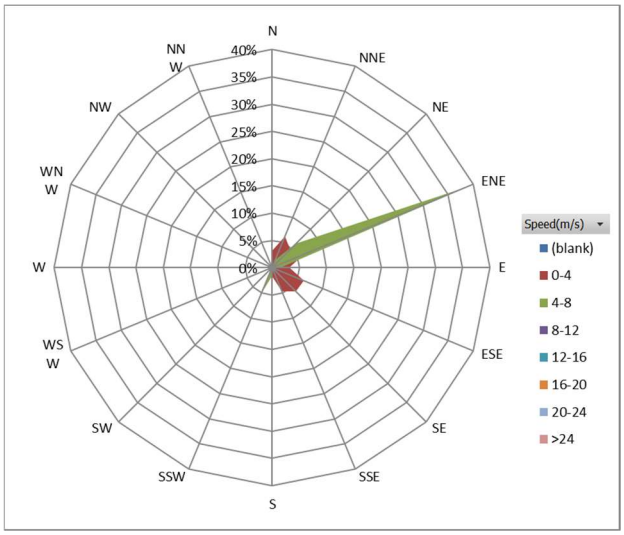
25 February 2013 – site visit, looking towards the Waipu Cove Stream, some mats of algae are visible along the high tide line.

25 February 2013 – site visit, *Carpophyllum* sp. and other brown species present also

25 February 2013 – site visit, matted algae containing green species.

25 February 2013 – site visit, internal area of red clumping algae, prominent in areas closer to the stream end of the beach.

Leigh 2 Ews - 18/02/2013 - 25/02/2013

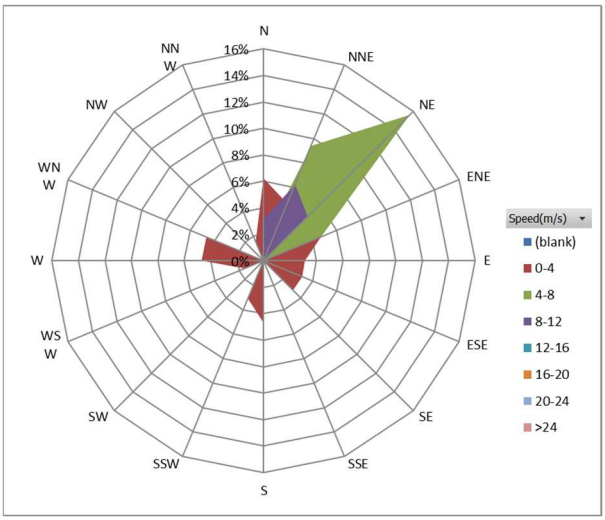


4 March 2013

18 March 2013

18 March 2013

Leigh 2 Ews - 11/03/2013 - 18/03/2013

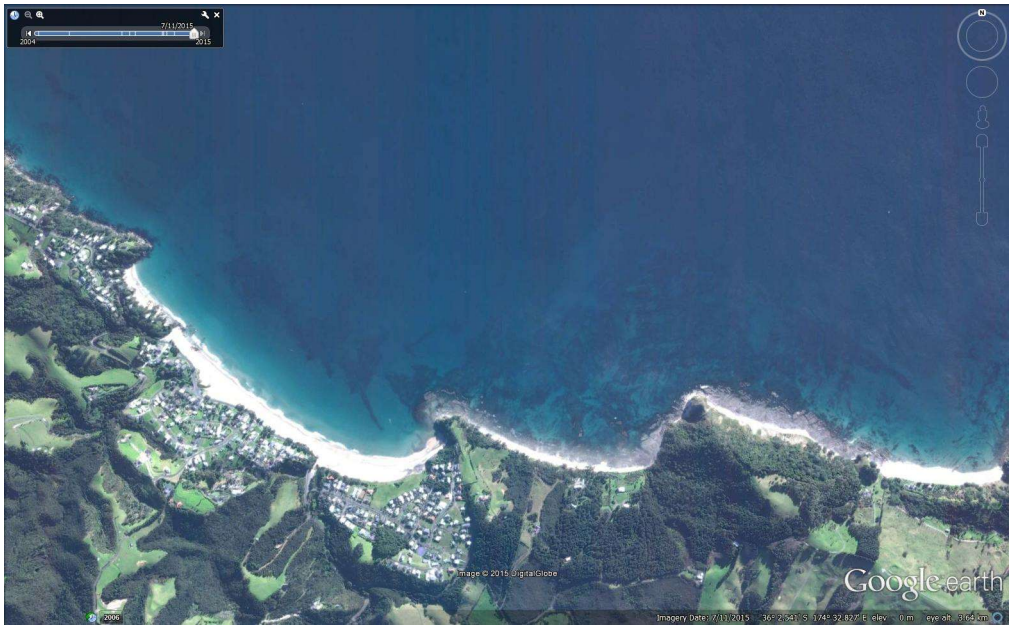


21 April 2014 - Langs Beach

21 April 2014 - Langs Beach

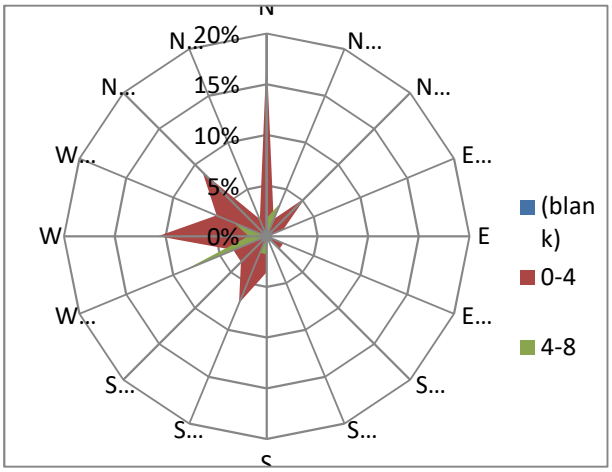
21 April 2014 - Langs Beach

July 2015 - Waipu (Nick Shears from Google Earth)

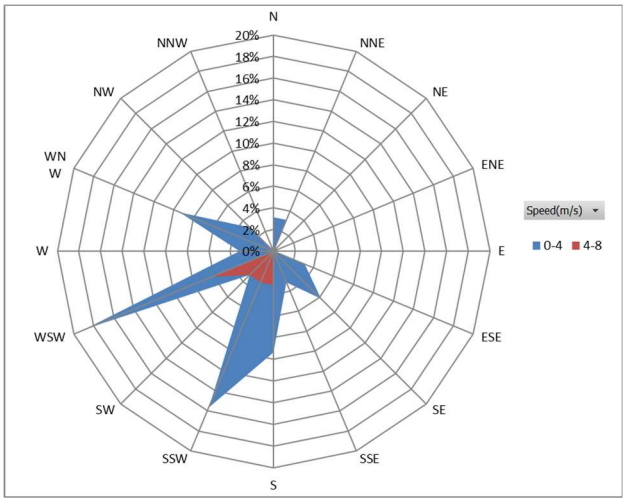


6 September 2015 – Waipu Cove, Susan Botting

Whangarei Ews Niwa – 31/08/2015 - 6/09/2015



Whangarei Ews Niwa – 5/09/2015 - 6/09/2015



17 November 2015 – Anton Trist

22 November 2015 – Richard Griffiths

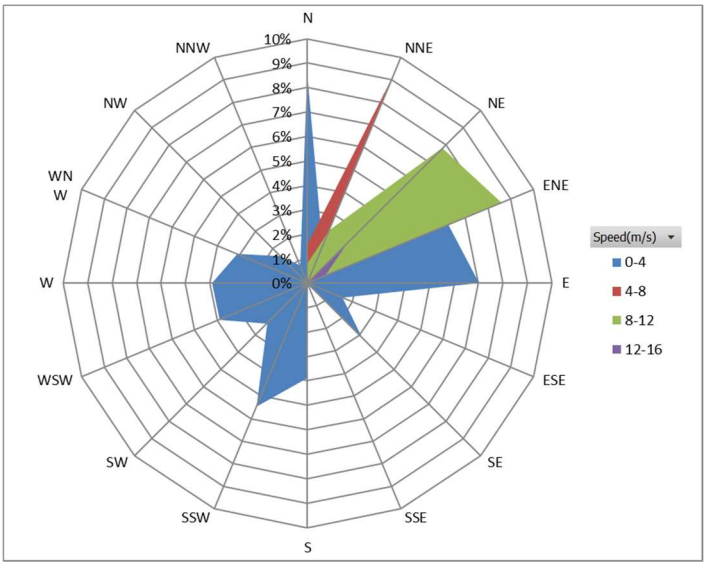
22 November 2015

14 December 2015 - Penny Johnston

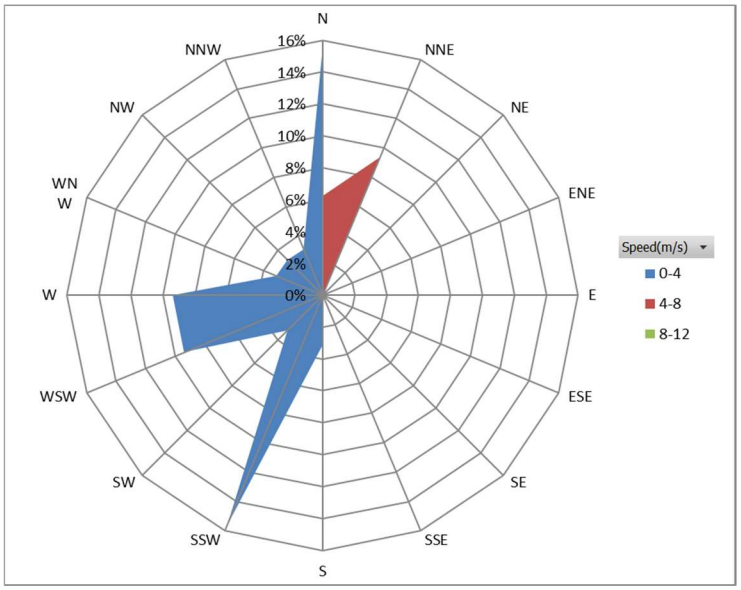
9 January 2016 – Anton Trist

9 January 2016

Whangarei Ews Niwa – 2/01/2016 - 9/01/2016



Whangarei Ews Niwa – 8/01/2016 – 9/01/2016



10 January 2017 – Nick Bamford

11 January 2017 – Richard Griffiths

8 August 2017 - Waipu River – confirmed sightings of algae

8 August 2017 - Waipu Cove Beach and Stream