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Spatial distribution and seasonal variation in *Undaria pinnatifida* populations around the Coromandel Peninsula

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A report prepared for the Waikato Regional Council

1. Executive Summary

Undaria pinnatifida (hereafter called *Undaria*) was first officially recorded in the Hauraki Gulf, on mussel farm infrastructure in the Firth of Thames, in 2002, and subsequently at Hobson West Marina in the Waitemata Harbour in 2004. The warmer waters of the Hauraki Gulf had been considered to be outside the optimal range for *Undaria* growth. However, this has proven to be inaccurate. Prior to this report no quantitative information was available on the distribution or ecology of *Undaria* populations in the Coromandel region.

Between November 2011 and February 2012 spatial surveys were carried out to investigate the distribution of *Undaria* populations and the level of infestation present on mussel farms and adjacent coastal sites around the Coromandel Peninsula. In addition, beginning in June 2011 *Undaria* populations were monitored monthly at two sites within Coromandel Harbour and fortnightly at two sites at Westhaven Marina in the Waitemata Harbour.

Sites where mussel farms are established provide suitable habitat for *Undaria* growth. The water quality, flow and nutrient levels required for mussel farming are in line with ideal *Undaria* growing conditions and the well-illuminated, artificial structures promote *Undaria* establishment without competition from other macroalga. A survey of *Undaria* was conducted across all mussel farm sites and large areas of adjacent coastline around the Coromandel Peninsula. Further areas of interest surveyed were high use public boat ramps, swing moorings, Hannaford's Jetty and the mussel loading facility at Te Kouma. At each site environmental data was collected and information on *Undaria* population structure and density were recorded. Other invasive species present were also recorded.

Undaria was found to be widespread on mussel farms around the Coromandel Peninsula. It is well established on mussel farm structures from Moturua Island to Wilson Bay on the west coast of the Coromandel Peninsula. Although not prevalent, during this survey, on mussel farms at Kennedy Bay or Port Charles, *Undaria* was found on artificial substrate at these sites. Thirty one mussel farms were surveyed, levels of *Undaria* infestation were defined as low to medium (1-100 plants per 50 m length of mussel line) on seventeen, high (>100 plants per 50 m of mussel line) on eleven and *Undaria* was not seen on three farms. Higher density populations were found at poorly maintained mussel farms and on mussel lines with large mussels, 80-120mm. The exception to this was the high densities of *Undaria* at all mussel farms surveyed at the Wilson Bay Marine Farming Zone (WBMFZ) in the Firth of Thames, a well maintained site. The vigour and density of the population seen within the WBMFZ, by far the largest aquaculture site surveyed, may be due to the fact that this is the most long-established population. The size and nature of the WBMFZ ensures a constant and immense supply of spores at this site. This high propagule pressure is likely to perpetuate the dense population at this site despite differing stages of mussel growth and line/float rotation at individual farms within the site. Further investigation into environmental influences could reveal other factors promoting the growth and proliferation of *Undaria* at this site. *Undaria* is likely spread between mussel farms, in its sporophyte or microscopic gametophyte phase, via fouled mussel barge hulls, mussel farming equipment (such as ropes and floats) and with mussel spat.

Undaria has not extensively invaded coastal reef areas adjacent to mussel farms. Approximately 12km of coastline adjacent to mussel farms was surveyed around the Coromandel Peninsula. *Undaria* was found at six out of the twenty six coastal sites surveyed. This is the first time Undaria has been recorded on the Coromandel Coast. Total numbers recorded at any coastal site were between two and fifty plants, including reproductively mature plants. Relatively low densities at coastal sites could reflect poor dispersal to coastal sites, high levels of predation and competition in these areas, insufficient time to allow extensive populations to establish in these coastal reef communities, or seasonal lows due to the timing of some of the surveys.

No *Undaria* was found at the mussel loading facility/boat ramp at Te Kouma, the swing mooring sites at Windy point/Puhe Rare and Takawhare Bay, Hannaford's Jetty or the two other boat ramp sites surveyed at Colville and Waikawau.

Monitoring studies found *Undaria* plants to be present, at varying densities, on Coromandel Harbour mussel farm structures and at Westhaven Marina year round (June 2011 to July 2012). The cycle of plant growth and density was related to water temperature. Size and density of *Undaria* plants increased steadily from June through until late October/early November when plant lengths and the presence and volume of sporophylls peaked. This peak in plant size and reproductive maturity coincided with water temperatures reaching ~17ºC. Average length then showed a steady decline, as the mature plants degraded, with the shortest average lengths recorded at Coromandel and at Westhaven in

late February when water temperatures peaked. In general the Hauraki Gulf temperatures recorded fall above the optimum *Undaria* growing conditions from November to May but still remain within the known range for sub-optimal growth and reproduction. Individual plants did not live for an entire year but overlapping generations occur with a continual recruitment and replacement of individuals. *Undaria* follows a distinct pattern of rapid recruitment and growth during the cooler months of winter-spring.

Results indicate that the warmer waters of the Hauraki Gulf may produce smaller plants with a slower growth rate than those found in cooler waters.

The impact of *Undaria* on mussel farming activities and on native rocky reef flora and fauna has not been examined in the Hauraki Gulf. The dense populations of large plants seen at the WBMFZ and on the four other heavily infested farms surveyed could potentially have strong impacts on light availability, nutrient cycling and food availability for the mussels being grown on these farms. It appears that careful and regular maintenance of existing mussel farms and associated equipment will help towards mitigating these potential impacts as well as minimising the spread of *Undaria* to coastal areas and new marine farms.

It is apparent that introducing mussel farm infrastructure to a site will likely result in the introduction of *Undaria* that site. If mussel farms are to be placed in High Value Conservation sites or sites near marine reserves it must be taken into consideration that *Undaria* will then be introduced to these sites. Coastal reef sites at risk of *Undaria* colonisation may be those with impaired or reduced native algal canopies or abundant natural open spaces, on reefs or rocks, in the shallow subtidal zone. We recommend that further monitoring and research be carried out around the Coromandel region to more accurately ascertain the extent of *Undaria* infestation around the Coromandel Coast and determine the factors influencing the abundance of *Undaria* at marine farming and coastal sites. Annual monitoring of *Undaria* populations could help understand the spread of populations and the potential risks to coastal environments and native species.

Two other invasive species were prevalent on mussel farm structures. The clubbed tunicate *Styela clava* was found on all the mussel farms surveyed and the green seaweed *Codium fragile ssp. tomentosoides* was present on twenty eight out of the thirty one farms surveyed. The Asian paddle crab *Charybdis japonica* was found at two coastal sites.

2. Introduction

Undaria pinnatifida (Harvey) Suringar is a large laminarian kelp. *Undaria* is an annual with several different life stages. It was introduced to New Zealand waters in the 1980's by Asian fishing vessels (Parsons, 1994; Verlaque, 2007). *Undaria* is known to have direct negative impacts on indigenous biota and it can change the entire structure of marine ecosystems (Ministry of Fisheries [MoF], 2001; Neill, 2008; Stuart, 2004). A single *Undaria* plant can produce one hundred million zoospores (Akiyama and Kurogi, 1982), meaning the establishment of a single mature plant is enough to found a vigorous new population (Hay and Luckens, 1987). *Undaria* grows rapidly in favourable conditions and can form dense mono-specific stands, allowing it to out-compete native species (Russell et al, 2008; Verlaque, 2007). *Undaria* has the potential to displace macroalgae (e.g. *Carpophyllum mascalocarpum,* and *Cystophora species*) and other native species such as paua (Hay and Luckens, 1987; Hay, 1990; MoF, 2001; Stuart, 2004), alter habitat for commercial species such as mussels, disrupt aquaculture activities, and may affect the cultural values of some marine sites (Cecere et al, 2000; Henkel and Hofmann, 2008; MoF, 2001; Neill, 2008; Russell et al, 2008; Sinner et al, 2000; Verlaque, 2007). Although *Undaria* can survive and reproduce at temperatures between zero and thirty degrees Celsius (Floc'h et al, 1991), growth of *Undaria* sporophytes (hereafter called plants) is optimum at 15-17 °C with growth continuing slowly to 20°C (Saito, 1975).

Since its detection in Wellington in 1987 (Hay & Luckens, 1987) *Undaria* has spread rapidly around New Zealand coasts. Vessel hulls and aquaculture equipment are known to be the main dispersal pathways (Hay, 1990; Neill, 2008; Russell et al, 2008; Sinner et al, 2000; Verlaque, 2007). *Undaria* is now widespread around most of New Zealand's eastern and southern coastlines from Auckland to Bluff (Neill, 2008; Russell et al, 2008; Verlaque, 2007).

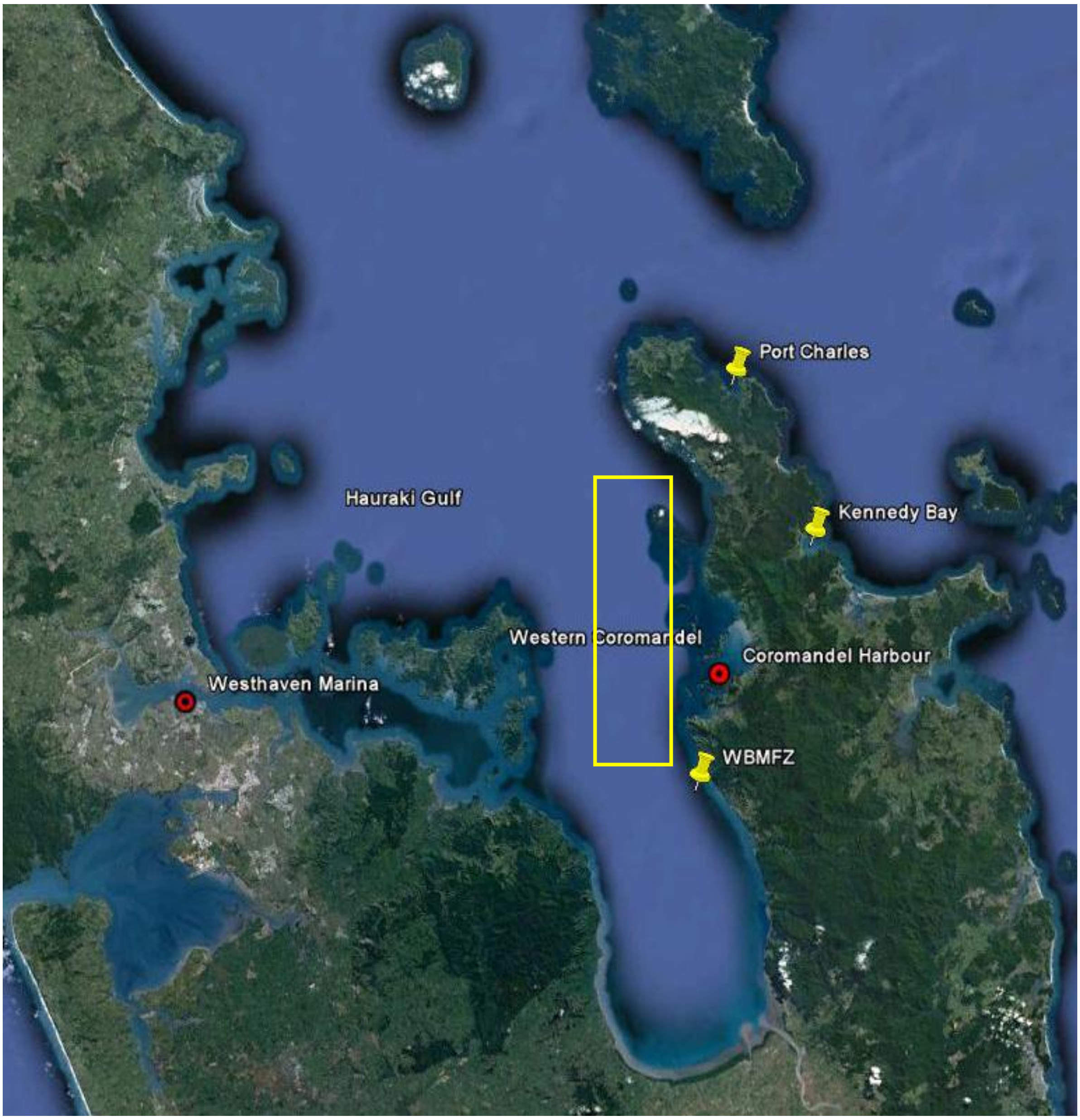
Undaria was first officially recorded, on mussel farm infrastructure, in the Firth of Thames in 2002 (Stuart, 2004). Mussel farmers report the presence of *Undaria* in the Firth of Thames since 1999 (Jessop, 2006). It was officially recorded in the Waitemata Harbour at Hobson West marina, in 2004. A subsequent investigation into the distribution and density of this population by Stuart and McClary (2004) concluded *Undaria* had at that time been present in the Waitemata Harbour, including Westhaven Marina, for 3-4 years. Quantitative data on the extent and nature of *Undaria* populations in the wider Hauraki Gulf including the Coromandel area are currently lacking. The potential exists for this highly invasive species to spread to regions regarded as having high conservation values such as marine reserves and Hauraki Gulf Islands (MoF, 2001; Neill, 2008). The impacts of *Undaria* are not well understood, but are expected to vary considerably depending on the location (MAF, 2010; Parsons, 1994). Data on the distribution and biology of *Undaria* in the Hauraki Gulf is necessary to determine the risks of future spread, the potential impact on environmental values and on marine farming, and in general to inform management decisions regarding this invasive species.

The present study has two main objectives:

1. **Investigate the spatial distribution of *Undaria* populations and levels of infestation on mussel farms and adjacent coastal sites around the Coromandel Peninsula.**
2. **Investigate seasonal variation in the structure and biology of *Undaria* populations at sites around the Coromandel Peninsula and at Westhaven Marina in the Waitemata Harbour. Sites at Coromandel and Westhaven were monitored from June 2011 to July 2012.**

The first objective was investigated by carrying out field surveys on mussel farms and areas of coast adjacent to mussel farms between November 2011 and February 2012 (Figure 1). The second objective was examined with monthly monitoring of *Undaria* populations on two mussel farms in the Coromandel Harbour and fortnightly monitoring at Westhaven Marina. Areas around the Coromandel with high boat traffic such as swing mooring sites and boat ramps were also surveyed in order to gather information around the potential mechanisms of spread of *Undaria.*

Figure 1: Main study locations for *Undaria* in the Hauraki Gulf. Red symbols indicate monitoring sites at Coromandel Harbour and Westhaven Marina. Yellow symbols indicate areas where *Undaria* surveys were carried out including the large western Coromandel area (yellow box), which includes the Wilson Bay Marine Farming Zone.



3. Methods

3.1. Spatial distribution survey

The starting point for this survey was mussel farm structures. Mussel farm locations were identified from Waikato Regional Council survey maps and although not all individual mussel farms could be surveyed at least one farm at each geographic grouping of farms was inspected. The possible spread of *Undaria* from mussel farm infrastructure to adjacent coastal reef systems was examined by surveying coastal sites adjacent to every mussel farm or group of mussel farms around the Coromandel Peninsula. Mussel farms and adjacent reef habitats were accessed from the University of Auckland research vessel *R.V. Hawere*. A combination of snorkelling and diving observations were used as required.

Other "high risk" areas for *Undaria* colonisation are those frequented by recreational and commercial boat traffic (Hay and Luckens, 1987; Hay, 1990, Russell et al, 2007; Verlaque, 2007). Areas with high boat traffic such as swing mooring sites and boat ramps were surveyed. In-water surveys were carried out at most sites. Some shore and kayak based inspections were also carried out.

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3.1.1. Mussel farm locations

The mussel farms around the Coromandel Peninsula were split into twelve survey locations. Ten locations are on the western side of the Peninsula and the other two are on the eastern coastline at Kennedy Bay and Port Charles (Figure 1). Survey locations comprised between one and seven mussel farms, except for the Wilson Bay Marine Farming Zone (WBMFZ) in the Firth of Thames which comprises more than 150 mussel farms in 1250ha of water approximately two kilometres offshore. Operational details and site maps for the eleven smaller locations were supplied by the Waikato Regional Council. A site map of the WBMFZ was supplied by the Sealord Marine Farms manager. These details were used to contact mussel farm owners and/or operators to ensure access was approved before visiting farms. Some farms could not be accessed due to operational reasons. Of the 53 individual mussel farms listed at the eleven smaller locations a total of 24 farms were surveyed. Seven representative farms were surveyed within the WBMFZ.

For each farm surveyed the outermost lines at each end of the mussel farm and a selection of inner lines were assessed. Mussel farm size was typically ten to sixteen lines and at least three lines at every farm were surveyed. The numbers of mussel lines surveyed at each farm was generally relative to the total number and size of lines present. However, some farms were surveyed less thoroughly than others due to poor weather conditions and some farms did not have lines in the water at the time of surveying. Farms with bare lines were not surveyed.

Surveys of lines were conducted on snorkel and/or SCUBA. Effort was concentrated near the surface as the vertical distribution of *Undaria* has been found to be mostly at the surface layers on artificial structures such as marine farms (Chen, 2012; Duder, 2009; Hay and Luckens, 1987; Hay and Villouta, 1993; Jessop, 2006). At each farm surveyors swam the length of each designated mussel line, on or near the surface, noting the presence and density of *Undaria* per fifty metre length of mussel line. Most mussel lines were approximately 100m long so comprised two transects each. A total of 268 transects were run along 132 mussel lines at 31 different mussel farms. Notes were taken on the size distribution and reproductive status of the *Undaria* surveyed at each line. The presence of other invasive species was also noted. Representative photographs were taken of *Undaria* and/or other invasive species present. A minimum of five mussels were measured on every line surveyed and the average mussel size was calculated for each of these lines.

Surveys of farms were carried out between November 22nd 2011 and February 3rd 2012. To examine the potential for differences in timing of surveys to influence the presence or infestation level of *Undaria* some farms were visited on both November and February sampling trips.

3.1.2. Coastal reef locations

Contiguous 50 x 10m transects were run along sections of coast adjacent to all mussel farm locations on the Coromandel Peninsula. A total of twenty six coastal reef areas were surveyed via SCUBA and/or snorkel. In New Zealand, *Undaria* populations that occur on native reef habitats are typically densest from the low intertidal fringe down to approximately three metres (Brown and Lamare, 1994; Parsons, 1994; Sinner et al, 2000; Stuart, 2004; Russell et al, 2007). Much of the reef adjacent to the farms in the western Coromandel is relatively shallow, with a sand-reef border at depths of less than 5m and a limited offshore extent of 15-30m. Sampling was concentrated on the shallow-subtidal margin of the reef, typically just below the low-tide mark. The depth of the surveys conducted ranged from one to five metres, depending on habitat and tide levels, with an average depth across the total 244 transects of 2.4m. In the case of the WBMFZ, where there is more than five kilometres of adjacent coastline, five coastal sites were selected where subtidal reef habitat occurred that could potentially be colonised by *Undaria*. A total of 2250 meters of this adjacent coast was surveyed. The nature of the benthic environment and algal species present was recorded for each 50m transect. The presence of other invasive species was noted.

Surveys were carried out between November 22nd 2011 and February 3rd 2012. To examine the potential for differences in timing of surveys to influence the presence or infestation level of *Undaria* two sites where *Undaria* was recorded in November were revisited in February and *Undaria* populations were qualitatively compared.

3.1.3. Other “high risk” locations

In order to investigate the potential spread of *Undaria* by recreational vessels, seven “high risk” sites of interest were surveyed in February 2012. These were comprised of two swing mooring sites in the Coromandel Harbour at Takawhare bay and Windy Point/Puhi Rare, three boat ramps; Waikawau (Thames coast), Port Charles and the Sugarloaf recreational and mussel loading ramp at Te Kouma, a set of mooring buoys in Kennedy bay and the infrastructure at Hannaford’s Jetty in the Coromandel Harbour were also surveyed. Boat ramp sites were surveyed via snorkel and/or SCUBA, surveyors searched artificial structures and surrounding coastal reef sites. The swing mooring site at Windy Point/Puhe Rare was surveyed via SCUBA, divers inspected a random subset of moorings and mussel barge hulls. The recreational swing moorings at Takawhare Bay were surveyed from kayaks, a random subset of mooring floats/lines and vessel hulls were inspected from the surface or mooring floats were lifted out of the water and inspected aboard the kayaks. The mooring buoys at Kennedy bay were inspected in a similar manner, by lifting them aboard a dinghy. At Takawhare Bay 43 out of 120 listed moorings were surveyed. At Puhi Rare 12 out of the seventy listed moorings were inspected, very poor visibility prevented more inspections at this site.

3.1.4. Semi-quantitative measurements of *Undaria* abundance

For each 50m section of mussel line or coast surveyed the number of *Undaria* plants sighted was placed in one of five categories, these are shown in Table 1:

Table 1: *Undaria* infestation categories

Category	Number of plants per 50m	Level of Infestation
0	0	None (green)
1	1-10	Low (orange)
2	11-100	Medium (orange)
3	101-500	High (red)
4	>500	Heavily infested (red)

For mapping purposes the *Undaria* categories were used to create colour coded levels of infestation (Table 1). Numbers are for *Undaria* plants per 50 of mussel line or coast surveyed: Green = no *Undaria* observed. Orange = 1-100 *Undaria* plants recorded. Red = >100 *Undaria* plants recorded.

3.1.5. Other invasive species

Direct surveyor observations as well as underwater photographs and some video records were taken at each site and used to assess the presence or absence of thirteen invasive species (in addition to *Undaria*): *Ascidiella aspersa* (tunicate), *Bugula neritina* (bryozoan), *Caulerpa taxifolia* (alga), *Charybdis japonica* (crustacean), *Ciona intestinalis* (bryozoan), *Codium fragile ssp. tomentosoides* (alga), *Musculista senhousia* (mollusc), *Polysiphonia brodiei* (alga), *Sabella spallanzanii* (annelid), *Schizoporella errata* (bryozoan), *Tubastraea coccinea* (coral) and *Watersipora subtorquata* (bryozoan).

3.2. Seasonal monitoring of *Undaria* populations

To investigate the phenology of *Undaria* populations in the Hauraki Gulf monitoring sites were set up in June 2011 on mussel farms in the Coromandel Harbour (Figure 2) and on the pontoons at Westhaven Marina in Auckland (Figure 3). Due to the different nature of these habitats the sampling methods used varied between these sites.

3.2.1. Coromandel monitoring

The monitoring site within Coromandel Harbour is located on two adjacent mussel farms (Figure 2). Mussels grown at this site are on the lines for approximately nine to twelve months, until mussels reach a size of 95-100mm when they are processed. After harvesting the floats are cleaned before re-deploying them – and they usually go back to the same site (Peter James, pers comm., 11/7/2011). Monitoring consists of boat based snorkelling along mussel lines. At both of the designated mussel farms, two mussel lines were chosen at random for inspection in June 2011. These lines were surveyed each month until the mussels were harvested. The harvesting process removes *Undaria* from the floats. So, when lines surveyed the previous month have been harvested, surveillance shifts to the nearest parallel lines with mussels present. Inspection occurs along the first ten mussel floats along the four designated mussel lines. All *Undaria* present on the mussel floats is counted and measured. Measurements are taken of the total length of the plants and the length and width of the reproductive tissue at the base of the plant, the sporophyll (if present). The submerged area of the float is approximately 1m by 1.2m. Consequently, densities are expressed on a m^{-2} basis. Data from both sites will be combined in this report. Representative photographs of *Undaria* are taken at each visit.

Figure 2: Coromandel Harbour monitoring sites

3.2.2. Westhaven monitoring

Westhaven Marina was chosen as a study site in the Waitemata harbour as it provides an easily accessible *Undaria* population to the University of Auckland. *Undaria* grows from the pontoons of the Marina. Surveys are pier based counts and measurements. Surveys have been conducted fortnightly at Pier Z and Pier W (Figure 3) since July 2011. Data from both piers will be combined in this report.

Figure 3: Westhaven Marina monitoring sites

Survey sites are at the ends of Pier Z and Pier W and consist of approximately 75m and 45m of concrete pontoon edge respectively. Surveys are carried out fortnightly. At both pier Z and Pier W. Measurements are taken of the total plant length and length and width of the sporophyll (if present) for forty random plants per survey visit. Once a month 24 random one metre sections of pontoon at pier Z and 12 random one metre sections at pier W are inspected and all *Undaria* plants to a depth of approximately 0.3m in each one metre section are counted (*Undaria* is typically only found in this depth range on the pontoons). Counts are expressed on a m^{-2} basis.

Twenty plants at each pier were tagged in July 2011, using a cable tie placed around the base of the stipe, and growth rate was monitored. Each fortnight a 5mm diameter hole was punched beside the midrib of each plant, 100mm above the blade/stipe junction and beyond the meristematic region (Stuart, 1999). The lateral displacement of the hole relative to the blade/stipe junction was then measured every two weeks to determine growth rate. This hole-punch technique is necessary due to the disintegration of the blade which occurs early in the life cycle of *Undaria* (Castric-Fey, 1999). Representative photographs of *Undaria* are taken at each visit.

3.3. Environmental data

Each time a monitoring or survey site was visited recordings were made of salinity using a Eutech Salt 6+ salinity meter and three surface water samples were taken in order to determine nitrate, nitrite, ammonium and phosphate levels. Temperature is logged at each monitoring site via a HOBO© temperature logger, a pendant suspended in the water approximately 1 m below the surface and set to log temperature every thirty minutes 24 hrs a day. Secchi depth was measured at each mussel farm in the spatial distribution survey with a standard 30 cm diameter secchi disk.

4. Results

4.1. Spatial distribution survey

4.1.1. Coastal survey

The infestation levels of *Undaria* at coastal locations surveyed on the western Coromandel Peninsula are mapped in Figure 4. *Undaria* was found at five out of the twenty six coastal reef sites surveyed from *R.V*. Hawere and one site surveyed separately from the shore (Waitataramoa bay). More detailed maps showing all sites including Kennedy Bay and Port Charles are shown in Appendix 1. Descriptions of the sites where *Undaria* was found are given in Table 2 and information on all sites surveyed is summarised in Appendix 2.

Table 2: Summary of coastal sites where *Undaria* was observed

Date	Location	GPS Co-ordinates	Number of *Undaria* plants	*Undaria* Substrate	Surrounding Habitat Description
29/7/2011	Waitataramoa bay *	36º 48’ 27 S 175º 27’ 41 E	6	Rocky reef edge at inter-tidal/subtidal boundary. Medium boulders.	Rocky reef shelf with bare rock, *Homosira banksii* and patches of coralline turf. Medium boulders with sparse *Ecklonia radiata*.
6/12/2011	Wilson Bay	36º 53’ 24 S 175º 25’ 35 E	2	Small boulders and pebble patches.	Mixed algae on boulders. Mainly *Ecklonia radiata* with *Carpophyllum flexuosum* and some *Carpophyllum plumosum*. Sand patches.
7/12/2011	Coromandel Harbour	36º 48‘ 27 S 175º 27’ 11 E	5	Inside edge of reef on rocks bordering sand flats.	Rocky boulder reef, mixed algae- *Ecklonia radiata, Carpophyllum maschalocarpum, Carpophyllum flexuosum*.
7/12/2011	Manaia Harbour (Wekarua Island)	36º 50’ 30 S 175º 25’ 17 E	3	Small boulders in open spaces inside kelp band.	Small boulders and lots of open reef Low density algae - *Carpophyllum flexuosum* and *Ecklonia radiata.*
7/12/2011 and 3/2/2012	Kirita bay	36º 51’ 49 S 175º 24’ 41 E	49	Coralline flats and on medium boulders between sand flats.	Low density mixed algal canopies –*Ecklonia radiata*, *Carpophyllum maschalocarpum* (dominant), *Carpophyllum plumosum.*
2/02/2012	Motukopake Island	36º 45’ 16 S 175º 25’ 11 E	2	Small boulders.	Small boulders with sparse Sargassum sinclairii and Carpophyllum flexuosum

*These plants were discovered outside the official survey during a separate site inspection from the shore.

Figure 4: Western Coromandel Peninsula coastal survey sites: Green paths indicate no *Undaria* was sighted and orange represents sites where *Undaria* plants were present.

Undaria was found in shallow reef habitats with easily colonisable open spaces, it was not found to be present at comparable sites with dense algal canopies. Plants were seen to be colonising areas of small to medium boulders or patches of clear rocky reef inside the subtidal algal belt or adjacent to it (low-intertidal or reef-sand border). Infestation levels were low (Category 1) at five of the coastal sites. Between two and six plants were recorded at these five sites, at each site the *Undaria* seen was clustered within one 50m transect only. A medium level of infestation (Category 2) was seen at Kirita Bay where forty-nine plants were counted. This site comprised a relatively large area (~30 x 30m) of relatively flat reef at ~mean low water that was dominated by coralline turf (*Corallina officinalis*). A sparse mixed algal assemblage, comprising *Ecklonia radiata*, *Carpophyllum maschalocarpum* (dominant) and *Carpophyllum plumosum,* occurred in a marginal subtidal fringe and sand occurred at about one meter depth.

The low densities and infestation levels of *Undaria* at coastal sites may have been influenced by the timing of surveys, with nine sites having been surveyed in February when temperatures were warmest and *Undaria* is typically at its lowest densities (see Section 4.2). However, to investigate the potential for seasonal variation to have influenced our results we revisited the Kirita site (mentioned above), where *Undaria* was reported in the November surveys, in February. All life stages of *Undaria* were seen growing here both the site visits carried out on the 7/12/2011 and 3/2/2012 (Figures 5A and 5B). *Undaria* remained prevalent on the mussel farms during February surveys, if only as large degraded sporophylls at some sites.

Figure 5: *Undaria* plantlets in coralline turf dominated habitat in the low intertidal zone (A) and mature *Undaria* sporophyte on the reef-sand border (~1m depth) (B). Kirita Bay, 3/2/12.

4.1.2. Mussel farm survey

Undaria was recorded at all of the mussel farms surveyed on the western Coromandel Peninsula (Figure 6). No *Undaria* was seen on the two mussel farms surveyed at Kennedy Bay and one of the farms surveyed at Port Charles. More detailed maps are shown in Appendix 1. The highest infestation levels were recorded at all Wilson Bay farms (>500 plants per 50m transect; Figure 7B), followed by three farms off Motukopake Island, Figure 7A, and one farm off Whanganui Island (>100 plants per 50m transect). Levels of *Undaria* infestation were defined as low to medium (1-100 plants per 50m transect) on seventeen mussel farms, high (>100 plants per 50m transect) on eleven mussel farms and zero on three mussel farms. A trend of decreasing density of plants with increasing depth was observed (Figure 7A). Although depth profiles were not taken at all sites, *Undaria* was generally seen to be most prevalent in the top two metres of water at all mussel farms. Plants were seen growing down to a depth of six metres at some sites (e.g. Motukopake and Wilson Bay).

Figure 6: Western Coromandel Peninsula mussel farm survey locations: Orange paths indicate a medium level of *Undaria* infestation and red represents sites where *Undaria* infestation levels were high. See Appendix 1 for detailed maps and maps for Port Charles and Kennedy Bay.

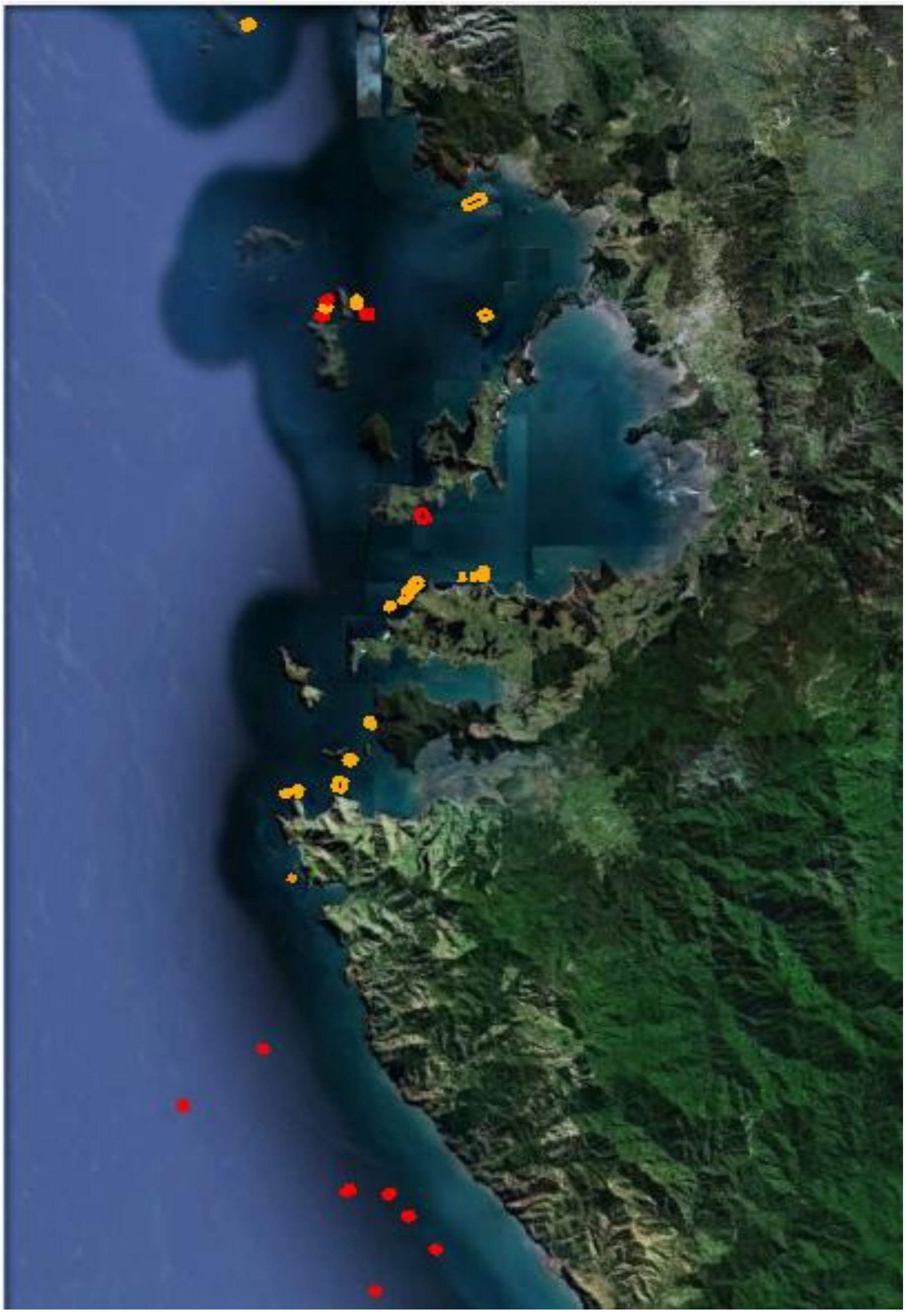
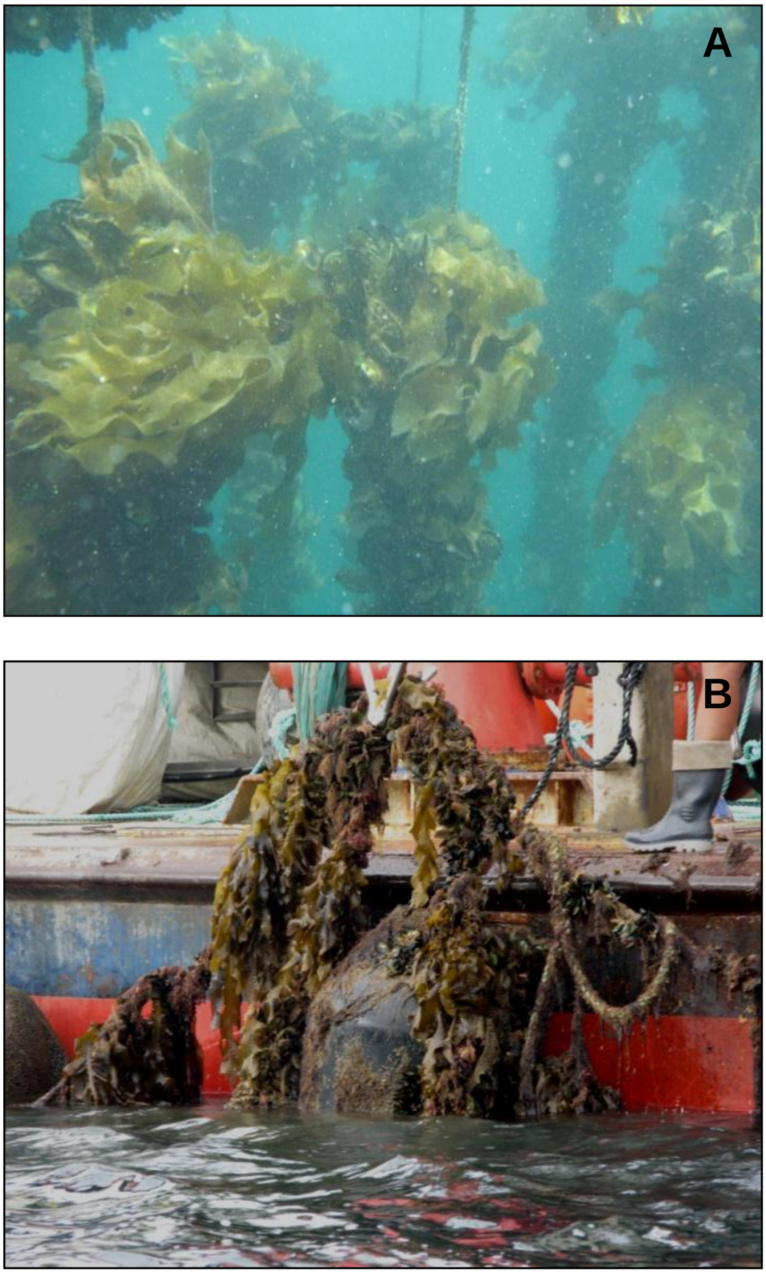
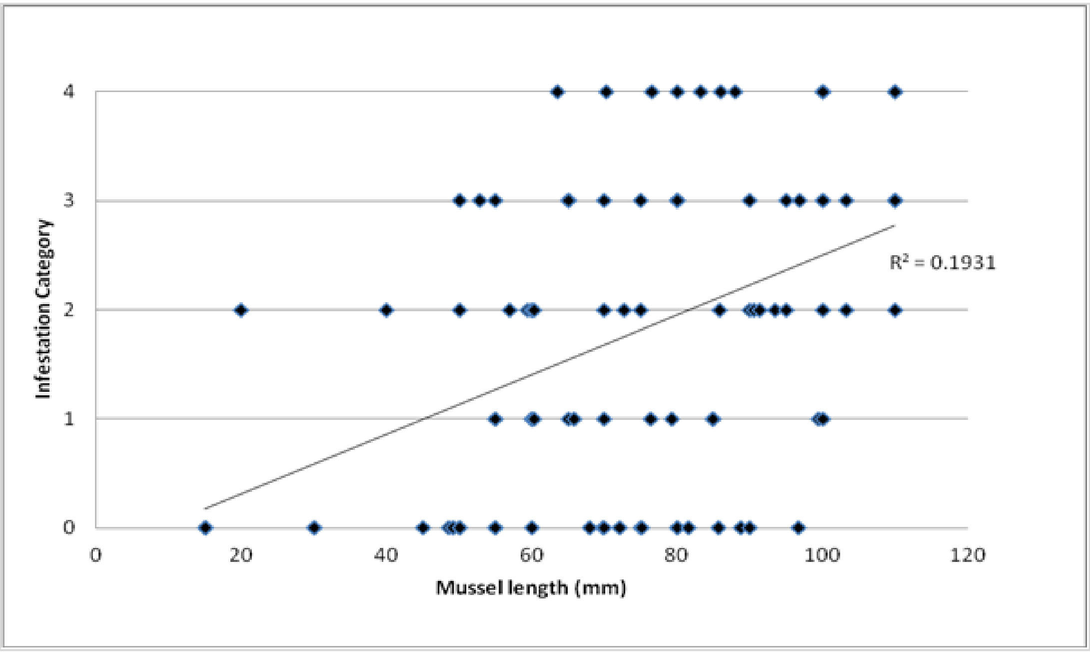


Figure 7: Heavily infested mussel lines, Motukopake Island, 23/11/12 (A) and Wilson Bay, 6/12/11 (B).



Levels of *Undaria* infestation were weakly positively related to the size of mussels. Mussel size is a general indicator of how long the lines have been in the water and can vary between individual lines within the same mussel farm. The highest *Undaria* infestation levels were generally seen on mussel lines with mussels larger than 50-60mm (Figure 8), which would have been in the water for at least 5-7 months.

Figure 8: Mussel length and *Undaria* infestation



4.1.3. "High risk" sites

High risk survey site results are summarised in Table 3 and are mapped in Appendix 1. No *Undaria* was found at the mussel loading facility/public boat ramp at Te Kouma, the swing mooring sites at Windy point/Puhe Rare and Takawhare Bay, Hannaford's jetty or the two other boat ramp sites surveyed in February 2012. A medium level of infestation (Category 2) was found on a single mooring float and line inspected at Kennedy Bay in February 2012.

Table 3: "High risk" survey sites

Date	Location	Site	*Undaria* plants sighted
1/2/2012	Port Charles	Public boat ramp and benthic surrounds.	0
1/2/2012	Kennedy Bay	Swing moorings.	30 mature and degrading plants on a single mooring buoy and line.
3/2/2012	Waikawau (Thames Coast)	Public boat ramp and benthic surrounds.	0
3/2/2012	Windy Point/Puhe Rare	Mussel barge swing moorings and barge hulls.	0
3/2/2012	Te Kouma/ Sugar Loaf	Mussel barge loading facility/boat ramp and benthic surrounds.	0
6/2/2012	Takawhare Bay	Public swing moorings.	0
6/2/2012	Hannaford's Jetty	Public jetty and benthic surrounds.	0

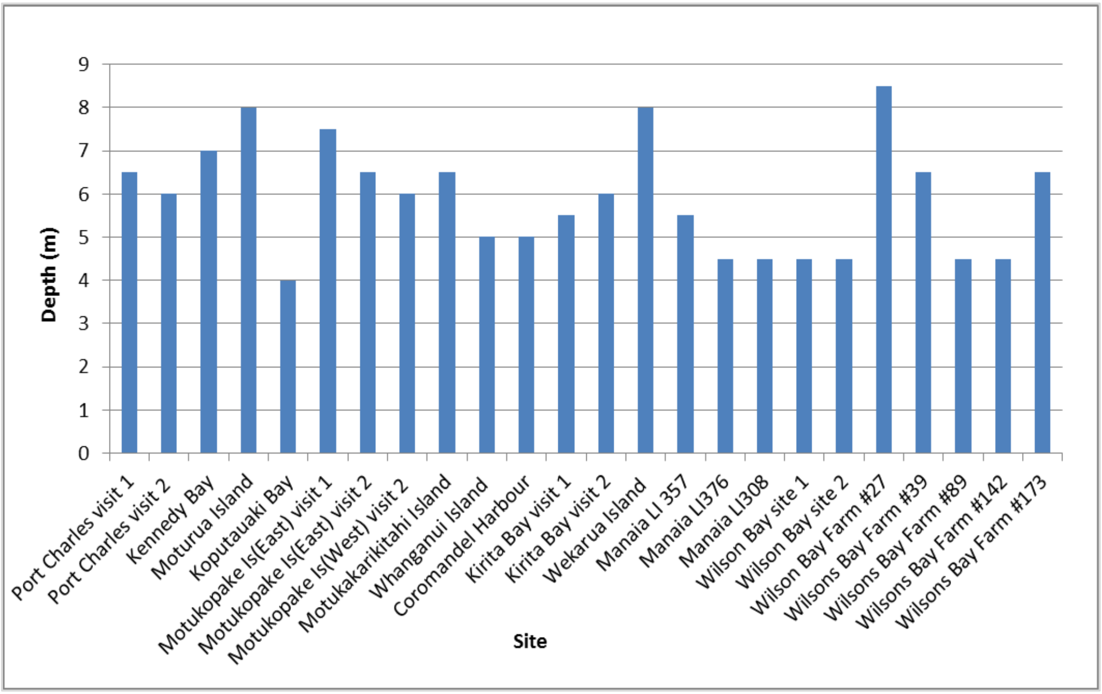
4.1.4. Other Invasive Species

Other invasive species recorded during coastal surveys are shown in Appendix 2. The invasive tunicate *Styela Clava* was recorded at ten of the twenty six coastal sites surveyed. The invasive alga *Codium fragile ssp. tomentosoides* was recorded at two coastal sites and the Asian paddle crab *Charybdis japonica* was also seen two coastal sites. Results for invasive species recorded on mussel farms are shown in Appendix 3A. All the mussel farms surveyed had *Styela Clava* growing on the lines and/or infrastructure. Twenty eight of the thirty one mussel farms surveyed had *Codium fragile ssp. tomentosoides* present. *Styela Clava* and *Codium fragile ssp. tomentosoides* were abundant on the mooring lines at Takawhare Bay. *Styela Clava, Codium fragile ssp. tomentosoides* and *Charybdis japonica* were recorded at the Waikawau boat ramp site and at Kirita Bay.

4.1.5. Environmental Data

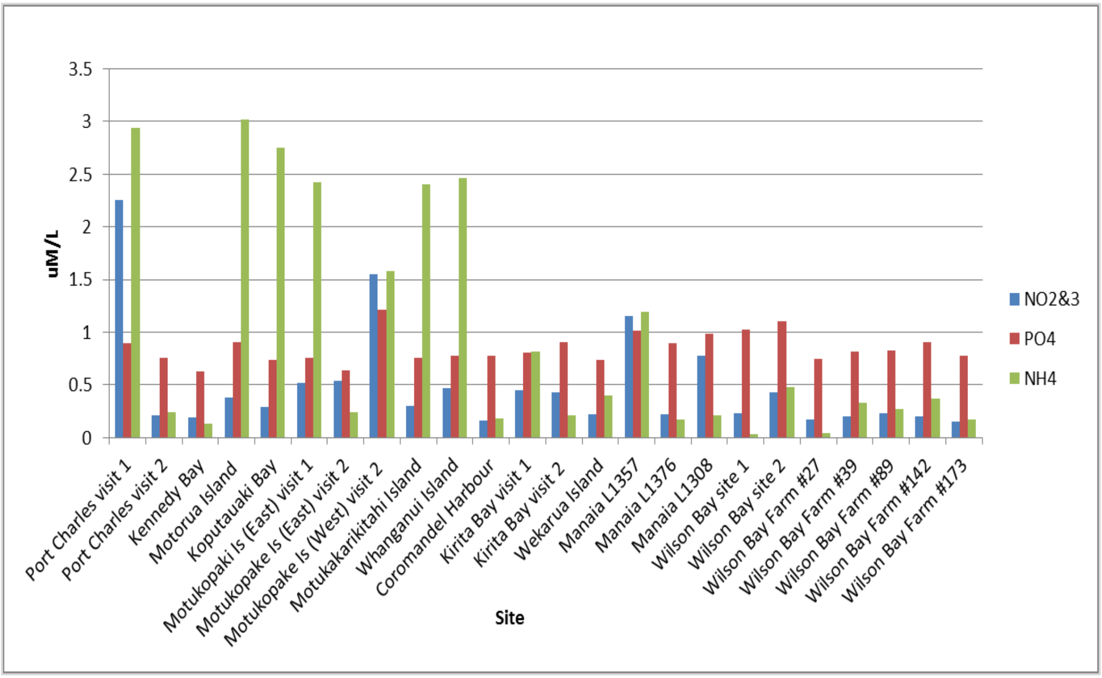
Site environmental information for the spatial survey is shown in Appendix 3B. During this survey average salinity recorded at mussel farm sites was 34.7 ppt with a range of only two parts per thousand recorded across all sites, maximum 35.5 ppt, and minimum 33.5 ppt. The average temperature recorded over the survey was 18.7ºC with a minimum of 16ºC and a maximum of 20.6ºC. Temperatures were measured at different times of day and in varying weather conditions so cannot be directly compared between sites. Secchi depths are shown (from northern (left), to southern (right) locations) in Figure 9. Sites had an average secchi depth of 5.9m across all mussel farm sites with a maximum of 8.5 recorded at Wilson Bay and a minimum of 4m at Koputauaki Bay.

Figure 9: Secchi depths: Spatial survey locations



Seawater nutrient data is shown in Figure 10. Very high ammonia readings seen at Port Charles, Motorua Island, Koputauaki Bay, Motukopaki Island, Motukakarikitahi Island and Whanganui Island were all samples taken in November. Differences in ammonia levels at the same site can be seen for Port Charles, Motukopaki East and Kirita Bay as they were each visited in November, visit 1 and February, visit 2. Nitrite and nitrate were relatively variable among sites, with the highest concentrations recorded in Port Charles and Manaia Harbour, as well as at one site at Motukopake Island. Nitrogen concentrations were typically low at the Wilson Bay farm sites. Phosphate occurred at relatively constant concentrations among sites and times. For details on sampling dates and sites see Appendix 3B.

Figure 10: Seawater nutrient data: Spatial survey locations

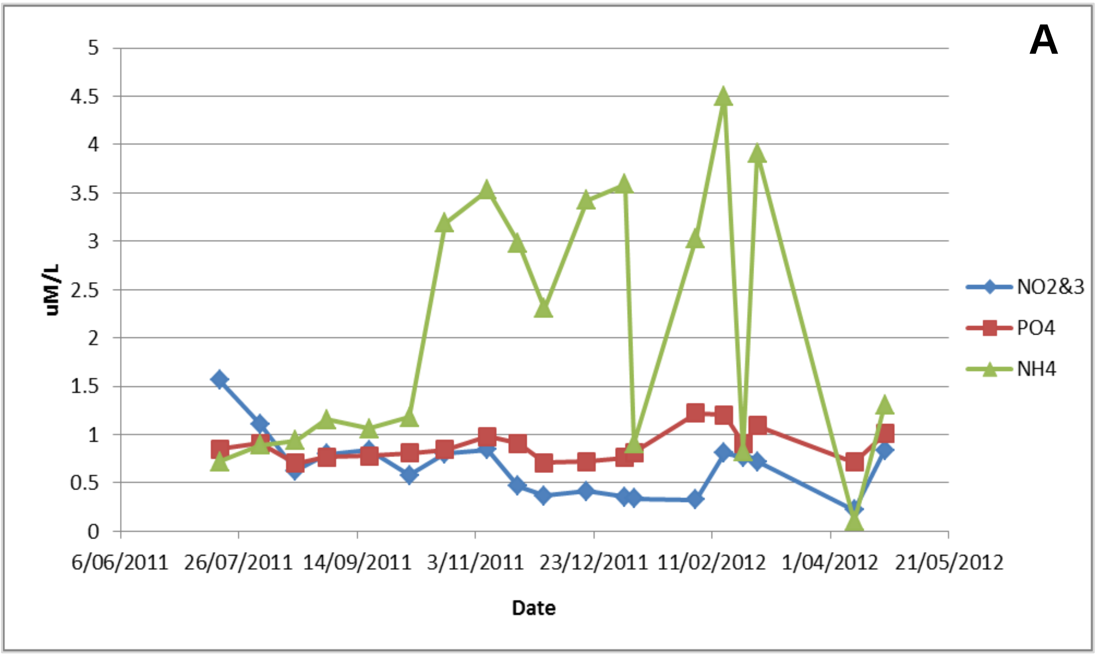


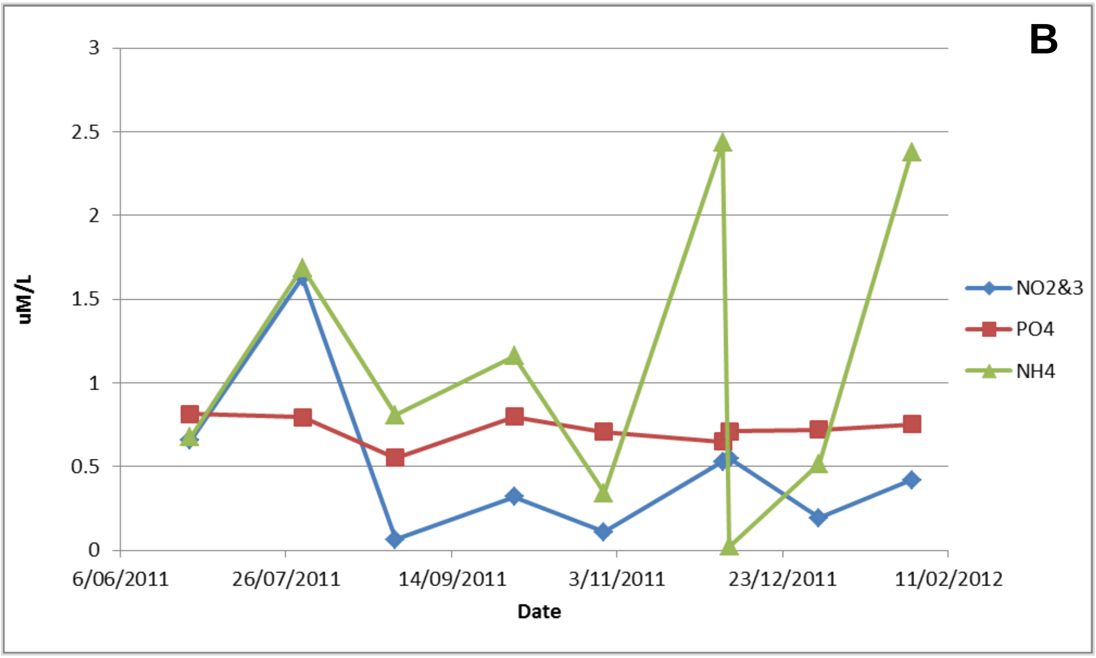
4.2. Seasonal monitoring of *Undaria* populations

4.2.1 Environmental variation at monitoring sites

Overall, seawater nutrient concentrations were similar between the Coromandel and Westhaven monitoring sites (Figure 11). Nitrate and nitrite tend to be highest in winter, whereas ammonia is generally higher but highly variable over the summer months (from November onwards). Phosphate is relatively stable through time and similar between sites.

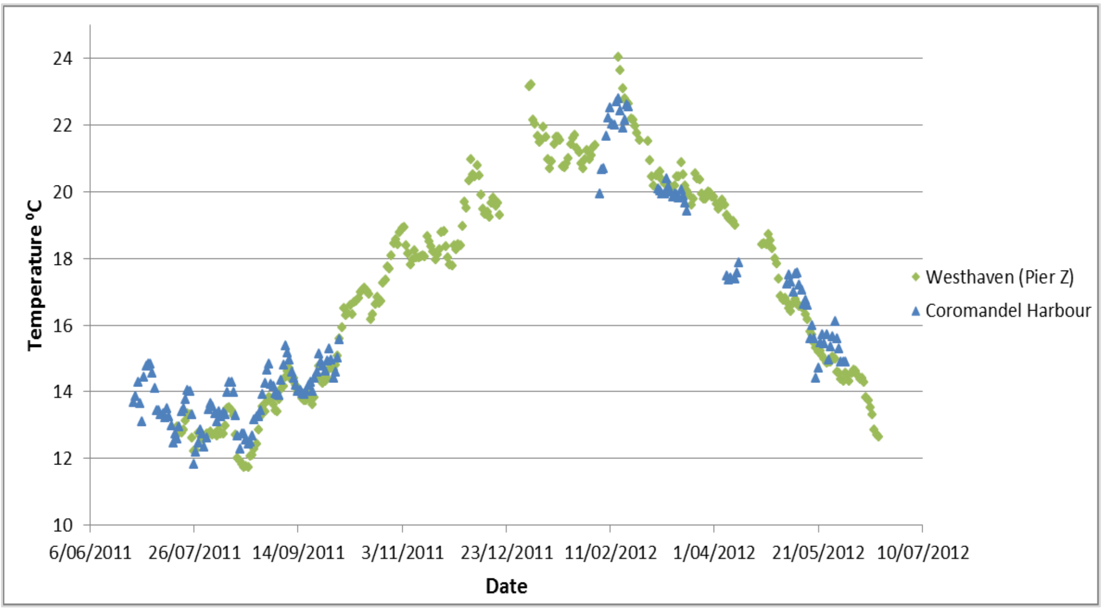
Figure 11: Seawater nutrient data at *Undaria* monitoring sites: Westhaven Marina (A) and Coromandel (B).





Temperature data recorded at Coromandel and Westhaven sites is shown in Figure 12. Monitoring of *Undaria* populations began in June 2011 when the average monthly temperatures were 13.4˚C and 12.8˚C at Coromandel and Westhaven Marina respectively. Temperature then increased through until February with average monthly temperatures of 24˚C at Westhaven and 23˚C at Coromandel. From the end of February temperatures began to drop rapidly, there is a monthly average in May of 16˚C at both Westhaven Marina and Coromandel as temperatures head down towards 12 ˚C in June 2012.

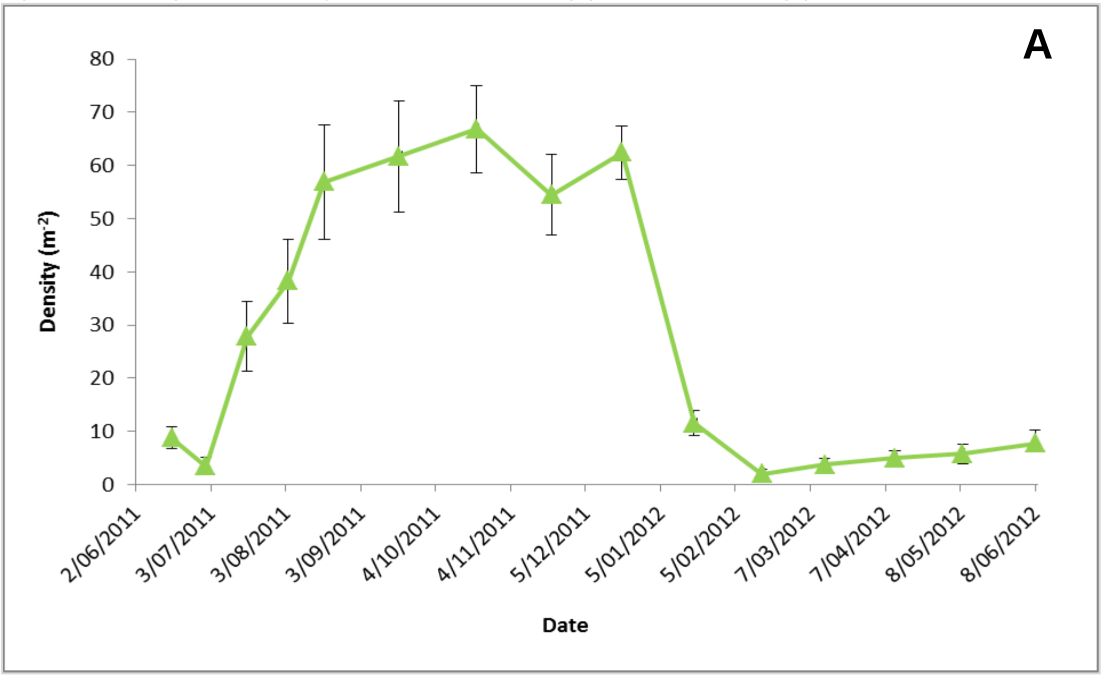
Figure 12: Average daily water temperature. Note: Coromandel temperature loggers were stolen from the monitoring site three times during the study and hence data from this site is missing for some months.

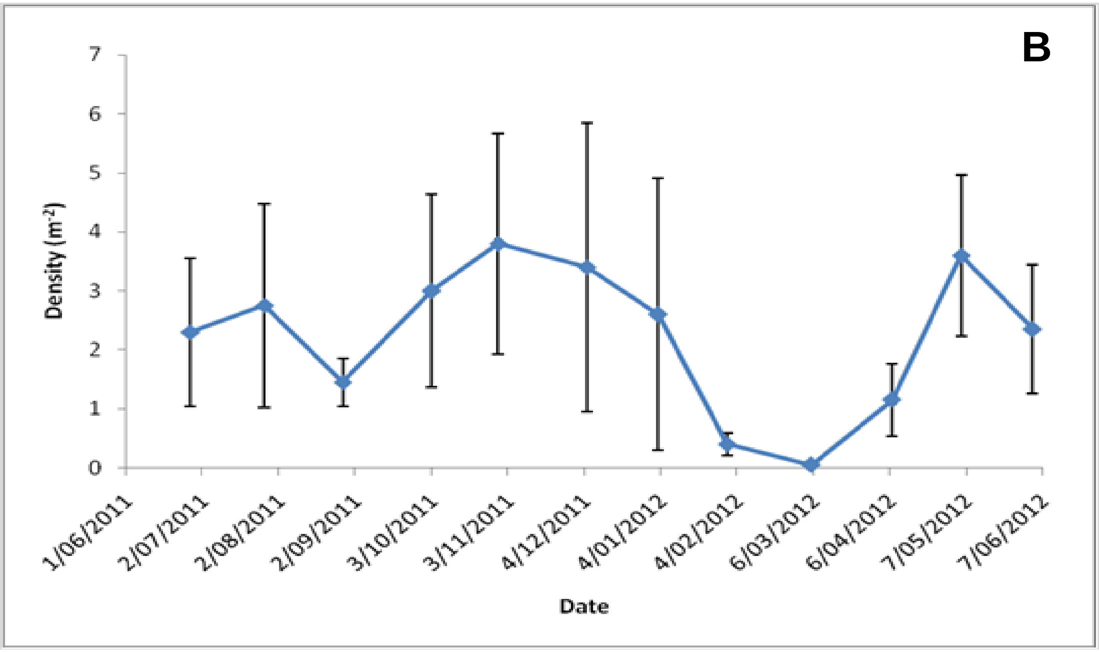


4.2.2 Temporal distribution and population dynamics of *Undaria* populations

Plant densities were much higher on a per meter square basis at Westhaven Marina compared to on mussel floats at the Coromandel study site (Figure 13). Plant densities were highly variable among floats at Coromandel but generally followed the same temporal pattern as Westhaven Marina, with an increase from June through until November, followed by large declines, down to near zero, at both locations between December and February. Densities at the Coromandel site began to increase again in April 2012.

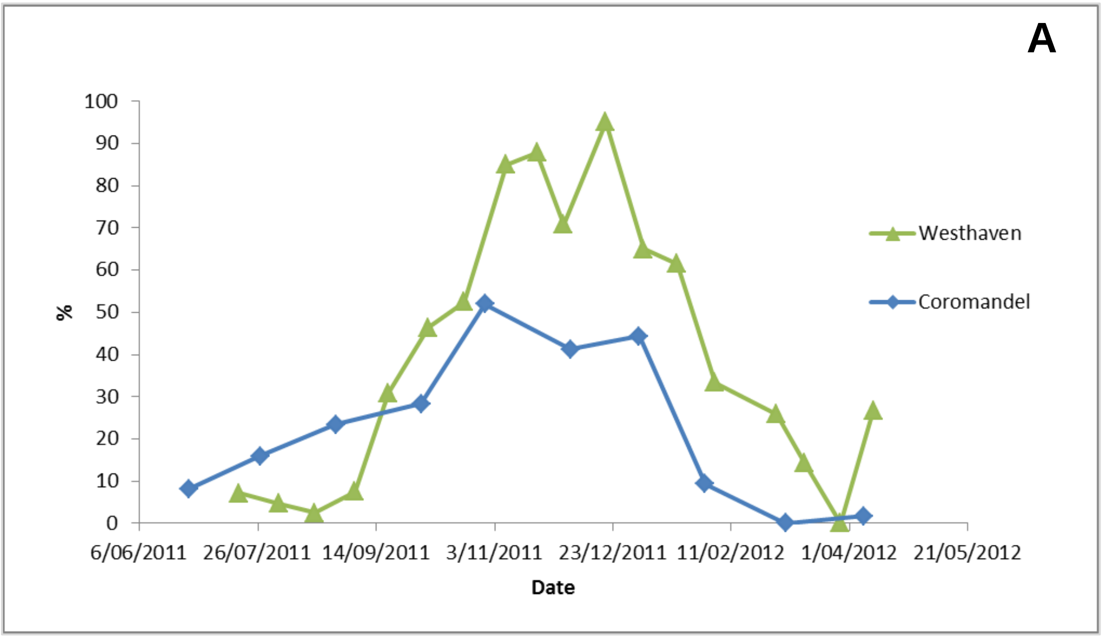
Figure 13: Average plant density at Westhaven Marina (A) and Coromandel (B). Error bars are ± one standard error.

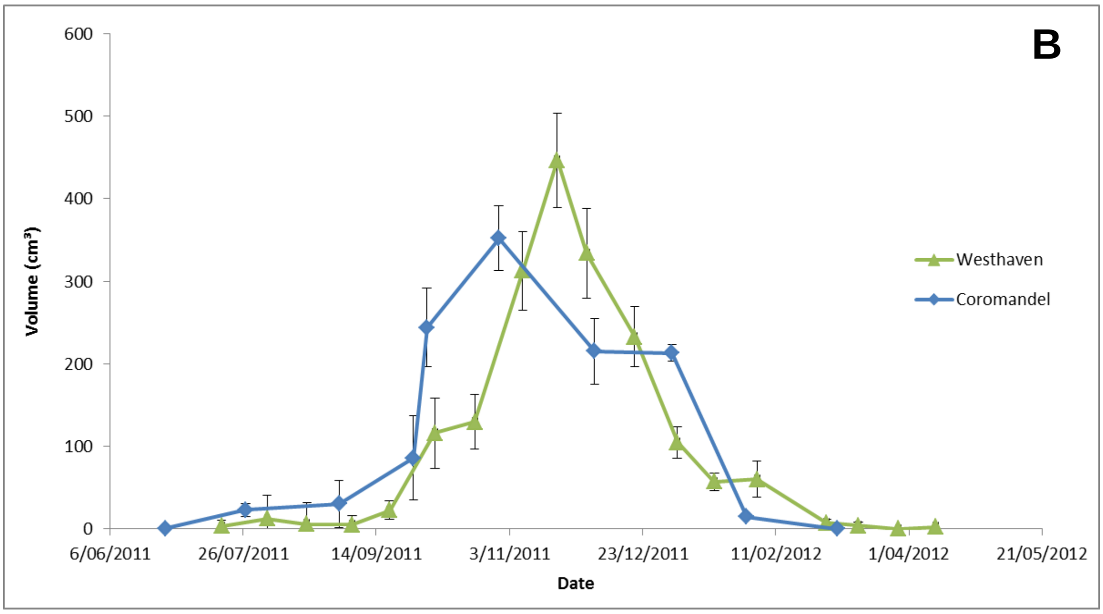




The percentage of plants with reproductive tissue, sporophylls, is shown in Figure 14A and the average sporophyll volume is shown in Figure 14B. Both sites had maximal reproductive plant numbers between early November and late December 2011. At Westhaven Marina, 95% of the plants measured had sporophylls by late December, whereas at Coromandel a maximum of 52% of the plants measured had sporophylls at any one time. The numbers of plants with sporophylls present at both sites collapsed from early January. No plants with sporophylls were recorded at either site in March 2012. Sporophyll volume peaked between early November and mid-December at both Westhaven Marina and Coromandel.

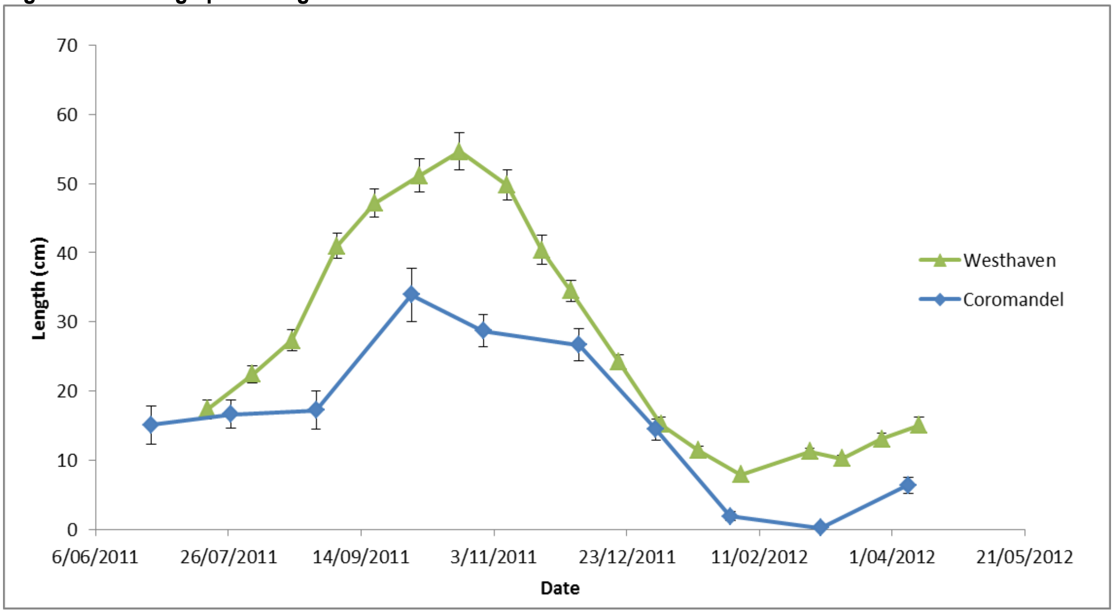
Figure 14: Reproductive status of *Undaria* populations. Percentage of reproductive plants with sporophylls (A) and Average Sporophyll Volume (B). Error bars are ± one standard error.





Average plant length increased steadily from June 2011 and peaked during October at Westhaven Marina and at Coromandel (Figure 15). The largest individual plants were recorded in October, with maximum sizes of 102 cm at Westhaven and 120 cm at Coromandel. Average length shows a steady decline from October as plants decay from the apex. Although no plants were seen in the survey area in Coromandel in February *Undaria* was seen on surrounding infrastructure. A gradual increase in plant length is evident from February to April 2012 as new recruits appear.

Figure 15: Average plant length at Westhaven Marina and Coromandel. Error bars are ± one standard error.



Average growth rate of *Undaria* plants at Westhaven is shown in figure 16. The average growth rate peaked during August 2011 at 0.59cm day^{-1}. Growth rate then declined steadily down to 0.28cm day^{-1} in November. All tagged plants had then died and were no longer present by December 2011.

Figure 16: Average growth rate at Westhaven Marina. Error bars are ± one standard error.

Note: growth was only recorded at Westhaven and from July to November 2011 as tagged plants were all gone by November 2011.

Size frequency graphs showing plant sizes at Westhaven Marina and Coromandel are shown in Appendix 4. Plantlets (<10 cm total length) were recorded in size frequency sampling year round at both sites except at Westhaven Marina in October (Appendix 3). However, the lack of plantlets recorded at this time may have been due to the large biomass and dominance of large plants, which would have made the detection of small plantlets difficult. Over the summer months, the remaining populations at both sites generally consisted of shorter degraded plants or sporophylls only less than 30 cm total length.

The sharp decline in the size and abundance of *Undaria* plants at Westhaven Marina between October 2011 and January 2012 can be seen in Figure 17.

Figure 17: *Undaria* plants at Pier Z Westhaven Marina

21/10/11	6/01/11

5. Discussion

5.1. Spatial distribution of *Undaria* around the Coromandel Peninsula

Undaria is widespread on mussel farms around the Coromandel Peninsula. It is well established on mussel farm structures from Moturua Island (off the Papa Aroha coast) to Wilson Bay on the west coast of the Coromandel Peninsula. Of the thirty one mussel farms surveyed, levels of *Undaria* infestation were defined as low to medium (1-100 plants per 50 m transect) on seventeen of these mussel farms, high (>100 plants per 50 m transect) on eleven farms and *Undaria* was not seen on three of the farms inspected. The three mussel farms where *Undaria* was not recorded were at Kennedy Bay (two farms) and Port Charles (one farm). Small amounts of *Undaria* were found on an adjacent mussel farm at Port Charles and on a mooring line at Kennedy Bay which is an indication that *Undaria* is likely to be present on the mussel farms during peak growing season or when conditions are more favourable, such as when mussel lines have been in the water for longer. *Undaria* may have been present on lines not inspected in this survey. *Undaria* is known to require high light levels for successful growth and reproduction (Stuart, 2004). Hence *Undaria* was generally concentrated on the upper 2 m of mussel lines with densities declining rapidly at greater depths, consistent with Duder (2009) and Chen (2012).

Undaria infestation levels tended to be higher on mussel lines with mussels larger than 60mm present. Mussels of a size of ~60 mm will have been growing for 5-7 months, therefore giving *Undaria* this same amount of time to colonise the lines. The high density *Undaria* populations found on the three mussel farms around Motukopake Island and one off Whanganui Island were on lines with large mussels, 80-120mm. These farms were also infested with the other invasive species *Styela Clava* and *Codium fragile ssp. tomentosoides* as well as native seaweeds (e.g., *Ecklonia radiata, Sargassum ssp.*) and other encrusting organisms, indicating a low level of farm maintenance or cleaning at these sites. Cleaning of the floats and other infrastructure at small mussel farming sites does appear to reduce *Undaria* biomass on the farms. However, even well cleaned mussel farms were seen to have “hot spots” of *Undaria* infestation at the ends of lines and on warp lines which are not pulled out of the water and cleaned as regularly as the rest of the floats and lines. These “hot spots” may then act as reservoirs from which *Undaria* can spread back across mussel dropper lines and floats when they are deployed at a site.

The seven mussel farms surveyed within the WBMFZ had *Undaria* present at more than 500 plants per 50m transect. These farms appeared well maintained, with no “oversized” mussels and with low levels of other pest species present. The vigour and density of the populations seen here, by far the largest aquaculture site surveyed, may be due to the fact that this is the most long established population of *Undaria,* it is where *Undaria* was first noted in the Coromandel region in 1999 (Jessop, 2006). The size, ~1250ha, and nature of the WBMFZ likely ensures a constant and immense supply of *Undaria* spores at this site. This high propagule pressure is likely to perpetuate the dense population at this site despite differing stages of mussel growth and line/float rotation at individual farms within the Zone. Further investigation into environmental influences could reveal other factors promoting the growth and proliferation of *Undaria* at this site.

Coastal survey results indicate that *Undaria* has not extensively invaded coastal sites adjacent to Coromandel mussel farm locations. *Undaria* was found at six out of the twenty six coastal sites surveyed. In general, numbers found at the coastal sites were relatively low compared to densities found on the farms, total numbers seen at individual coastal sites were between one and fifty plants. At this stage it is unknown whether the low densities are a result of recent colonisation and therefore insufficient time for establishment of large populations, whether other mechanisms may prevent the establishment of large populations at these coastal sites, or if the timing of some surveys may have coincided with low densities of plants. *Undaria* was found in shallow reef habitats with easily colonisable open spaces. It was not found to be present at comparable sites with dense macroalgal canopies. Plants were seen to be colonising areas of small to medium boulders or patches of clear rocky reef inside the subtidal algal belt or adjacent to it at the low-intertidal or reef-sand border.

Coastal sites adjacent to mussel farms potentially present less favourable conditions for the colonisation of *Undaria* than the mussel farms themselves. The abundance of Undaria on floating and suspended structures may be linked to the reduction in grazing pressure which occurs on these surfaces as opposed to coastal sites (Castric-Fey et al, 1993; Floc’h et al, 1998; Sinner et al, 2000). Relatively low densities at coastal sites could reflect poor dispersal to these locations or high levels of predation and competition in these areas. While relatively low densities of grazers such as sea urchins were observed on the adjacent reefs, most of the reefs adjacent to farms were dominated by dense macroalgal stands of *Ecklonia radiata*, *Carpophyllum maschalocarpum* and/or *C. flexuosum*. Therefore it is likely that dense stands of perennial macroalgae adjacent to farms may play a role in preventing or slowing the colonisation of *Undaria* at these sites. The presence of other kelp species (e.g. *Ecklonia radiata)* does however indicate favourable conditions for *Undaria* growth around these sites if it were to become established (Stuart and McClary, 2004).

The short life span of *Undaria* spores results in a "step-wise" colonisation pattern (Gurois et al, 2011) as the short lived spores only travel 100m or so from the parent plants (Forrest et al, 2001). Drifting plants and/or fragments that release spores can be important modes of spread for seaweeds (Forrest et al, 2001). The harvesting of mussels and other operational procedures on *Undaria* infested mussel lines would strip off such material and release it into the surrounding environment. The distance these plants or fragments travel depends on the water currents (Forrest et al, 2001; Torres et al, 2004: Verlaque, 2007). Given that *Undaria* does not have bladders, drift is not likely to facilitate the long distance spread of *Undaria* (Parsons, 1994). This limited ability to spread naturally via spore release (Sinner et al, 2000) or floating reproductive material (Parsons, 1994) results in what Russell et al (2007) refer to as a lag phase which lasts "a few years" being observed before *Undaria* invades areas beyond its founding population. Range expansion is also reliant on the appropriate substrate being available for colonisation. *Undaria* prefers primarily to colonise areas clear of other alga (Hay, 1990), but has been seen to penetrate the kelp and fucoid zone, competing with native species after being established for long enough to overcome the initial lag phase (Russell et al, 2007). It should be noted that "Natural rates of dispersal are, however, likely to depend on local conditions, and may in any case be secondary importance to human-mediated dispersal" (Stuart 2004). Vessel hulls and aquaculture equipment are thought to be the main dispersal pathways (Hay, 1990; Neill, 2008; Russell et al, 2008; Sinner et al, 2000; Verlaque, 2007). The macroscopic sporophytes as well as the microscopic gametophyte stage can be spread by vessels of all sizes (Sinner et al, 2000) and the easily transportable microscopic phase is present at much greater levels over the summer when water temperatures are the highest, coinciding with the period of most recreational boat traffic (Thornber et al, 2004). Marine farming equipment and spat are known to facilitate the transfer of *Undaria* from place to place (Perez et al, 1991; Stuart, 1997), as well as general fishing gear such as ropes, anchors, crayfish pots, nets and diving gear (Sinner et al, 2000).

Although the surveys carried out were extensive, proof of absence of *Undaria* in coastal areas adjacent to mussel farm sites is difficult to assert when distribution could be discontinuous and surveys were not all inclusive. Some of the coastal surveys were carried out in late summer when *Undaria* is typically at its lowest abundance (see below). Nevertheless, based on our monitoring data and observations at Kirita we would still have expected to see low numbers of plants or aged sporophylls at coastal sites during the summer months. The benthic habitat surrounding the boat ramps surveyed at Port Charles, Te Kouma, Waikawau and at Takawhare Bay was similar to that of coastal sites where *Undaria* was found adjacent to mussel farms. The absence of *Undaria* at these popular recreational boating sites and the swing moorings at Takawhare Bay indicates that the spread of *Undaria* around the Coromandel may not be closely associated with recreational nautical activities.

No *Undaria* plants were sighted on the mussel barge hulls at Windy Point/Puhi Rare, but presence and transport of the *Undaria* gametophytes via barge hulls is highly likely. The absence of *Undaria* plants at the mussel barge mooring site could possibly be due to the unsuitable nature of the habitat found there. This site is an inner Harbour site with high turbidity, Secchi depth 2.7m. Another reason for the absence of *Undaria* may be the frequent use of the barges not allowing for the growth of visible *Undaria* plants.

Mussel farm sites are inherently areas with good water flow and sufficient nutrients to provide for the rapid growth and health of mussels for commercial harvesting. The provision of artificial substrates such as lines and floats in the highly illuminated shallow water (<2 m) provides ideal growing conditions for kelps in places that would otherwise be too turbid to support their growth and survival on naturally available substrates. The findings of this survey are consistent with research showing *Undaria* has been found to colonise artificial substrata more readily than natural reef systems in New Zealand (Hay, 1990; Hay & Luckens, 1997; Parsons, 1994; Russell et al, 2007). In benthic areas *Undaria* prefers to colonise naturally open sites or those which have been disturbed by wave action, sand scour, urchin grazing or native kelp die-back (Duder, 2009; Sanderson, 1997; Sinner et al, 2000). The coastal sites where *Undaria* was sighted in this survey provided easily colonisable open spaces. *Undaria* was not found to be present at comparable sites with dense canopies of perennial macroalgae. Instead, plants were seen to be colonising areas of small to medium boulders or patches of rocky reef where canopy-forming algae were lacking such as adjacent to the reef-sand interface or in low-intertidal areas dominated by coralline turf (*Corallina officinalis*). In general all plants recorded at coastal sites were very shallow (<1m below mean low water).

5.2. Temporal distribution and population dynamics

Undaria is an annual in its native range. Recruitment of the plant occurs in autumn, the plant grows rapidly through winter and spring, zoospore release occurs in early to mid-spring and senescence occurs in mid-summer (Choi et al, 2007; Stuart et al, 1999). The dormant gametophyte, which can tolerate temperatures up to 30ºC (Saito, 1975), then persists until the following winter (Hewitt et al, 2005). *Undaria* phenology is known to vary both within and between *Undaria* populations (Dean, 1997; Parsons, 1994) and studies have shown that the appearance of the plants is variable and can occur in autumn, spring to winter or year round (Akiyama and Kurogi, 1982; Hay and Villouta, 1993; Parsons, 1994; Stuart et al, 1999). *Undaria* plantlets were observed year-round at both Westhaven Marina and Coromandel monitoring sites, showing overlapping generations exist at both these sites. Year round recruitment has also been observed in Wellington and Tauranga harbours (Hay and Luckens, 1987; Hay, 1990; Jessop, 2006). Populations in the Hauraki Gulf display the largest recruitment pulse in autumn/winter, showing the dominant pattern of recruitment, growth and senescence follow the same pattern as in its native range. The populations were seen to become reproductive "en masse" in late spring-early summer before plants degraded and died in late summer.

The onset of reproductive maturity is known to coincide with retardation in sporophyte growth (Choi et al, 2007). This was seen to occur in Hauraki Gulf populations as maximum plant length and growth rate were reached in October before sporophyll number and volume peaked between early November and late December. This peak in sporophyll formation and size is assumed to align with spore release. Once all the spores are released, the plant dies (NIMPIS, 2002), this occurred at Westhaven and Coromandel between late November and early February. Although some small plants and degraded old plants were still present in low numbers and on auxiliary infrastructure, the monitored populations at both sites had collapsed before water temperatures peaked in mid-February.

The entire cycle of growth was closely related to water temperature. Although *Undaria* can survive and reproduce at temperatures between zero and thirty degrees Celsius (Floc'h et al, 1991), growth of *Undaria* plants is optimum at 15-17°C with growth continuing slowly to 20°C (Saito, 1975). When monitoring of *Undaria* populations began in June 2011 the average monthly temperatures were 13.4˚C and 12.8˚C at Coromandel and Westhaven Marina respectively. The highest growth rates occurred in August and early September when temperatures were around 15˚C. Temperature then increased through until February with average monthly temperatures of 24˚C at Westhaven Marina and 23˚C at Coromandel. Size and density of *Undaria* plants increased steadily from June through until late October/early November when plant lengths and the presence and volume of sporophylls peaked. This peak in plant size and reproductive maturity coincided with water temperatures reaching 17ºC. Average length then shows a steady decline, as the mature sporophytes degraded, with the shortest average lengths recorded at Coromandel and at Westhaven in late February when water temperatures peaked. In general the Hauraki Gulf temperatures recorded fall above the optimum *Undaria* growing conditions from November to May but still remain within the known range for sub-optimal growth and reproduction. Although present year-round, *Undaria* follows a distinct pattern of rapid recruitment and growth during the cooler months of winter-spring.

Results indicate that the warmer waters of the Hauraki Gulf may produce smaller plants with a slower growth rate than those found in cooler waters. In Otago Harbour maximal growth rates have been recorded at 1.07cm d^{-1} by Stuart (1997) and 0.93 cm day^{-1} by Dean and Hurd (2007). Average growth rates of *Undaria* plants in this study at Westhaven Marina peaked at 0.59cm day^{-1} with a maximum recorded growth rate of 0.88cm day^{-1}. The plants surveyed at Coromandel Harbour and Westhaven did not generally reach the recorded length of wild plants found in their native temperature range which is listed as commonly between one and two metres (Adams, 1994). The largest individual plants were recorded in October, with maximum sizes of 102 cm at Westhaven and 120 cm at Coromandel. In general, plants greater than 1 m in length were rare. Plant densities were in line with those recorded in cooler waters. Maximum plant densities found in this temporal study were 66 plants m^{-2} at Westhaven and ~4 plants m^{-2} on mussel floats at Coromandel. Comparable studies of artificial substrata are lacking in New Zealand, but sporophyte population densities reported in the intertidal to 3m depth zone are 50-100plants m^{-2} or less (Brown and Lamare, 1994; Brown, 1999; Sinner et al, 2000). This is consistent with data from other populations outside its native range (Castric-Fey et al, 1993; Campbell and Burridge, 1998).

Seawater nutrient data showed a higher availability of nitrogen during the winter months. Nitrogen levels in sea water are known to be lowest in the summer and highest in winter within temperate coastal waters and ammonia and phosphate are present at consistent concentrations throughout the year (Dean and Hurd, 2007) as was observed, although ammonia levels were highly variable over the summer months (from November onwards).

The availability of seawater nutrients is one of the primary factors regulating the growth, reproduction and biochemistry of seaweeds, with evidence suggesting that N, P and Fe can limit the growth of seaweeds (Lobban and Wynne, 1981). Undaria crop yield in Asia is commonly increased through the application of nitrogen fertilisers (Dean, 1998). Seawater nutrient levels from temporal monitoring sites showed overall seawater nutrient concentrations were similar between the Coromandel and Westhaven Marina monitoring sites, this indicates the mussel farm does not influence these seawater nutrient levels at the Coromandel site. These results agree with those of an investigation by Duder (2009) which found that mussel aquaculture around Great Barrier Island did not raise seawater nutrient levels or enhance the growth of *Undaria*.

5.3. Other invasive species

Styela clava was found on all the mussel farms surveyed and *Codium fragile ssp. tomentosoides* was present on twenty eight out of the thirty one farms surveyed. Both these species are known for being introduced and spread via shellfish aquaculture (Pagad, 2012). They also have the potential to impact negatively upon both the mussel farming industry through heavy fouling and on native benthic communities by outcompeting native species for resources. *Charybdis japonica,* the Asian paddle crab, was found at two coastal sites. This species could impact negatively upon native benthic communities though competition for space and resources with native crab species. *Charybdis* japonica is also known to transmit disease and prey on native shellfish, which is a potential threat to local fisheries and shellfish (Pagad, 2012).

5.4. Implications and considerations

All the mussel farm sites surveyed had similar environmental conditions and all provide suitable habitat for the colonisation and growth of *Undaria*. The open structures supply shallow, well illuminated substrate free from grazing pressures and competitive algal species. The farms are positioned in areas of good water flow and with sufficient nutrients to provide for the rapid growth and health of mussels for commercial harvesting, salinity readings taken during the spatial and the temporal surveys showed little freshwater influence over time or between sites. These conditions are consistent with ideal *Undaria* habitat (Verlaque, 2007). In general the longer the mussel ropes have been in the water growing the mussels the greater potential there is for *Undaria* to grow on the lines. The dense populations of large *Undaria* plants seen at the WBMFZ and on the four other heavily infested farms on the western Coromandel will have strong impacts on light availability, nutrient cycling and food availability for the mussels being grown on these farms (Cecere et al., 2000; Henkel and Hofmann, 2008).

The dense population seen at the WBMFZ, where heavy infestations included the presence of all life stages of *Undaria* plants on both site visits, ensures a constant and immense supply of spores at this site. This high propagule pressure is likely to perpetuate the extensive population at this site despite differing stages of mussel growth and line/float rotation at individual farms within the MFZ. For smaller mussel farms, cleaning of the floats and other infrastructure does appear to reduce the prevalence and potential effects of *Undaria,* as well as other invasive species at these sites.

Undaria was found at six coastal sites. Plants were found within one of the 50m transects at each of these sites. Sampling was concentrated on the shallow-subtidal margin of the reef, typically just below the low-tide mark. Much of the reef adjacent to the farms in the western Coromandel is of a similar physical composition, relatively shallow, with a sand-reef border at depths of less than 5 m and a limited offshore extent of 15-30 m. Although many of the sites surveyed were similar in nature it was not possible to easily predict the presence or absence of *Undaria*. The factors involved in the establishment of *Undaria* populations at coastal sites are likely to be complex and site specific (Sinner et al, 2000).

Grazing by urchins, fish and molluscs, and interactions with other macroalgae are potential influences which are difficult to quantify but have been shown to be important in determining the colonisation success and impact of *Undaria* (Valentine and Johnson, 2003). Through this survey it was apparent that *Undaria* will colonise open spaces as opposed to invading intact algal communities. Therefore, it seems that ensuring the maintenance of healthy native macroalgal canopies will help in preventing the spread of *Undaria* to coastal reef habitats. As *Undaria* is being found in more northern regions of New Zealand it is worth noting that urchin barrens, where large brown macroalgae are rare, are common on wave-exposed reefs in north-eastern New Zealand (Shears and Babcock 2004). Such habitats are highly vulnerable to the establishment of and facilitating the spread of *Undaria* (Valentine and Johnson, 2003). Currently mussel farming activities are primarily restricted to the more sheltered locations in the Hauraki Gulf where urchin barrens habitats typically don't occur. Any plans to expand mussel farming or aquaculture activities to more exposed parts of the Hauraki Gulf should take this into account. *Undaria* may still be experiencing a "lag phase" around the Coromandel Peninsula which would implicate much more rapid establishment is likely to occur at coastal sites as founding populations, at mussel farm sites, continue to proliferate. We recommend that further monitoring and research be carried out around the Coromandel region to more accurately ascertain the extent of *Undaria* infestation around the Coromandel coast and determine the factors influencing the abundance of *Undaria* at marine farming and coastal sites. Annual monitoring of *Undaria* populations could help understand the spread of populations, the possibility that *Undaria* is currently in a "lag phase" of coastal invasion, and the potential risks to coastal environments and native species.

The influences of aquaculture activity on the success of *Undaria* are still largely unknown. Although *Undaria* has not spread extensively to coastal areas adjacent to mussel farms on the Coromandel Peninsula it is apparent that introducing mussel farm infrastructure to a site will likely result in the introduction of *Undaria* to that site. If mussel farms are to be placed in High Value Conservation areas or areas near marine reserves it must be taken into consideration that *Undaria* will then be introduced to these areas. Careful and regular maintenance of existing mussel farms and associated equipment will help towards minimising the spread of *Undaria* to coastal areas as well as new marine farms. Un-infested coastal reef sites at risk of *Undaria* colonisation may be those with impaired or reduced native algal canopies or abundant natural open spaces in the shallow subtidal zone.

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Appendix 1 - Maps of *Undaria* infestation at mussel farms, “high risk” and coastal survey sites

Green paths indicate no *Undaria* was sighted, orange paths represent sites where *Undaria* plants were seen at numbers 1-100 per 50m transect (averaged across the transects surveyed) and red lines indicate *Undaria* was present at >100 plants per 50m transect when averaged across the transects.

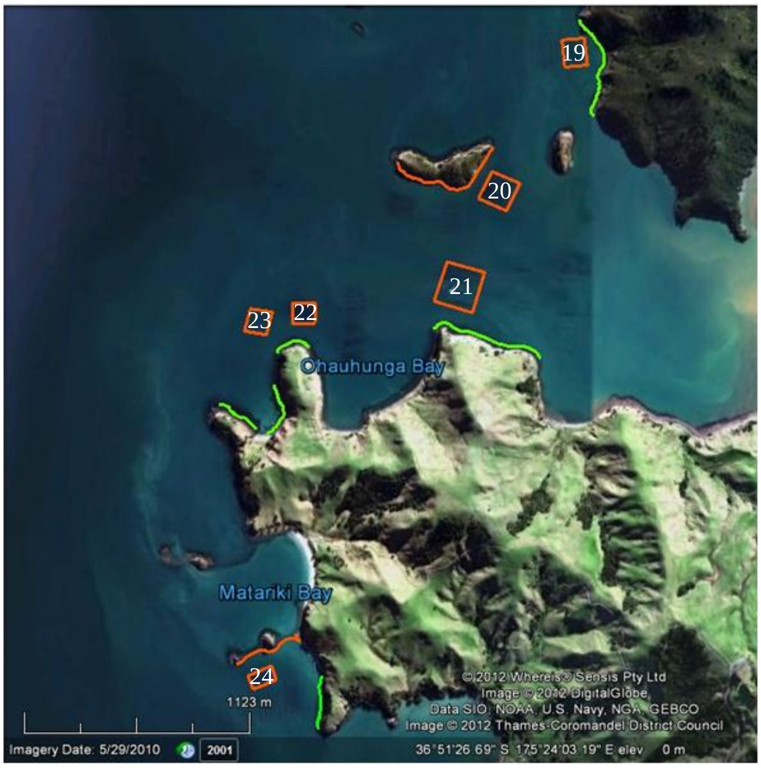
Kennedy Bay

Port Charles

Moturua Island

Koputauaki Bay, Motukakarikitahi and Motukopake Islands

Whanganui Island and Coromandel Harbour



Kirita Bay, Wekarua Island, Manaia Harbour

Wilson Bay

Takawhare Bay, Windy Point/Puhe Rare, Hannaford's jetty and Te Kouma boat ramp

Appendix 2 –Summary of coastal transect information

Date	Location	GPS Co-ordinates	Number of Transects	Total Distance Covered (m)	*Undaria* Category	Other Invasive Species Sighted
22/11/2011	Port Charles	36° 30’ 51 S 175° 28’ 13 E	16	800	0	
23/11/2011	Moturua Island	36 ° 41’ 57 S 175° 23’ 48 E	10	500	0	*Styela Clava*
23/11/2011	Koputauaki Bay	36 ° 43’ 47 S 175° 26’ 42 E	13	650	0	*Styela Clava*
23/11/2011	Motukapake Island (east)	36 ° 45’ 22 S 175° 25’ 21 E	7	350	0	
23/11/2011	Motukakarikitahi Island	36 ° 45’ 26 S 175 ° 27’ 07 E	8	400	0	
23/11/2011	Whanganui Island	36° 47’ 35 S 175 ° 26’ 14 E	9	450	0	*Styela Clava*
6/12/2011	Wilson Bay (Kereta)	West: 36° 53’ 09 S 175° 25’ 24 E East: 36° 53’ 13 S 175° 25’ 32 E	5	250	0	*Styela Clava*
6/12/2011	Wilson bay (Kereta North)	36° 53’ 24 S 175° 25’ 35 E	8	400	1	*Styela Clava*
7/12/2011	Kirita Bay	North: 36° 51’ 49 S 175° 24’ 41 E South: 36° 51’ 59 S 175° 24’ 47 E	9	450	2	*Styela Clava*, *Codium fragile ssp. tomentosoides*
7/12/2011	Coromandel Harbour west (Papakarahi Bay)	36° 48’ 27 S 175° 27’ 11 E	12	600	1	
7/12/2011	Manaia (Wekarua Island)	36° 50’ 30 S 175° 25’ 17 E	8	400	1	
1/02/2012	Kennedy Bay north	36° 40’ 08 S 175° 34’ 21 E	16	800	0	
1/02/2012	Kennedy Bay south west	36° 41’ 12 S 175° 34’ 04 E	5	250	0	
1/02/2012	Kennedy Bay south east	36° 40’ 45 S 175° 34’ 45 E	5	250	0	
1/02/2012	Port Charles2	36° 31’ 07 S 175° 28’ 15 E	3	150	0	
2/02/2012	Motukopake east	36° 45’ 22 S 175° 25’ 21 E	13	650	0	*Codium fragile ssp. tomentosoides, Styela Clava*
2/02/2012	Motukopake west	36° 45’ 16 S 175° 25’ 11 E	19	950	1	*Codium fragile ssp. tomentosoides, Styela Clava*
2/02/2012	Manaia north	36° 50’ 08 S 175° 25’ 46 E	12	600	0	
2/02/2012	Manaia - Ohauhunga Bay	36° 50’ 59 S 175° 25’ 21 E	12	600	0	*Styela Clava*
2/02/2012	Manaia - Onepoto Bay	East: 36° 50’ 59 S 175° 24’ 38 E Mid: 36° 51’ 12 S 175° 24’ 37 E West: 36° 51’ 12 S 175° 24’ 28 E	15	750	0	
3/02/2012	Coromandel Harbour west	East: 36° 48’ 38 S 175° 26’ 13 E West: 36° 48’ 53 S 175° 25’ 59 E	15	750	0	
3/02/2012	Kirita Bay	36° 51’ 49 S 175° 24’ 41 E	1	50	2	*Codium fragile ssp. tomentosoides, Styela Clava, Charybdis japonica*

3/02/2012	Kereta South	36º 54' 14 S 175º 25' 53 E	11	550	0	
3/02/2012	Waikawau	36º 56' 12 S 175º 27' 59 E	12	600	0	*Codium fragile ssp. tomentosoides, Styela Clava, Charybdis japonica*
Total			**244**	**12100**		

*GPS co-ordinates are given for the approximate centre of the set of coastal transects surveyed or the approximate area where *Undaria* was sighted if the location was positive for *Undaria*.

Appendix 3 – Summary of mussel farm survey information

Appendix 3A: Mussel farm invasive species information

Date	Location	GPS Co-ordinates*	Farm Number	Lines	Number of Transects	*Undaria* Category	Population Structure	Other Invasive Species Sighted
1/02/2012	Kennedy Bay	36° 40′ 22 S 175° 34′ 12 E	1	2,9,12,21	10	0		*Codium fragile ssp. tomentosoides*
		36° 40′ 21 S 175° 34′ 12 E	2	7,8,12,21	10	0		*Codium fragile ssp. tomentosoides*
22/11/2011	Port Charles	36° 30′ 47 S 175° 28′ 00 E	3	1,6,9	6	1	Degraded sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
1/02/2012	Port Charles	36° 30′ 47 S 175° 28′ 00 E	3	1,2,4,6,13, 15	14	0		*Codium fragile ssp. tomentosoides*
		36° 30′ 54 S 175° 28′ 03 E	4	3,5,9,10	8	0		*Codium fragile ssp. tomentosoides, Styela Clava*
23/11/2011	Moturua Island	36° 41′ 56 S 175° 23′ 56 E	5	1,4,8,12	8	1	Sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
23/11/2011	Koputauaki Bay	36° 44′ 02 S 175° 26′ 56 E	6	2,4,8	6	2	Sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
23/11/2011	Motukakarikitahi Island	36° 45′ 20 S 175° 27′ 11 E	7	1,3,4,5,7,9, 14	14	2	Plantlets and sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
2/02/2012	Motukopake Island	36° 45′ 11 S 175° 25′ 25 E	8	1,2,3,6,10	12	2	All life stages	*Styela Clava*
23/11/2011	Motukopake Island	36° 45′ 19 S 175° 25′ 35 E	9	2,5,6,7,10	12	2	Sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
2/02/2012	Motukopake Island	36° 45′ 19 S 175° 25′ 35 E	9	1,3,4	6	3	All life stages	*Codium fragile ssp. tomentosoides*
		36° 45′ 09 S 175° 20′ 02 E	10	1,2,4,7,9	10	3	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
		36° 45′ 15 S 175° 25′ 01 E	11	1,3,4,7,9	10	1	Degraded sporophylls	*Codium fragile ssp. tomentosoides*
		36° 45′ 21 S 175° 24′ 58 E	12	1,3,6,7,10	12	3	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
23/11/2011	Whanganui Island	36° 47′ 40 S 175° 26′ 20 E	13	2,6,10	6	3	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
7/12/2011	Coromandel Harbour	36° 48′ 22 S 175° 27′ 10 E	14	1,3	4	2	Sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*
3/02/2012	Coromandel Harbour	36° 48′ 28 S 175° 26′ 17 E	15	1,3,4	6	1	All life stages	*Codium fragile ssp. tomentosoides*
		36° 48′ 33 S 175° 26′ 10 E	16	2,9,14	6	1	Plantlets	*Styela Clava*
		36° 48′ 40 S 175° 26′ 06 E	17	2,4	4	2	All life stages	*Styela Clava*
		36° 48′ 44 S 175° 25′ 55 E	18	10,15	4	1	Degraded sporophytes and sporophylls	*Codium fragile ssp. tomentosoides*
2/2/2012	Manaia North	36° 50′ 06 S 175° 25′ 39 E	19	2,7,1,1	8	1	All life stages	*Styela Clava*
7/12/2011	Manaia (Wekarua Island)	36° 50′ 32 S 175° 25′ 23 E	20	1,2,3,6	8	2	Sporophytes	*Codium fragile ssp. tomentosoides, Styela Clava*

2/02/2012	Manaia	36° 50' 49 S 175° 25' 13 E	21	1,4,13,16	10	2	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
		36° 50' 55 S 175° 24' 40 E	22	1,2,6,7	8	1	All life stages	*Codium fragile ssp. Tomentosoides, Styela Clava*
		36°50' 56 S 175° 24' 30 E	23	1,5,9,13	8	2	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
		36° 50' 56 S 175° 24' 30 E	23	1,5,9	6	2	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
7/12/2011	Kirita (Matariki Island)	36° 51' 55 S 175° 24' 35 E	24	1,2,3,5	8	1	Small sporophytes	*Styela Clava*
6/12/2011	Wilson Bay MFZ	36° 53' 55 S 175° 24' 12 E	25	1,3,6	6	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
6/12/2011	Wilson Bay MFZ	36° 54' 36 S 175° 23' 08 E	26	1,3,4,6	8	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
6/12/2011	Wilson Bay MFZ	36° 55' 35 S 175° 25' 22 E	27	2,3,5	6	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
3/02/2012	Wilson bay MFZ	36° 55' 37 S 175° 25' 56 E	28	1,2,3,10,13	10	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
3/02/2012	Wilson Bay MFZ	36° 55' 52 S 175° 26' 12 E	29	1,4,9,12	10	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
6/12/2011	Wilson Bay MFZ	36° 56' 16 S 175° 26' 34 E	30	1,3,6	6	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
6/12/2011	Wilson Bay MFZ	36° 56' 45 S 175° 25' 45 E	31	1,3,6	6	4	All life stages	*Codium fragile ssp. tomentosoides, Styela Clava*
Total			**31**	**132**	**268**			

*GPS co-ordinates are given for the approximate centre of each mussel farm surveyed.

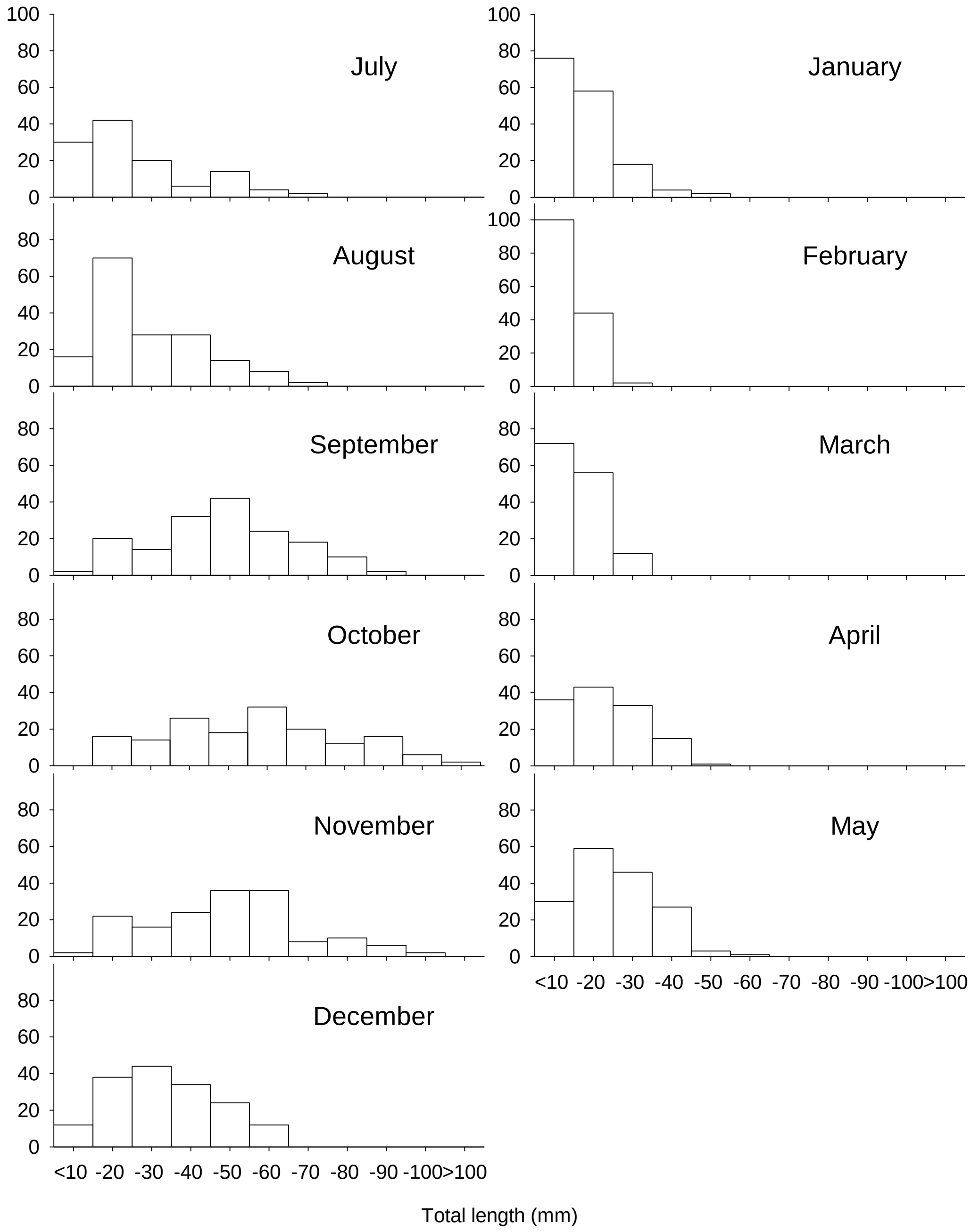
Appendix 3B: Mussel farm site environmental information

Date	Location	Farm Number	Time	Salinity	Depth (m)	Secchi depth (m)	Temperature (˚C)	Weather conditions
22/11/2011	Port Charles	3	11:00	35.4	12.0	6.5	16.0	Sunny
23/11/2011	Moturua Island	5	15:00	35.1	10.0	8	17.0	Overcast
23/11/2011	Koputauaki Bay	6	9:00	35.1	10.0	4	17.0	Overcast
23/11/2011	Motukopake Island (East)	8	11:15	35.5	22.0	7.5	17.0	Sunny
23/11/2011	Motukakarikitahi Island	7	15:00	33.5	19.0	6.5	17.0	Overcast
24/11/2011	Whanganui Island	13	17:00	35.3	7.8	5	17.0	Cloudy
6/12/2011	Wilson Bay MFZ farm #27	25	9:30	34.2	24.2	8.5	18.1	Overcast/showers
6/12/2011	Wilson Bay MFZ farm #39	26	11:00	34.2	23.0	6.5	18.1	Overcast/showers
6/12/2011	Wilson Bay MFZ farm #89	27	13:00	34.4	19.0	4.5	18.2	Sunny/cloudy
6/12/2011	Wilson Bay MFZ farm #142	31	15:15	34.4	16.0	4.5	18.2	Overcast
6/12/2011	Wilson Bay MFZ farm #173	30	16:05	34.1	15.0	6.5	18.2	Overcast
7/12/2011	Kirita Bay	24	8:45	34.4	6.0	6 (bottom)	18.2	Overcast
7/12/2011	Wekarua Island	20	10:30	34.7	13.0	8	18.1	Overcast/showers
1/02/2012	Kennedy Bay	1&2	12:30	34.5	8.0	7	19.3	Half cloud/overcast
1/02/2012	Port Charles	4	17:30	35.5	9.2	6	19.1	Cloudy/overcast
2/02/2012	Motukopake Island (East)	8	9:30	35.0	10.3	6.5	19.4	Overcast
2/02/2012	Motukopake Island (West)	11	11:15	34.7	9.0	6	19.4	Overcast
2/02/2012	Coromandel Harbour	16	1:30	35.0	10.4	5	19.8	Overcast
2/02/2012	Manaia LI357	19	15:00	34.5	8.5	5.5	20.6	Sunny/partly cloudy
2/02/2012	Manaia LI376	21	14:00	35.0	8.3	4.5	20.1	Overcast
2/02/2012	Manaia LI308	23	18:00	35.0	8.3	4.5	20.1	Overcast
3/02/2012	Kirita bay	24	9:00	34.5	6.0	5.5	19.2	Overcast
3/02/2012	Wilson Bay MFZ	28 & 29	9:30	34.5	16.8	4.5	20.0	Overcast

Appendix 4 - Size frequency distribution of monitored *Undaria* populations

Westhaven Marina.

160 random plants were measured every month.



Coromandel Harbour

The plants present on the 40 sampling floats were measured every month.

Note: no sampling was carried out in September 2011