Growing edible Taro in Waikato streams: effects of frost events

A. Parshotam, V. Parshotam and O.M. Parshotam

The Narrows Experimental Research Station, Hamilton, New Zealand

Abstract

Experiments were run in the 2013-14 winter season to determine the effects of frost events on taro plants grown at four locations: 1) a raised-bed, vegetable garden which was well maintained and watered, 2) in streams, 3) in container pots under sheltered conditions, and, 4) in open ground. Taro tubers were divided and planted at these locations in November, 2012. The growth characteristics were observed and tabulated in June 2013 prior to a frost event. Temperature probes were installed at these locations and measurement data collected through successive frost events. Photographs were taken at strategic times. The results showed that taro in streams was able to survive and thrive through seven successive frost events whereas taro grown at the other locations "keeled over" after the first frost event. The experiment was continued for four years with observations made. The results give us a better understanding of how taro grows in, and away from streams.

Additional keywords: temperature, setback, taonga

Introduction

Historically Taro (*Colocasia esculenta* (L.) Schott) is a widely distributed tuber vegetable crop and staple food in many localities in the humid tropics and subtropics. Taro's range extends into the temperate zones of East Asia, southern Africa, Australia, and New Zealand. The genetic and cultural origins of taro in New Zealand and other parts of the Pacific is discussed by Matthews (2014). Taro was originally brought to Aotearoa by the first Polynesian settlers. Not long after contact with Europeans and Americans, who provided alternative sources of food, the crop fell into disuse in most districts. However, some old taro plantings persisted in waterways, and new varieties were also introduced and cultivated in some districts. Taro is therefore still to some extent a cultural treasure or "taonga".

Taro in New Zealand is grown as a minor crop, largely in the gardens of Pacific Islanders in many parts of New Zealand. To our knowledge, taro is only grown commercially on a large scale at Pukekohe, near Auckland, and at Ngataki in the far North. Taro has been grown commercially for its leaves in plastic houses with fertiliser in Pukekohe, or with shelter to protect from frosts at Ngataki. Leaves picked for the Pacific Island dish *palusami* and the Indian dish *patra*, are generally at a stage where they are emerged and fully-unrolled but not fully-expanded.

High quality leaves have been grown successfully in plastic tunnel houses during late spring, summer and autumn (Bussell and Triggs, 2010). There has been interest in growing year-round production of taro leaves in northern New Zealand and newer cultivars have been trialled. Recommendations for obtaining higher leaf yields from mid-winter to early spring include increasing greenhouse temperatures, using raised beds and possibly utilising cool-tolerant Japanese cultivars (Bussell, 2006). More common tropical cultivars grown in New Zealand produce leaves between mid-winter and early spring (Bussell and Triggs, 2010). However, the Japanese taro cultivars of temperate origin produced leaves throughout the period from May 2007 to May 2008. Bussell and Triggs (2010) recommend further study on how to best optimise year-round production of young taro leaves in northern New Zealand.

It is believed to be not possible to grow Pacific Island cultivars in New Zealand with large corms (Bussell and Goldsmith, 1999; Bussell *et al*., 2004). Only taro roots, not leaves, are imported from the Pacific Islands although taro for root production has been grown successfully only recently in the far North. The growing conditions (not high enough rainfall or too low mean temperatures) do not allow the development of large size corms (up to 1 kg). New treatment for taro to remove organic matter and unwanted organisms associated with taro imported from Samoa are being trialled by Plant and Food Research (2016).

The taro plant is originally semi-aquatic, and thrives in semi-submerged/emergent conditions. Conditions that favour large size and high rate of growth of leaves appear to include shelter, heat, and wet boggy ground. Taro appears to tolerate a very wide range of low to high-nutrient conditions, and has a natural ability to absorb and respond to nutrients when available. It also tolerates a wide range of light conditions, and responds positively to full sunlight when water is not limiting. Shelter can increase ambient temperature and humidity required for effective growth. In some countries, some varieties of wild taro are regarded as invasive in waterways. Their dense growth out-competes other native species through over-crowding and it is believed that they have very little wildlife habitat value. To our knowledge, taro does not appear to be invasive in New Zealand.

Non-cultivated wild taro found in streams and under bush is an important green vegetable for villagers throughout Fiji and is often protected for that purpose (Thaman, 1984). In New Zealand, non-cultivated taro in a variety of garden or wild settings may have served a similar purpose, including as sources of planting material (Matthews, 2014). Although its growth during the winter is very limited in northern New Zealand, taro can quickly grow to a large size during summer, from a standing population of vegetative shoots. Taro survives frosts in many areas of New Zealand but with growth setback. This has been reported by local informants of plants growing in areas prone to frosts, for example in parts of Coromandel (Matthews, 2014). Taro plants can usually survive even when frosted down to soil level.

Taro is present in waterways of northern New Zealand, mostly as a result of deliberate planting for the purpose of harvesting as a food or fodder. Kirk (1869) describes taro in the Auckland Province as a remnant or escaped from field cultivation, found growing in waste places or by roadsides, and in wet soil or water. Matthews (2014) reports numerous locations for taro, some reaching 1-2m in height, growing in small streams and ditches. At Coromandel sites, Matthews (2014) reported that plants growing in narrow streams at the entrances of exposed coastal gullies appeared limited in size due to the height of the banks which sheltered them. Commercial taro cultivation under shelter at Ngataki in Northland was actually motivated by observing wild taro growing successfully in streams. Matthews (2014) also reported wind and frost damaged plants with recently rotted and torn leaves growing in open ground near the Waikawau River.

A major problem with growing taro in open ground in New Zealand is the adverse effects of frosts. While the visual effects are obvious, there is no published research on how frosts affect taro plants. Although there is much research done on frosts and the frequency of its events on horticultural crops such as kiwifruit, there appears to be little or no research done on the effect of frosts on vegetable growing, let alone studies on edible plants, in aquatic environments.

This paper reports a pilot field trial on the effect of frosts on taro plants with a particular emphasis on taro growing on the edge of stream banks, in streams and away from streams. We observed that taro grown in small streams entering the Waikato river survive through the winter season and do not experience as much setback as plants growing away from a stream. Our hypothesis was that this lack of setback is due to moving air and higher stream ambient temperatures. Running water from streams creates air movement which protects against frosts. This we acknowledged, may not be the only condition allowing taro plants to better withstand frost events.

A motivation for the research is to advance the view that growing taro in farm streams and ditches might be a productive use of dairy farm streams and drains, add to on-farm diversification options, and potentially increase locally grown, all year round, fresh taro leaves availability in New Zealand. Grown under the conditions proposed, taro would be a zero-input crop requiring zero irrigation, fertiliser, and management.

A further motivation for the research is the view that taro may provide an on-farm biological mitigation option for nutrient management in streams in a similar way to watercress's nutrient capture ability during active growth periods as shown by Howard-Williams *et al*. (1982) and Sukias and McKergow (2010). It has been shown by Bindu *et al*. (2008) that subsurface flow systems planted with taro could decrease the nitrate and phosphate content of wastewater, as well as organic matter. Taro's ability to capture other chemicals in aqueous environments is well reported in the literature. Taro has also been identified as a novel plant for the application of phytoremediation and was first reported in the international literature as a hyperaccumulator of heavy metals (Pramar *et al*. (2012). One of the interesting observations made is that the accumulation of Pb (which does not biomagnify) was highest in the leaves while for all other heavy metals in the study such as As, Ni, Cr, and Cd, the accumulation was the highest in the roots. It was concluded that this plant can be safely used for the remediation of these heavy metals, since grazing or consumption of the aerial parts will not lead to biomagnification. There are further uses for parts of the taro plant. The health benefits of taro (leaves and roots) are given by Cambie and Ash (1994) and the nutritional information of imported taro root acquired by consumers in New Zealand is given by Busch *et al*. (2003). Taro has also been shown to have an anticancer agent (Kundu *et al*., 2012) and taro has been listed by Toensmeier (2016) in a global toolkit of perennial crops for climate change mitigation and food security.

Materials and Methods

This paper reports a pilot study on whether an edible form of taro, and to our knowledge, non-invasive form of taro, is able to grow successfully in Waikato streams and withstand the frost events experienced in the area. Experiments were run in the 2013-14 winter season to determine the effects of frost events on taro plants grown at four locations: 1) a well-watered and maintained, raised-bed vegetable garden, 2) in streams, 3) in container pots under sheltered conditions, and 4) out in the open ground. Temperature probes were installed in and above the stream, out in the open ground, above the container pots, and in the vegetable garden. The study investigates the response of taro grown in streams to successive frost events and compares the response with taro not grown in streams. The experiment was allowed to continue for four years, without temperature measurements, and observation results noted.

The study site was the Narrows Experimental Research Station, adjacent to the Narrows Bridge in Hamilton. An RR (red petiole and rounded blade) variant (Matthews, 2014) was used in the study. These were acquired from the same location in Kamo in Whangarei where they were propagated over time from several plants. This variant may be recognised in the field simply as with red petioles (or leaf stalks) and rounded blades. The taro plants were uplifted in November 2012. The sizes of the corms were randomly distributed and divided and distributed into four unequal portions. These corms were planted in the stream, open ground, vegetable garden, and in container pots under conditions given in Table 1, under variable physical environments, water and light conditions, manure treatment and weeding. The vegetable garden area and area where pots were left were approximately 40m away from the streams. The open ground area was approximately 60m away from the streams and is an area prone to flooding several times a year and where the grass never gets very long.

The plants were examined every week for five months and growth rates and sizes and growing conditions tabulated. Photos were taken monthly and sizes logged. The mean size of leaves (cm), height of plants and thickness of petioles were approximated by taking a representative small area sample of $1m^2$ and using a tape measure. In June and before any signs of a frost event, HOBO™ temperature loggers were placed strategically at seven locations: two in the vegetable garden, three at the streams, one in open ground, and one at the container pots. The stream was 1 m wide and three temperature probes were placed along a transect across the stream 40-50cm above the surface of the water. One probe fell into the stream on the 21st of June and was left there to record stream water temperatures instead. At the other locations, temperature probes were placed at a height of 40-50cm from the surface of the soil. Temperatures were logged at 15 minute intervals from June 11 to July 17. The temperature data from the two probes at the stream and vegetable garden were averaged to given single readings.

Table 1: Description of the conditions the taro corms were planted in including numbers of tubers planted.

	Number of corms planted	Physical environment	Weeding and manure treatment	Water conditions	Light conditions
Vegetable garden	14	Raised beds. Planted with regular spacing.	Weeded regularly, fowl manure applied	Automatic sprinkler system watering twice a day	Full sunlight
Stream	5	Most were planted in the middle of the stream. One was planted on the stream bank.	No manure, no weeding	No watering	Full and partial sunlight
Pots	5	Under heavy canopy (protected). Well shaded. Not watered over the dry summer.	No weeding	Very little or no watering	Shaded
Open Ground	4	Under natural conditions. Not watered over the dry summer. Not weeded.	No manure, no weeding	Very little or no watering	Full sunlight

From June onwards, and at the onset of frosts, met service data was checked regularly for news of frost events. These were verified by observation, not by temperature measurement data. Photographs were taken at all sites before and after every frost event. Data from the temperature loggers were downloaded by USB and summarised in Excel.

The experiment was continued for four years and observations made during that time. Several new sites were also added during that time including a riparian margin 5m wide at one side of the stream site to compare in-stream, and out-of-stream taro growth.

Results

Figure 1 shows photos of taro growing under the conditions of the experiment in June 2013 before the first frost event. What is immediately obvious is how well taro has grown in the stream.

Table 2 presents some of the tabulated data at the same time in June before the first frost event. The plants grown in the stream were the most healthy looking, and grew higher than plants at other locations with lots of new vegetative shoots and very deep root structures. These plants had the highest number of leaves on average and while there was high variation in leaf size, the leaves, on average, were larger than leaves on plants at the other locations. The plants grown in the vegetable garden under well-watered conditions (automatic sprinklers) experienced some insect and wind damage, but had new shoots and deep root structures. Plants, on average, were half the height of those grown in the stream and had considerably fewer and smaller leaves. While plants grown in the container pots suffered no insect or wind damage they, in contrast, grew little, and plants had no new shoots and no extensive root systems. Overall, plants grown in the pots were considerably shorter than plants grown in the stream and vegetable garden and had fewer, smaller leaves. Likewise plants in open ground grew little, due to no water, had no new shoots and obviously poor root structure since they were easily pulled out. These plants, on average, reached only 12cm in height and had only two, relatively small leaves per plant. The mean thickness of the petioles of the plants grown in the vegetable garden, stream, container pots and open ground was 1cm, 1.5cm, 0.8cm and 0.7cm, respectively.

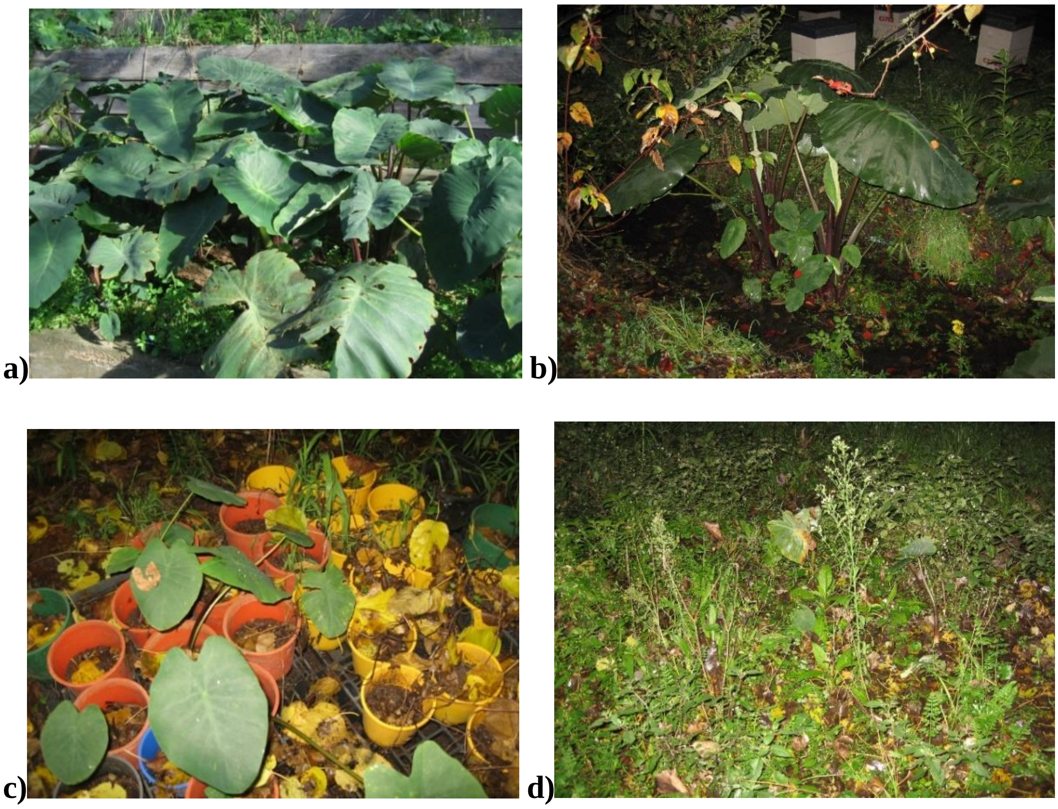

Figure 1: Taro growing in the a) vegetable garden, b) stream, c) container pots and, d) open ground. Photographs taken June, 2013, prior to the first frost event.

Figure 2 presents photographs of the first frost event of 23 June. Note the frost settling on leaves in all areas including taro plants grown in the stream. Figure 3 taken at three days after the first frost event of 23 June shows frost damage but no frost damage to plants grown in streams. Figure 4 presents photographs taken after seven sucessive frost events showing frost damage to leaves in taro grown in all areas except taro grown in streams. Figure 5 presents photographs of the whole plant including the roots of these plants after seven successive frost events. It may be observed that the taro plants in the stream survived all seven frost events but “keeled over” after the first frost event at the other locations. No taro was frost effected down to the soil.

Table 2: Summary of observations of the plants and small random plant samples.

	Vegetable garden	Stream	Pots	Open Ground
Visual observation of the plant	Insects chewed, some wind damage	Healthy	Small, no insect damage, no wind damage	Little growth due to no water
Visual observation of shoots	Some new shoots	Lots of new shoots	Grown a little but with no new shoots	No new shoots
Visual observation of the root structure	Deep rooted	Very deep rooted	No extensive root system	Easily pulled out
Average number of leaves per plant	9	23	2	2
Mean size of leaf length (cm)	30	65	10	10
Variation in size of leaves	High variation	Very high variation	Little variation	Little variation
Maximum leaf size (cm)	40	80	20	20
Mean height of plant (cm)	50	105	20	12
Maximum plant height (cm)	65	130	25	15
Mean thickness of petioles (cm)	1	1.5	0.8	0.7

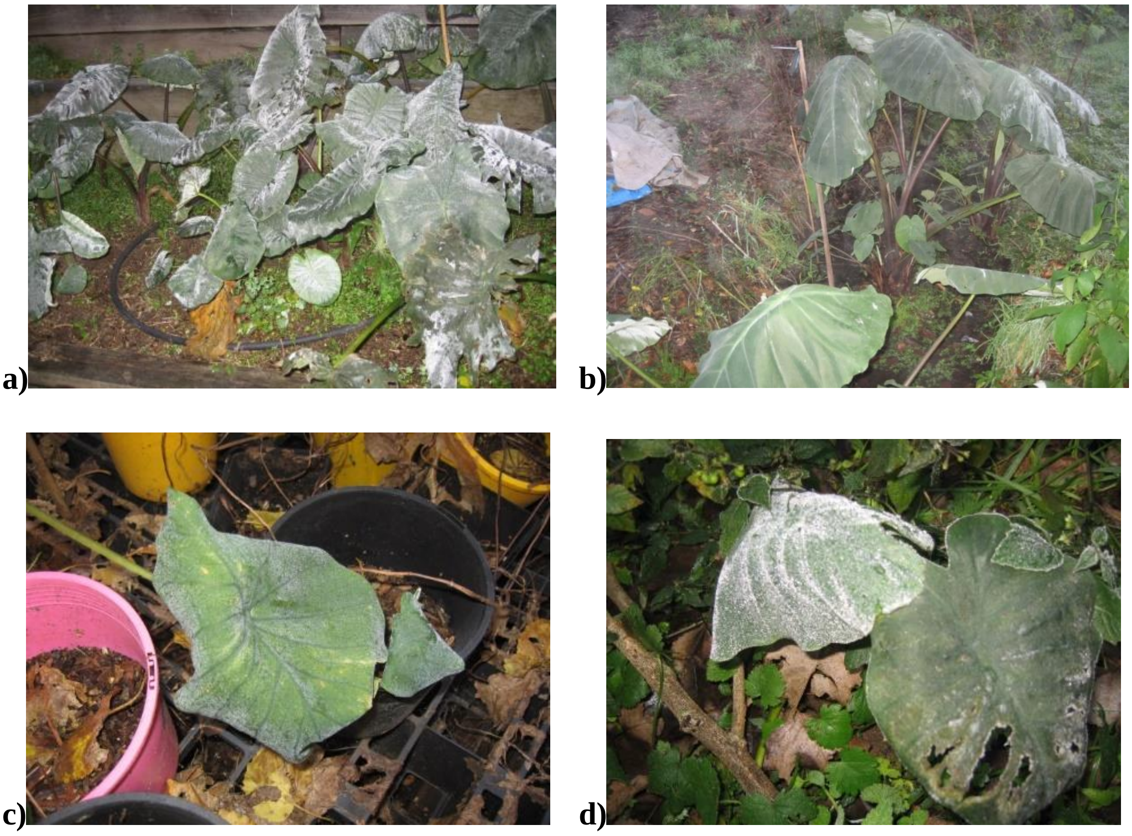

Figure 2: Morning after the first frost event of 23 June in the a) vegetable garden, b) stream, c) container pots and, d) open ground. Photograph taken at 6am.

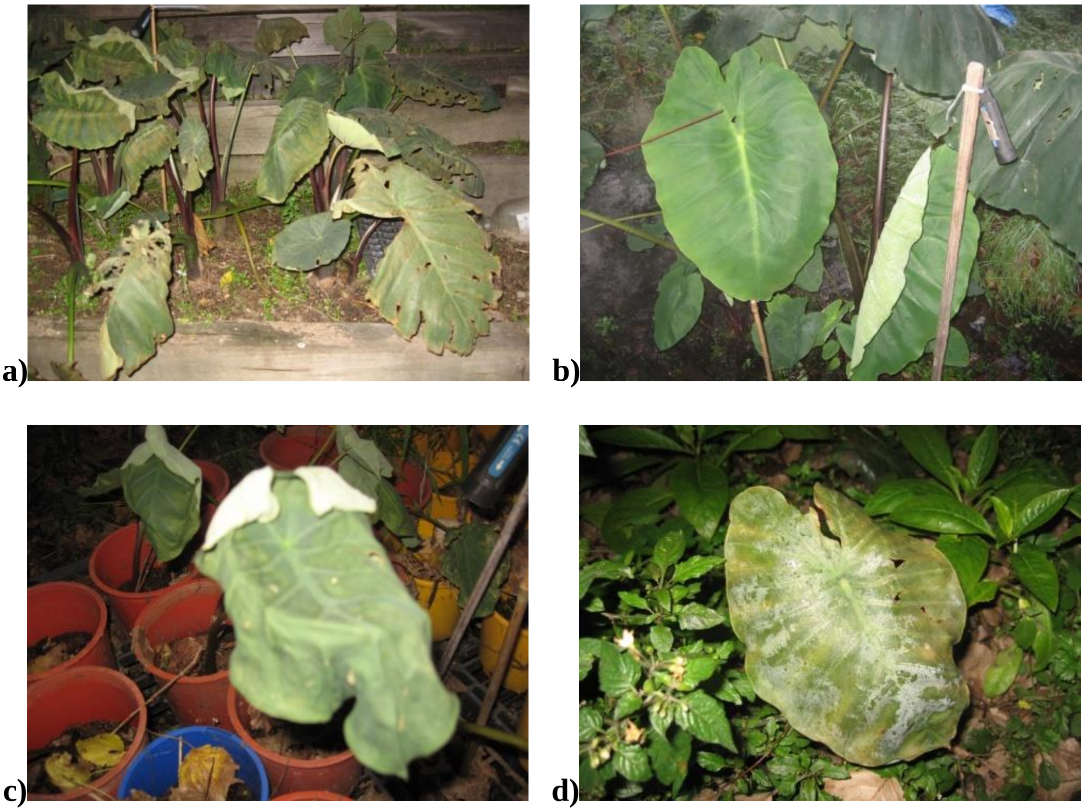

Figure 3: Taro three days after the first frost event in the a) vegetable garden, b) stream, c) container pots, and d) open ground. Photograph taken at 9am.

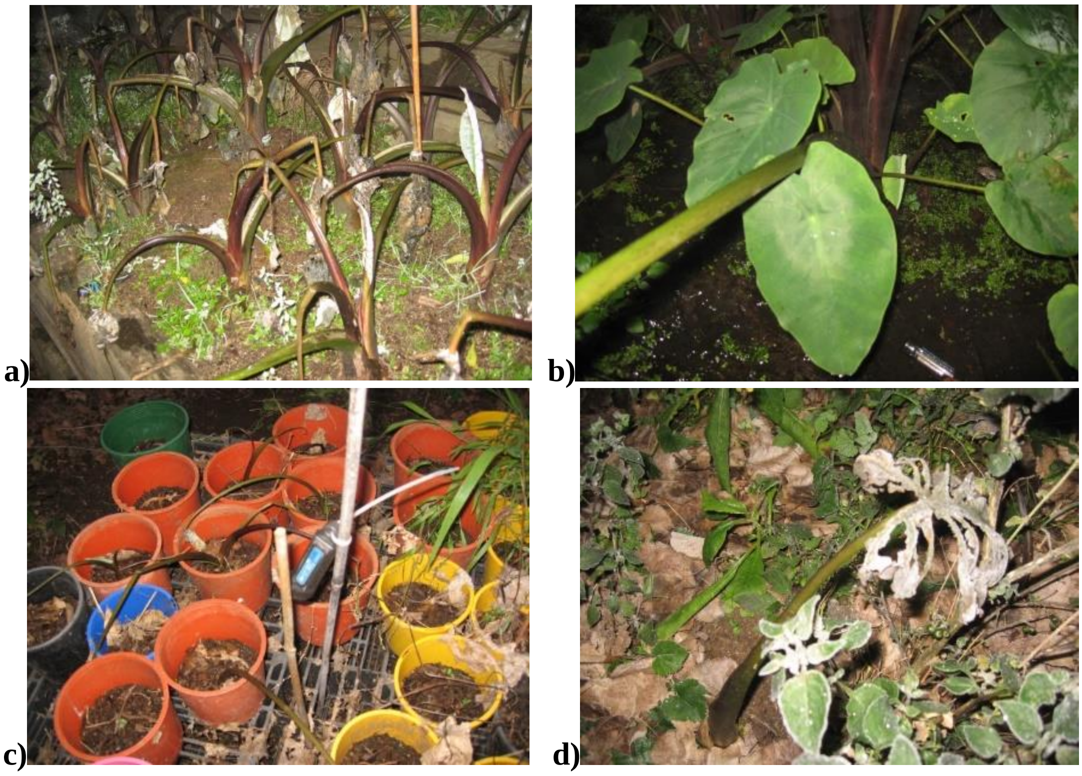

Figure 4: Taro after seven frost events in the i) vegetable garden, ii) stream, iii) container pots, and iv) open ground. Photograph taken at 9am on 20 July, 2013.

Figure 5: Photograph of taro taken after the seventh frost event on 1 September, 2013. The first photograph is of taro in the vegetable garden, the second in container pots, the third in the open ground and the forth in streams.

Figure 6 and Table 3 present temperature results at the four locations. The ambient air temperatures are on average 0.7 °C higher at the stream site than at the sites, and the minimum ambient air temperature is 0.9 °C higher at the stream site than the other sites. The temperature of the stream (from 21 June to 19 July) is about 4.8 °C higher than the stream ambient air temperature during this measurement period and is less variable.

Table 3: Number of nights where temperatures were below zero, the mean and minimum ambient air temperature from 11 June to the 19 July, and the mean and minimum water temperature from 21 June to 19 July, 2013.

Location	Number of nights of sub-zero temperatures	Mean temperature (^{o}C)	Minimum temperature (^{o}C)
Vegetable garden	7	9.2	-2.8
Stream	5	10.1	-1.9
Stream (water)	–	13.5	3.5
Pots	6	9.8	-2.5
Open ground	7	9.2	-3.1

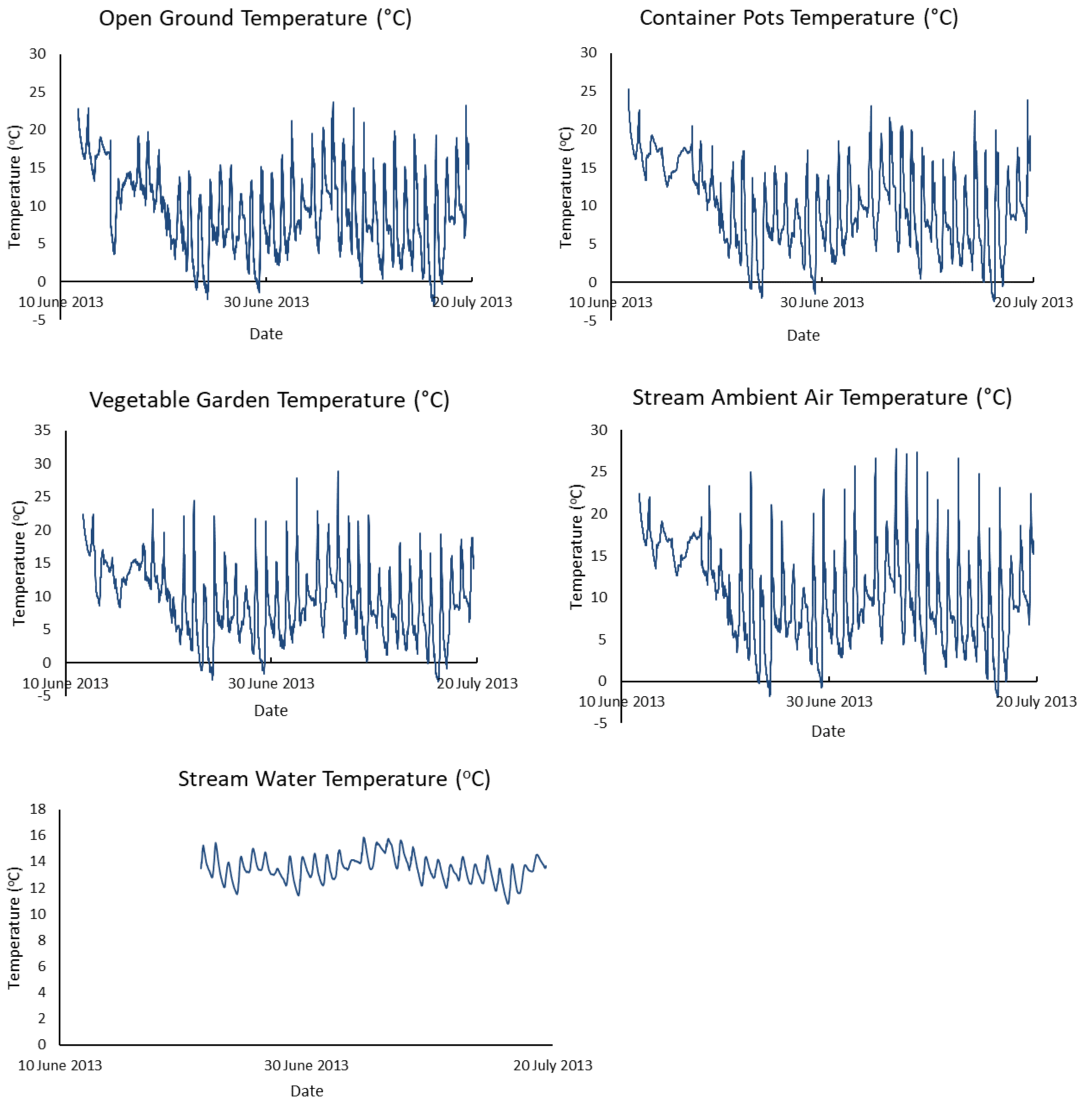

Figure 6: Temperature results (°C) for the open ground, container pots, vegetable garden and stream (water and ambient air) temperatures between mid-June and the end of July, 2013.

The experiment was allowed to continue for four years and into the 2017 season, and observations noted. In the 2016 winter season, plants grown in the streams did experience some setback, presumably because they were not new seasons' plants. However, it was noted that they were much less frost damaged than plants growing at the new experimental area on the riparian margin. The taro plants in the open ground took up to three years to establish and ultimately outgrow the weeds. The ones grown in container pots and left under sheltered conditions have remained the same size overall for four years. However, plants in streams continued to grow and thrive. Figure 7a presents photograph of the plants in the stream in mid-September, 2017 which show wind damage but not frost damage. Figure 7b shows a close-up photograph of the corms of some plants at this site and their sizes in mid-September, 2017 with larger sized corms around 25cm long and 10 cm wide.

a) b)

Figure 7a: Photograph of taro growing in the stream taken on 13 September, 2017, after successive 2017 frost events.

Figure 7b: A close-up photograph of the stream taro corms taken on 13 September, 2017, after successive frost events.

Discussion

A smaller number of tubers were planted directly in the stream because they were presumed to rot and die. However, in this study tubers planted directly in the stream thrived, matured and were able to withstand the frost events over the study period and beyond.

The current study did not compare data from taro growing in streams with taro growing in the adjacent riparian margins and that is the subject of a further study. Preliminary results do however suggest frost damage on taro plants a few metres away from the stream. Our results may give us a better understanding of how taro grows in and beside streams and indirectly, a better understanding of the reasons for the deliberate planting of taro in New Zealand waterways, particularly in Northland. It must be noted that different plants have different frost point thresholds which are generally below sub-zero temperatures. The experimental site is only 3 km away from the Mystery Creek and Hamilton Airport Weather stations. Data from the Mystery Creek weather station covers data not collected here and may prove to be useful in estimating frost points. The response of plants to frosts and frost mechanisms in aquatic environments needs further study and there is a paucity of information on this. Plants may well be better able to take in warm water to withstand frosts and move water around in the plant when necessary and withstand the damaging effects of frosts.

Growing taro in streams in a zero-management regime may present an alternative method of producing leaves all year round. It is assumed that only young taro leaves will be harvested under these conditions, and that no soil will be disturbed. Since taro essentially stops growing during the winter period, there will need to be a considerably greater number planted. Apart from the environmental benefits, there is also economic and commercialisation potential. There is already a sizable market for edible taro leaves in New Zealand with leaves fetching over $10/m^2$. Today, the widespread practice of fencing streams from cows is raising the question of what may be grown along streams. A riparian food forest that includes taro could be an option. Streams of orders one to seven in the Waikato catchment have a total length of 44 million metres and taro may potentially be planted on both sides of a stream in 1 m wide strips, and as we have shown, potentially in a stream, as well. This length estimate does not include the numerous ponds, farm drains and ditches also available for planting but where there could be food safety concerns issues preventing the use, harvest, or sale of this taro.

Methods to quantify nutrient capture by taro in different seasons as shown for floating watercress growing in water columns (Sukias and McKergow, 2010), requires further experimental exploration. Taro leaves, unlike watercress are not generally in contact with water and are not expected to carry food-borne illnesses like giardia, liverfluke and *e.coli*. However, this too needs further exploration.

Our results also suggest other potential areas on a farmer's property which could be set aside for growing taro with little or no management. The area of open ground which was prone to flooding took taro about three years to establish and outgrow the grass.

New experimental sites in the Waikato catchment have been trialled for growing taro. Some emerging challenges include *pukeko* digging up newly planted young plants in at least one site, and plants being washed away in flood events in late autumn 2017. However, plants which were not accessible to *pukeko* survived through the winter period and thrived. The use of wetlands and floating islands for growing taro as used in many parts of the world where there is a scarcity of land is also being explored as a possibility for nutrient removal in ponds. Preliminary results show that a GP (green petioles and pointed blades) variant (Matthews, 2014) grown in a stream were able to produce extremely large roots with few new tubers and may indicate stream nutrient variations.

Further experiments need to be conducted to find the best taro variants to grow in Waikato streams, including the potential of the original taro cultivars to New Zealand, generally considered to be not very palatable. In our discussions and investigation of the wider potential of growing taro in Waikato streams, we encountered strong cultural perceptions of which taro should be grown in New Zealand streams and waterways, and whether it should be planted at all. There was a strong view that it had better not compete with our native plants and we might be better off without it. Although we see this study as part of a revival of interest in a historically important part of our Polynesian-introduced flora, we have been encouraged by some culturally and ecologically motivated people to use only locally-present varieties of taro for environmental remediation. However, other people, including some *tangata whenua* acknowledge that taro is not strictly native to New Zealand and all varieties (Maori and Pacifika) may support common goals of sustainability. Further controlled studies are also merited on the potential invasiveness of taro.

Conclusions

Taro was originally brought to Aotearoa by the first Polynesian settlers and is therefore still to some extent a cultural treasure or "taonga". Taro is an important part of the diet of many New Zealanders but it is a marginal crop due to its sensitivity to frost. There has been interest in growing year-round production of taro leaves in northern New Zealand with newer cultivars, raised bed and increased greenhouse temperatures trialled in an attempt to solve the problem of very low or no taro production from mid-winter to early spring. Our study showed that taro grown in a Waikato stream thrived throughout the winter period and was able to withstand all major frost events compared to plants grown away from the stream. These results present an alternative method of producing taro leaves all year round that may also have some environment and economic benefits.

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