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**A study of the Length-weight relationships and diets of non-indigenous
Poecillids in New Zealand geothermal streams**

A thesis
submitted in partial fulfilment
of the requirements for the degree
of
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at
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Abstract

Poecillids are highly specialised and well adapted to surviving in highly undesirable conditions. Because of this they have been able to establish populations in many areas where they have been released. There are two species of poecillids in New Zealand that have established populations in thermal waters. Sailfin mollies (*Poecilia latipinna*) are found the South Taupo wetlands near Tokaanu, and the Guppies (*Poecilia reticulata*) are found at multiple sites in and near Reporoa. These fish were known to have been present in New Zealand since at least the 1930s. However, there has been very little study carried out on their ecology in New Zealand. In order to fill this knowledge gap, a study was carried out to assess the approximate population numbers and the health of each of these species. As well as this it was unknown what exactly these species were feeding on in the thermal waters; therefore a gut analysis was carried out to find out which species of invertebrates if any are part of the diets. It was found that both species have very healthy populations in New Zealand thermal waters; as well as this their diets vary considerably between both species. The sex ratios for both species in New Zealand are quite different from those found in other feral populations. The current populations are found to be of reasonable size especially the Sailfin Mollies; which shows just how well adapted these species have become to the New Zealand conditions. Because of the apparent lack of knowledge of these species numbers and feeding habits in New Zealand and the well-known ability of these species to colonise new habitats; it is important to understand the current population health to allow for any potential management programs in the future.

Introduction

Biological invasions are occurring throughout the world at an alarming and increasing rate (Duggan et al., 2006). Invasions are usually a result of either the unintentional or intentional introductions by humans. Every environment and ecosystem throughout the globe that has had contact with humans has had some form of biological invasion, with varying differences in effects to the local flora and fauna (Duggan *et al.*, 2006). Quite often, many introduced species fail to establish and soon die off with minimal impacts to the local environment. As well as this, some environments are far more resilient than others and can sustain the arrival of new species without the loss of indigenous species or extreme levels of destruction to the local environment (Beatty & Morgan, 2014). Conversely, there are numerous examples of unique and isolated environments that can suffer greatly from the establishment of non-indigenous species. This can then lead to large numbers of extinctions and widespread environmental degradation (Beatty & Morgan, 2014).

Some of the most vulnerable environments are freshwater ecosystems, which often have high levels of endemism and have geographically isolated species and populations. Many of these freshwater ecosystems are under enormous pressure from not only pollution but also the introduction of non-indigenous species, which are causing widespread damage to these fragile and unique ecosystems (Duggan, 2010). Freshwater ecosystems are crucial for the survival of many animal species, ranging from indigenous species to humans, and as such they are a high priority for conservation and protection from damage caused by human interactions. Many freshwater environments are situated close to cities and towns, allowing for easy access and therefore interference by people (Rahel & Olden, 2008). Because of this, there have been many cases of non-indigenous species being introduced to local waterways, despite such introductions being illegal in most countries due to the potential for these species cause irreparable damage. Often people that release biota into these habitats have no appreciation of the damage such species can cause. Once non-indigenous species establish populations in new waterways, eradication is typically impossible (Duggan, 2010).

In New Zealand, many nonindigenous species have established populations in freshwater systems. Reasons for introductions have included the release of Brown Trout (*Salmo trutta*), Rainbow Trout (*Oncorhynchus mykiss*), European Perch (*Perca fluviatilis*) and Common Rudd (*Scardinius erythrophthalmus*) for recreational purposes; to the release of species from the aquarium trade such as Koi Carp (*Cyprinus carpio*) and Goldfish (*Carassius auratus*), to species such as Gambusia (*Gambusia affinis*) released for mosquito control (McDowall, 1990). However, due to New Zealand having a temperate climate, the established species primarily originate from temperate regions and are thus able to survive cool winter conditions (McDowall, 1990). Nevertheless, several tropical fish have established populations in, and are restricted to, waterways that are thermally heated.

Currently only two fish species are known to have established populations in geothermal waters in New Zealand; Sailfin Mollies (*Poecilia latipinna*) and Guppies (*Poecilia reticulata*). A third species, the Swordtail (*Xiphophorus hellerii*), was present until recently; however, due to the cooling of the thermal stream via the extraction of heat for energy use; where Swordtails lived, Waipahihi Stream, they have now been extirpated from this site (McDowall, 2004). These species are all native to tropical regions and are found in waters above 19 °C and up to 40 °C, and all are in the family Poeciliidae, which are well known worldwide for their ability to colonise new environments and establish successful populations due to the adaptation of live bearing instead of laying eggs (McDowall, 1999). A fourth poecillid within the aquarium trade that has also been found to establish a feral population in New Zealand is the Caudo (*Phallogercus caudimaculatus*). This species has only recently been discovered, approximately 10 years ago in New Zealand, and as yet the exact origin and potential threat this fish could cause has not been properly assessed (McDowall, 2004). Lastly, the Western Mosquitofish (*Gambusia affinis*) is a poecillid species found throughout the North Island of New Zealand, and has been recorded from the top of the South Island, but is not restricted to geothermal sites (McDowall, 2004). This species is widespread throughout the world and, as the name suggests, was originally released to control mosquito numbers rather than the aquarium trade (McDowall, 1999). The Mosquitofish is able to survive in temperate waters, which greatly increases

the potential for them to spread in New Zealand. This species is now registered as an unwanted organism in New Zealand, and is known to have significant ecological effects (McDowall, 2004).

Despite the impacts and research focus on this species, the effects of the two species of Poeciliid established in geothermal waters have not been studied.

Many members of the family Poeciliidae globally, including Mollies and Guppies, are popular fish species in the aquarium trade, due to the ease of care and ability to survive in a large range of water conditions (Beatty & Morgan, 2013). Because of this popularity, as well as availability and survivability, this family of fish are now well established worldwide in many different environments including hot springs (Duggan *et al.*, 2006). For example, Mollies and Guppies have both established populations in geothermal streams in temperate New Zealand and Canada. They have also been found in Iceland where temperatures are far below freezing for large parts of the year; and yet due to the heated waters of the many volcanic springs stable populations can be found here (Deacon *et al.*, 2011).

It is likely that very little study has been carried out on Mollies and Guppies in New Zealand, as the habitats they are found are small and isolated. As such, there has been a perception that these pose little threat to native species (McDowall, 1990). However, there is also little knowledge about the invertebrate populations in these thermal waters, including whether their genetic makeup is similar to those in non-geothermal streams. This could mean that potentially endemic species, found only in thermal waters, are being preyed on (McDowall, 2004). This has the potential to cause extinctions of highly adapted species, which could put the ecological integrity of these thermal waters at risk. An additional issue with Molly and Guppy is that with predicted climate changes, the current limited range occupied by these species could well increase dramatically, creating a wider problem than is currently evident (Beatty & Morgan, 2013).

The aquarium trade is an important vector for the transportation, introduction and establishment of non-indigenous freshwater species. This vector is seemingly especially important for the

introduction of tropical fish into hot springs (Duggan, 2010). In New Zealand, all of the exotic fish species established in geothermal springs have resulted from illegal intentional releases (Arthington *et al.*, 1989). However, there are a number of motivations for these introductions, such as people thinking it is more humane to release them than to kill them (Chang *et al.*, 2009). Added to this, some aquarists like to establish a continuous population that can then be accessed when needed for use in their own aquariums or to allow breeding to occur in a semi wild population with the potential for new and different colours or physical characteristics (Chang *et al.*, 2009).

One of the key reasons that allow a species to establish in a new environment is propagule pressure, i.e., the number of individuals released into a site and the number of releases allowing for sufficient numbers to survive long enough to reproduce and self-sustain in a foreign environment (Duggan, 2010). Also, the introduced species need to be morphologically and physiologically adapted to survive in the new habitat (i.e., 'habitat matching'), especially if there has been no known native species that previously filled one or more niches in an ecosystem (Duggan, 2010).

Poeciliids: The Invasion Specialists

There are eight species of Poecilidae that are allowed to be imported and used in the aquarium trade within New Zealand. Four of these species are classed as high risk for potential biological invasions; *Poecilia reticulata* (guppy), *Poecilia latipinna* (Sailfin Molly), *Xiphophorus maculatus* (Platy) and *Xiphophorus hellerii* (Swordtail) (McDowall, 2005). All of these species are globally important as risks for biological invasions into thermal waters. One of the most important factors that have allowed the spread of these fish throughout the world is their popularity within the aquarium trade (Duggan *et al.*, 2006). This often means that wherever people can be found, these fish are not far behind due to the ever-increasing global demand for home aquariums. Aquarium invasions are well documented as often the most important reason for the introduction of Poeciliids (Duggan, 2010). Both Guppies and Sailfin Mollies originate from Central and South America (Courtney & Meffe, 1989). From there have been captured and transported via the aquarium trade globally (Courtney & Meffe, 1989). Guppies and Mollies imported into Australasia are primarily bred and transported from Singapore. Once in New Zealand the fish are transported to pet shops for sale, as they are worldwide from various other fish breeders and distributors. Because of the numerous and varied colours of these fish they are highly popular with aquarium owners. The next phase involved in the introduction of these fish occurs often when people get bored or have no time to look after their fish (Duggan, 2010). In many cases the owners believe that it is preferable to release the fish than the alternative, which is killing them. Because of this, many owners release their fish into local waterways. The Poeciliids utilised in the aquarium trade require a minimum of 19°C to survive, so in temperate countries they do not survive past summer, and usually cannot establish self-sustaining populations in local environments (Chang *et al.*, 2013).

A significant reason why Sailfin Mollies and Guppies are good at establishing feral populations is due to their low cost and popularity within the aquarium trade, meaning they are widely available for release (Chang *et al.*, 2013). Secondary to this are their biological characteristics, which allow for

high survivability and probability of establishment (Meffe & Snelson, 1989). These fish are highly adaptable, and within a few generations can exhibit genetic and phenotypic differentiation from the founding members, found within the aquarium trade (Endler, 2011). Both the Sailfin Mollies and the Guppies have been known to develop post zygotic incompatibilities due to reproductive isolation from other Poeciliids. One particularly good example of this is a population of mollies found in a cave in Southern Mexico that show high amounts of these physiological adaptations due to the isolation and harsh living environment (Greenway *et al.*, 2014). Additionally, some isolated populations have particular sexual selection behaviours that prohibit the mixing of the resident population with immigrants, which may not be as well suited for the local environment (Bierbach *et al* 2012). This ability to adapt to specific conditions over short time scales, and to rapidly become genetically distinct, demonstrates how adept these fish are at establishing feral populations, and also how much of a potential risk they are to native ecosystems (Courtney & Meffe, 1989).

The live bearing nature of Poeciliids is another reason for increased survivability of both young and the parents. This is because the internal gestation of the young allows the female to select more favourable habitats for the fry; which may increase the survival rates of young (Deacon *et al.*, 2011). Also, since the young are already active when born they are far more able to avoid the attention of predators than a clutch of eggs, which are at the mercy of predators. This reproductive strategy has another important advantage over most other fish species, because it allows the fry to reach sexual maturity far quicker than egg laying species (Deacon *et al.*, 2011). For example, guppies are able to reach sexual maturity within 4 to 5 weeks of being born; Goldfish, in contrast, take 12 months. This increased rate in the production of sexually mature adults allows for a greater proportion of the population to breed and therefore increase the overall population numbers far quicker than egg laying species (Endler, 2011). Even in habitats with less ideal conditions for survival, these fish are able to breed. Due to the harsh environmental conditions, larger and more developed young are produced. Although usually at smaller numbers, the increased size allows for faster reproductive development and therefore increases the overall survival rate of the population (Reisch *et al.*, 2012).

In addition to reproductive adaptations, these species are able to engage in compensatory behaviour when living in harsh conditions, such as being able to breathe air from the surface when faced with anoxic habitats. The other key biological adaptation that these fish have is the ability to change the trophic resource use, such as being able to switch from one food source to another. This can be followed by physiological changes both within the gastrointestinal and vicerocranial systems (Păsărin & Petrescu-Mag, 2011). This ability to change their diets and then physiologically adapt to the conditions within just a few generations' means the survival rate greatly increases. These adaptations, added to the popularity in the aquarium trade, means that these fish have been transported to almost every continent via the aquarium industry (Deacon *et al.*, 2011).

The establishment of feral populations occurs when the poeciliids are released into thermal waters, which remain warm all year around. In most cases, the release of these fish is often incidental and is not intended to cause damage to the local ecosystem; as it is seen as the humane way of getting rid of unwanted aquarium fish (Chang *et al.*, 2013). The potential damage they could cause is not appreciated (Chang *et al.*, 2013). Due to the ongoing popularity of these fish, they may be released multiple times in the same area and often in large numbers, as they are well known to breed and become prolific in home aquaria. This sheer number of releases coupled with the number of fish in each release increases the likelihood that the fish will successfully establish a population in these environments (Duggan, 2010).

Poeciliids are one of the most adaptable family of fish found in freshwater environments, and due to this adaptability are highly capable of surviving in some of the most hostile environments. This allows these fish to spread to other waters within short time periods, with very few individuals needing to be present when first released, to establish a healthy and long lasting population (Endler, 2011). In some regions around the world such as Central America but especially Mexico, they can be found living in highly acidic hot pools where conditions would seem too harsh for any other fish species to survive. However, this is an exception rather than the typical habitats these species are

found to establish, but it still emphasises their overall survivability and adaptability (Greenway *et al.*, 2014). As Poeciliids have a short generation turnover time, due to the live bearing reproductive strategy and early reproductive maturity, these fish are able to develop adaptations far more quickly than other fish. For example, this increased rate of reproduction and sexual maturity can allow for increased lengths of time living and reproducing in water that is high in hydrogen sulphide (Greenway *et al.*, 2014; Deacon *et al.*, 2011). To most metazoans, hydrogen sulphide is a respiratory toxin and is normally lethal at high levels or during prolonged exposure. This is due to the fact that hydrogen sulphide is an inhibitor of aerobic respiration and hampers the function of the mitochondria and the production of ATP. Nevertheless, a population of *Poecilia mexicana* (Shortfin Molly) occurs in sulphur rich waters in a cave in southern Mexico (Greenway *et al.*, 2014). Due to this, non-adapted individuals succumb to the effects quickly and perish relatively quickly. However, adapted individuals invest energy in producing a more effective somatic maintenance system, thereby stopping the hydrogen sulphide from affecting the respiration cycle (Greenway *et al.*, 2014).

Poeciliids are able to switch from an herbivorous diet to a more carnivorous one with little effort. A change in food availability can require them to switch from a solely algae rich diet to one that is more broad and that will often consist of both micro- and macro-invertebrates found in thermal waters (Cortney & Meffe, 1989). In inhospitable conditions where very few other animals live, poeciliids are well adapted to find sufficient food to survive. This is especially apparent in the normally herbivorous Molly species, which show both a decrease in the intestine length and a broadening and increase size of head and mouth (Beatty & Morgan, 2013). These physiological changes are indicative of a change in diet, and are important adaptations that allow these species to be able to survive (Langerhans, 2010). Yet these fish are able to get everything they need to not only survive but also reproduce and establish reproductively viable populations. Other stressors are often found in conjunction with the high hydrogen sulphide levels in thermal environments and will add further problems for survival. Often high temperatures are associated with geothermal environments. This usually means a reduced retention of oxygen in the water leading to even more

extreme anaerobic conditions, causing any fish found here to be more efficient at using the oxygen present or be able to breathe directly from the air (Lange, 2013).

The environments that Poecillid fish are found to have established feral populations are sometimes so harsh that they are the only fish found to be living in them. This creates opportunities in itself, as it reduces interspecific competition due to there being no similar sized fish with which to compete with for resources. However, many Poecillid species will live sympatrically in non-sulphuric waters leading to competition between them for resources and space (Beatty & Morgan, 2013). This can lead to a reduction in the overall health of the population as well as reduced population densities.

The smaller population can have issues with mate selection and resources accessibility if the competition is too intense (Endler, 2011). Predation from larger fish is non-existent in New Zealand thermal waters and will mean that fry that are normally eaten by larger fish will be more likely to survive to adulthood and will therefore reproduce (McDowall, 2004). This also has a further effect as it makes the environment the deciding factor on which individuals are able to survive and reproduce rather than being able to escape and avoid piscivorous fish, as this is of no consequence in the New Zealand geothermal environments (McDowall, 2004).

The previously mentioned adaptations can be highly specialised to environments that have higher levels of hydrogen sulphide and are therefore not shared or even present across all environments that the Poecillid fish have been able to colonise. They are, however, a good example of how easily these fish are able to establish in even extreme environments once released. The many different combinations of behavioural and physiological adaptations that allow Sailfin mollies and Guppies to exploit the local environments, means that they are then capable of becoming highly destructive to native species. This can be due to either direct exploitation of native species as food sources or by direct competition with native fish (Arthington *et al.*, 1989). Both of these negative pressures have been recorded elsewhere due to the presence of Poecillid fish in the local environment. Direct competition with native thermal water fish species has been reported from thermal waterways in

Nevada, USA; the native Moapa dace (*Moapa coriacea*) and the Moapa White River Spring fish (*Crenichthys baileyi moapae*) are both under pressure from Sailfin Mollies (*Poecilia latipinna*). Both direct resource competition and even aggressive bullying by the introduced Mollies has caused a slow but constant decline in the populations of the native fish (Scoppettone *et al.*, 1998).

Direct predation on native invertebrates by invasive fish species has been studied and recorded in many waterways throughout the world. One of the best examples is the decline and loss of certain Megalagrion damselfly (Ordonata) species in Hawaii. There, intentional release of Poeciliids as a means to control mosquito populations was undertaken in the early 19th Century, including of Sailfin Mollies (*Poecilia latipinna*), Guppies (*Poecilia reticulata*), Swordtails (*Xiphophorus hellerii*) and Platies (*Xiphophorus maculatus*). The consequences for other species present in these waterways were not considered before the fish were released (Englund, 1999). Like many of the intentional releases of Poecillid fish, they have not been successful for the job intended, and have instead eaten many of the native insects. The Hawaiian example is especially significant because the dramatic decrease in the native damselflies is not matched by a decrease in introduced damselfly species, which occur in the same waterways. The main difference in the susceptibility of introduced and native damselfly species was the chosen strategy used by the nymphs when confronted by a predatory fish (Englund, 1999). The introduced damselfly nymphs actively tried to escape from the fish by swimming away when the fish got close. The native species, however, did not move, which was an adaptation for hiding from native predators such as birds and other insects. Due to the inability of the damselflies to evade predation, many once widespread species are now confined to small areas, often upstream of physical barriers where fish are unable to traverse (e.g., waterfalls) (Englund, 1999). This specific example shows the damage that these fish can do to native invertebrate species. It also shows that they are a potential issue worldwide. It is only due to the fact that they are unable to survive in lower temperatures in many of the countries they are found in, which means that many invasive populations of these fish globally are geographically isolated (McDowall, 2004). The continued establishment and spread of populations of Poecillid fish in many

parts of the world will continue, and in some cases may increase, as they become more popular in the aquarium trade, which in turn will increase as the human population grows. Many of the Poeciliids currently found in home aquaria worldwide are no longer wild caught but bred in captivity (Cheong, 1996). The sheer ease of keeping these fish and the ability for anyone to breed them has made them one of the most important and popular groups of fish in the aquarium trade. With high popularity and adaptability, as previously stated poecillids have been found in geothermally influenced waters in Canada, in multiple sites in the USA, and hot pools in Iceland, where their movement is considerably restricted due to the extreme cold weather throughout the rest of the country (Chang *et al.*, 2013).

Poecillid species found in New Zealand aquariums are bred and raised in Singapore (Cheong, 1996). Fish breeders in Singapore supply almost all of the fish to the many shops and suppliers, that then supply the many home aquariums throughout Southeast Asia and Australasia. With the continued popularity of Poeciliids in the aquarium trade, the threat of invasion is a constant issue that every country with suitable habitats must be concerned with both in the present and the future (Ng *et al.*, 1993). The aquarium industry is one of the fastest growing and most popular hobbies across the world, and as more people become involved there is no doubt that some of the most popular fish species will be Poeciliids. This popularity is the number one concern for potential introductions in the future. It is also the reason why these fish are so widespread and will continue to establish feral populations. Whether the releases are intentional or not, the sheer number of these fish being collected and kept in aquariums increases the potential threat worldwide (Chang *et al.*, 2013; Beatty & Morgan, 2013).

In New Zealand Poecillid fish are found at two sites influenced by geothermal activity; Sailfin Mollies are found within the Tokaanu wetlands south of Lake Taupo, and Guppies are located at Golden Springs near Reporoa. There are no native fish species that are resident in thermal waters in New Zealand, so no competition between them and the poecillids is occurring (McDowall, 1990).

However, there are a number of native invertebrate species that are found within these waters that could provide a food source for these species (Forsyth, 1983). Nevertheless, no known study has been undertaken into whether these invertebrates are affected, and if the poeciliid fish are the direct reason for any decline in invertebrate populations.

The examples given as to why the Poeciliids are such specialists at establishing feral populations and how they become so destructive to the local flora and fauna show that they are a real threat to the future integrity of many freshwater ecosystems (Endler, 2011). This, coupled with their ever-increasing popularity in the aquarium trade, means that they are an important study area when examining how non-indigenous species can affect native species composition and distribution within selected environments (Chang *et al.*, 2013). Poeciliids also provide a unique opportunity for study into the increased ability these fish have to adapt and survive in new environments and how over relatively short time periods a species is able to become both physiologically and genetically distinct from the original species that was introduced (Langerhans, 2010).

Poeciliids in New Zealand

In order to assess the health of the poeciliid populations, some of the physical measures include both weight and length of individual fish. As well as these, the approximate total population number and sex ratios are important when trying to determine the overall health of these fish in New Zealand. The physical health of individual fish allows for an understanding of how well adapted the fish are to the local environment and the potential food sources they are accessing (Courtney & Meffe, 1989). The physical condition of the fish will have a flow on effect on the reproductive capabilities as well as the likelihood of survival once introduced to new environmental conditions (Beatty & Morgan, 2013). In New Zealand both the Guppies and Sailfin Mollies are well established in their respective environments, both have individuals filling each life stage from tiny fry, to juveniles and larger reproductively active and viable adults (Arthington & Lloyd, 1989).

Poeciliids are documented as being able to establish 'healthy' populations in numerous and highly variable environments around the world. However, there are several measures as to what counts as a healthy population, which are dependent on both the species being studied, and most importantly the environment that they found in (Hellmann *et al.*, 2009). The two species with feral populations in New Zealand, Sailfin Molly (*Poecilia latipinna*) and Guppy (*Poecilia reticulata*), are relatively well studied in regards to what a healthy population is described as and which conditions are required to achieve this, both physiologically and environmentally. Because of the high adaptability of these two species, there are several ways to describe and therefore predict the potential health of individual populations (McDowall, 2004).

Poeciliids are a globally important family of fish when looking at potential biological invasion threats in freshwater environments (Beatty & Morgan, 2013). The distinct lack of knowledge of the ecology of these species in New Zealand means that very little is known of what kind of damage they are doing. Without this knowledge it is not known whether they are a problem that needs to be managed, or if in fact they have no possibility of wider establishment in New Zealand. With this in mind it is important to determine and compare known ranges and habitats of both Guppies (*Poecilia reticulata*) and Sailfin Mollies (*Poecilia latipinna*). Along with this the size, weight and therefore overall health of the populations found in New Zealand will further show how well these populations are doing in New Zealand.

The three main aims for this thesis are;

- 1) To show how and why Poeciliid fish are such good invasion specialists by describing the reproductive, physiological and behavioural adaptations that help them establish populations.**
- 2) To determine what the diets are of the two species of Poeciliids found in New Zealand thermal waters.**

3) To examine the comparative health of both species of established Poeciliid species by studying the sex ratios, the size and weight distributions, and by carrying out a population estimate.

Methods

Guppies and mollies were collected from multiple site visits between January 2016 and April 2016. Sailfin mollies were found in a thermally heated ditch behind the Oasis Motel in Tokaanu, which connects two thermally heated wetlands found at the southern end of Lake Taupo near Turangi (38.9615° S, 175.7646° E). Guppies were found in a thermally heated stream at Golden Springs near Reporoa (38.4696° S, 176.3087° E). Environmental parameters (temperature, dissolved oxygen and conductivity) were recorded from three randomly selected sites 5 metres apart moving downstream at both the Tokaanu wetlands and the thermal stream at Golden Springs.

At each site, both poeciliid species were captured using a scoop net or hand held pole net with 500 µm mesh. Each net was left for up to 15 minutes at randomly selected sites 5 m apart. After the allotted time the fish were captured with the net and removed into containers and placed into an ice slurry in order to euthanize the fish and halt the digestive process. Once dead the fish were placed into labelled containers holding 90% ethanol in order to preserve the fish and gut contents. Fish were then returned to the laboratory. To determine the overall sex ratios for both species of Poeciliid the capture process was repeated at each site for both species. To ensure there was no preference for capturing of males or females or larger or smaller fish, the same process was followed each time fish were captured so as not to cause bias towards one size or sex of fish. Also, the sites used for capture were selected with no preference for ease of access or apparent fish presence beforehand. Captures occurred both in the morning and afternoon and from the 7/1/2016 to 15/4/2016.

In the laboratory the fish were weighed to the nearest milligram (mg) and measured to the nearest millimetre (mm). In order to obtain an accurate comparison of both the males and females,

individuals were sexed by looking for the gonopodium (modified anal fin) which is physically apparent on the underside of males of all poecillids.

20 males and 20 females of each species were selected, and their stomachs dissected and removed from the digestive tract and other viscera with the use of a dissecting microscope. In addition, the use of a scalpel and tweezers allowed firstly the removal of the guts from the bodies, and then to spread them on the slides. The stomachs were then split down the middle and spread onto individual slides. Then, 70% glycerol was placed onto them to prevent them from drying out, and a cover slide was placed on top. The gut contents were identified using a compound microscope at 40x magnification. Any macroinvertebrates found were identified to the lowest practical taxonomic level using the keys of Winterbourn & Gregson (1989) and Snell (2005).

In order to estimate the overall population numbers of both the Guppies and Sailfin Mollies, each was measured with the use of the DeLury Method of Population Estimation depletion technique. At each site for both species a net was placed at a randomly selected position, along the most accessible section at each site, and left for a total of 15 minutes then removed. The fish caught were removed and placed into a bucket in which they were counted. The net was then replaced and left for another 15 minutes. This process was repeated five times, and each time the fish were removed and counted. The numbers of fish caught on each occasion were then used in the formula:

$$\log_e (C_t/f_t) = \log_e (qN_0) - qE_t$$

Where:

C_t = number of fish caught at time t

f_t = effort expended in taking C_t

q = catchability

N_0 = initial population size

E_t = cumulative effort

The natural log of this expression was then graphed to find the slope (q) and the y intercept. These were then expressed as intercept/slope, to find out the total estimate for each population.

The Length/weight Relationship was calculated with the use of the expression:

$$W=aL^b$$

Calculations were completed for both sexes of both species, where W is weight in mg and L is length in mm, a (the condition factor), b (the allometric index) are fitting constants.

Fulton's Condition Factor was used to measure the overall health of each individual fish by comparing the weight and length. The idea is that larger fish in both length and weight are healthier. By comparing each individual measurements, the average overall health factor for the population can be estimated. When using Fulton's condition factor, the lengths of each individual fish were converted to cm. An average condition factor below 1 indicates the population is in poor condition, around 1 is fair, and above 1.2 typically indicates the population is in good condition. Proposed by Fulton in 1904, it assumes that the standard weight of a fish is proportional to the cube of its length: $K=100(W/L^3)$. Where W is the whole body wet weight in grams and L is the length in centimetres.

In order to work out the percentage of each prey species found in the guts of the guppies the number of heads from each different invertebrate were counted. This was achieved by examining each slide under a compound microscope at 40x magnification. The number of each prey species was divided by the total number of samples for males and females (20), and then multiplied by 100 to obtain a total percentage. The invertebrates were divided into two groups; those invertebrates of aquatic origin and those of terrestrial origin. The reason they were separated was in order to find out where exactly the main part of the diet originated from, thus allowing an understanding of the predation pressure on invertebrate communities within the geothermal waters.

Results

Environmental conditions

Water temperatures at Tokaanu where the Sailfin mollies were captured varied from 20.1 °C to 39.6 °C, depending on the distance from the source of the hot spring. However, fish were found to be living across this entire temperature range. Dissolved oxygen saturation ranged from 55% to 197% and the specific conductivity ranged from 219 to 260 $\mu\text{S}/\text{cm}$. The salinity levels were 1.3 ppm and pH was 8.1.

Water temperatures at Golden Springs were consistent at 37.8 °C on each occasion measurements were taken; even at different points both down and up stream. The dissolved oxygen saturation ranged from 69% to 72% and the specific conductivity ranged from 101 to 109 $\mu\text{S}/\text{cm}$. The salinity level was 0.4 ppm with a pH of 7.4. Measurements of environmental variables in Golden Springs were overall more stable both at different points in time and along the actual stream, than those at Tokaanu.

Weights, Lengths and Sex Ratios

The size and weights of collected fish were as representative of each life stage as possible, from fry to mature reproductive adult. The sexual maturity was measured in the Sailfin Mollies by looking at the both size and physical health. In addition, the physical maturity of the males represented by the size of the dorsal fin and overall colouration was used; the bigger and more colourful the fins the more sexually mature the male (McDowell, 2005). In the Guppies, again, the size and overall health was examined to determine approximate sexual maturity; however, it was more difficult to develop an accurate understanding of the ages of this species (McDowell, 2005). This was able to show the overall health of the population; as expected, the larger the individual the heavier and the more mature. The mean weight for male Sailfin Mollies was 0.92 g and the mean length was 39.4 mm. The females were considerably larger, with a mean weight of 3.06 g and mean length of 57.5 mm. The

Guppies also showed this difference in size between males and females, with the mean weight and length for males being 0.23 g and 22.3 mm, and for females 0.54 g and 29.5 mm.

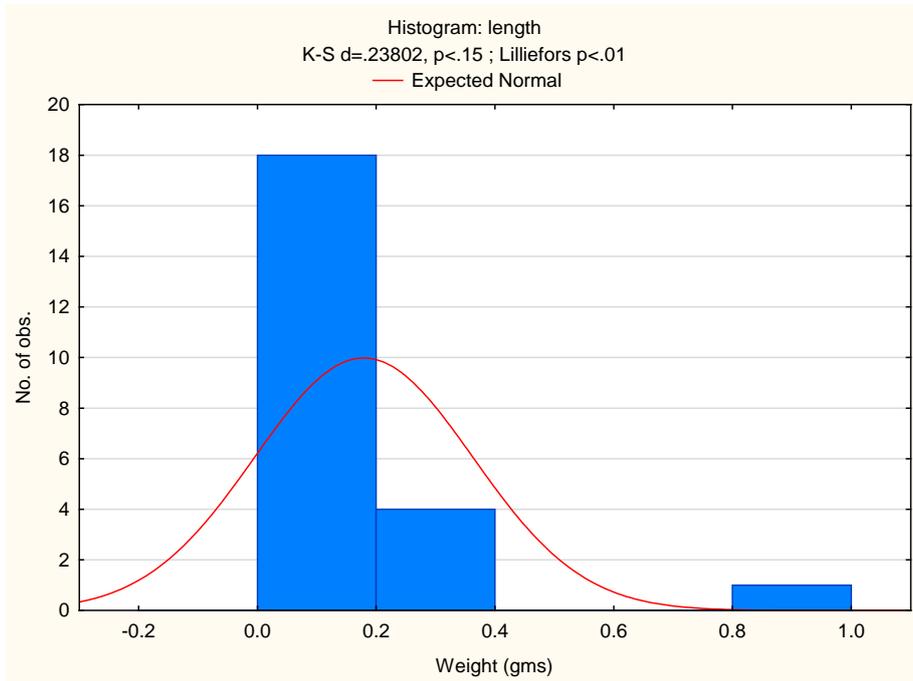


Figure 1: Weight variance of Male Guppies collected from Golden Springs

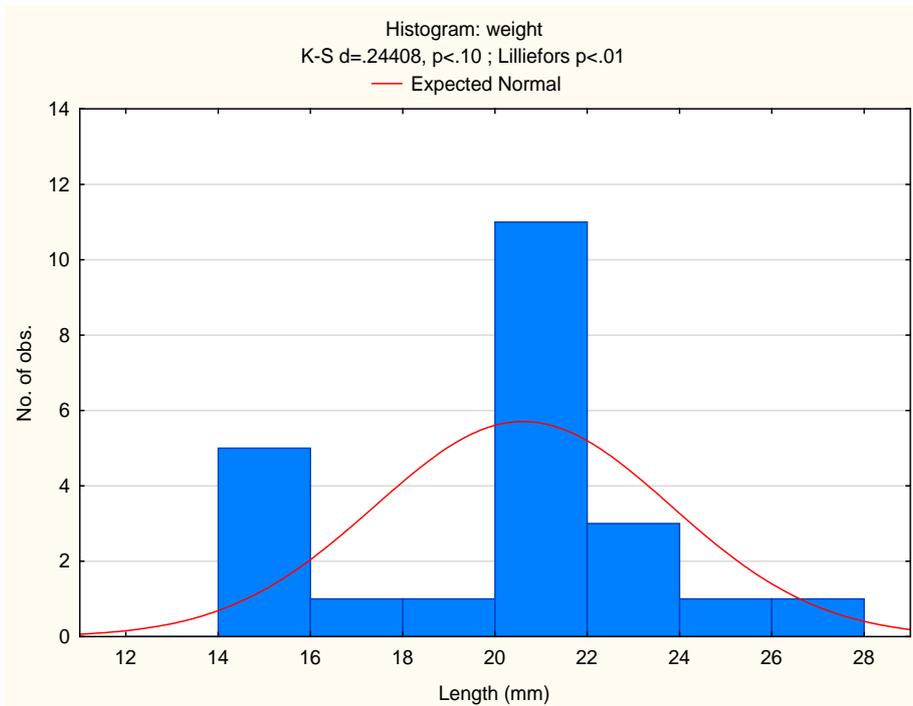


Figure 2: Length variance of Male Guppies collected from Golden Springs

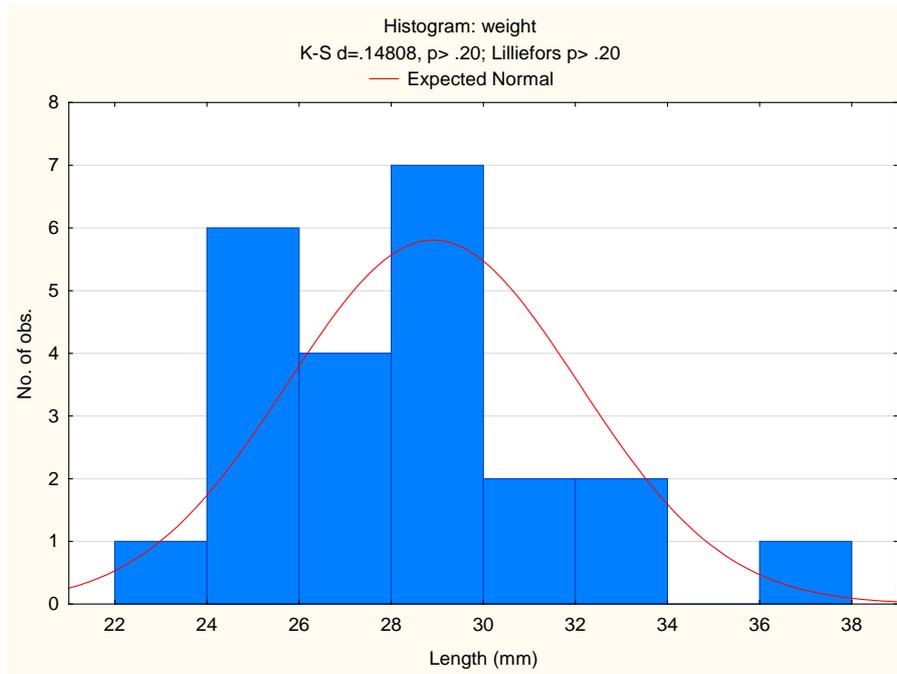


Figure 3: Length variance of Female Guppies collected from Golden Springs

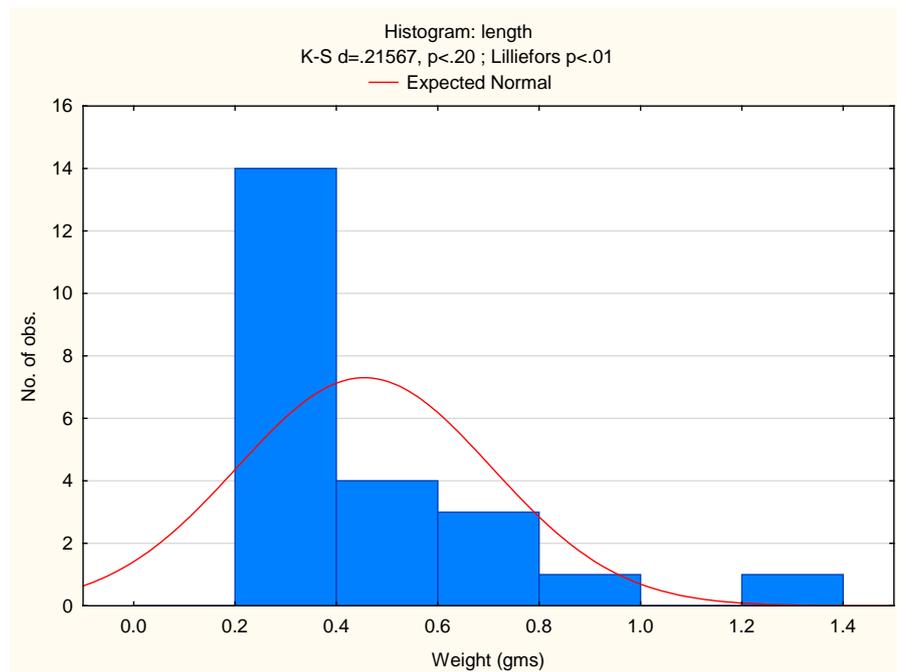


Figure 4: Weight variance of Female Guppies collected from Golden Springs

The length of the male guppies is shown in figure 1 and the weights in figure 2; the females lengths are shown in figure 3 and the weights in figure 4. There was a large difference between not only the maximum and minimum measurements but also the spread across both the weights and lengths. Males had much tighter groupings within both the lengths and weights than females, with the majority of male individuals found within the 200 mm to 240 mm range for length and the 0.2 g weight range. The females in comparison were more spread out over both, ranging from 220 mm to 380 mm and from 0.2 g to 1.3 g. Even though the average for both measurements is higher for the females, they still had greater variation.

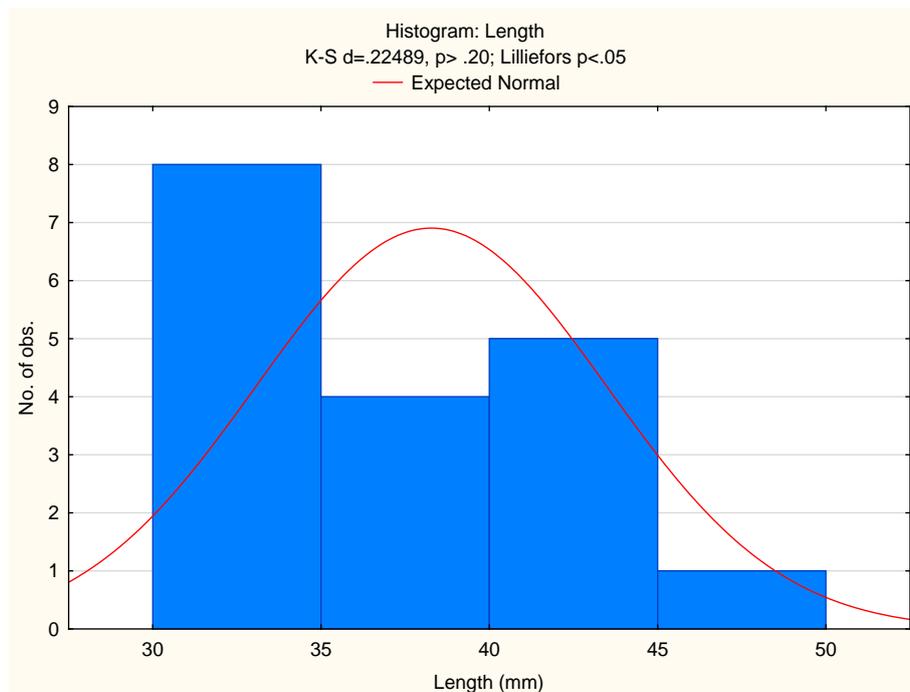


Figure 5: Length variance of Male Sailfin Mollies collected from Tokaanu wetlands.

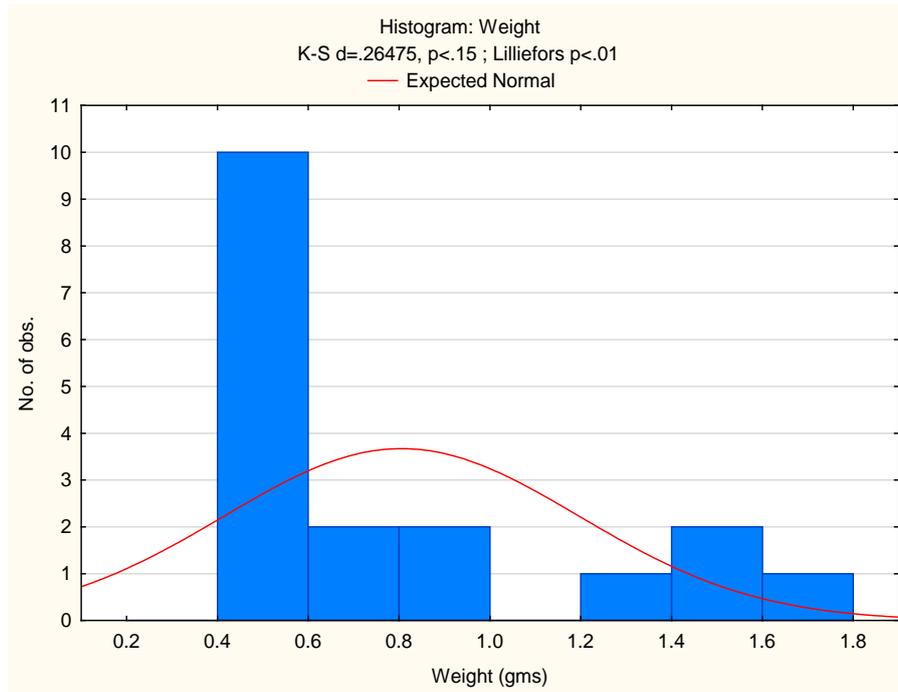


Figure 6: Weight variance of Male Sailfin Mollies collected from Tokaanu wetlands

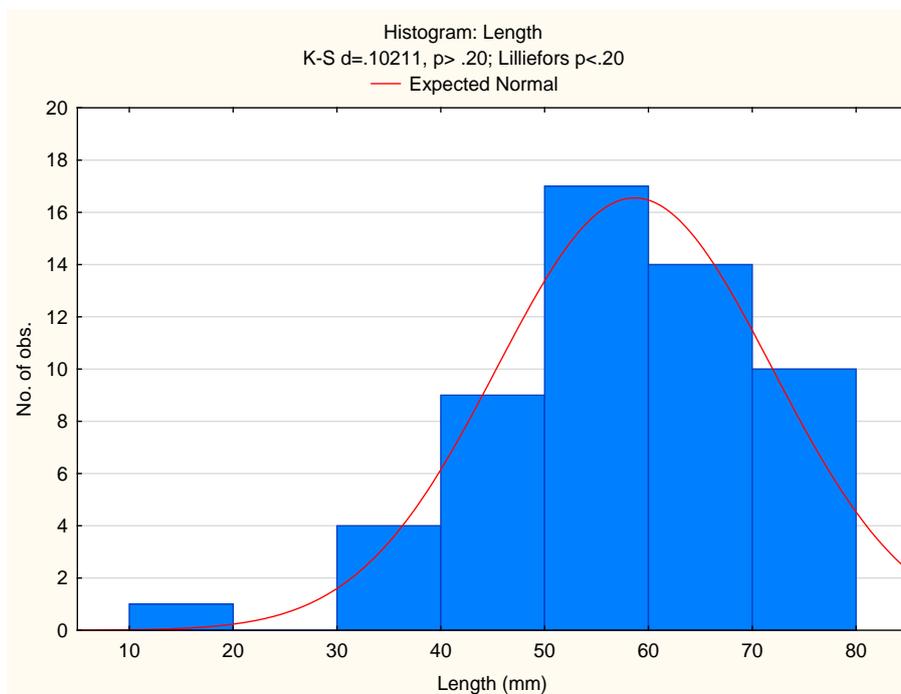


Figure 7: Length variance of Female Sailfin Mollies collected from Tokaanu wetlands

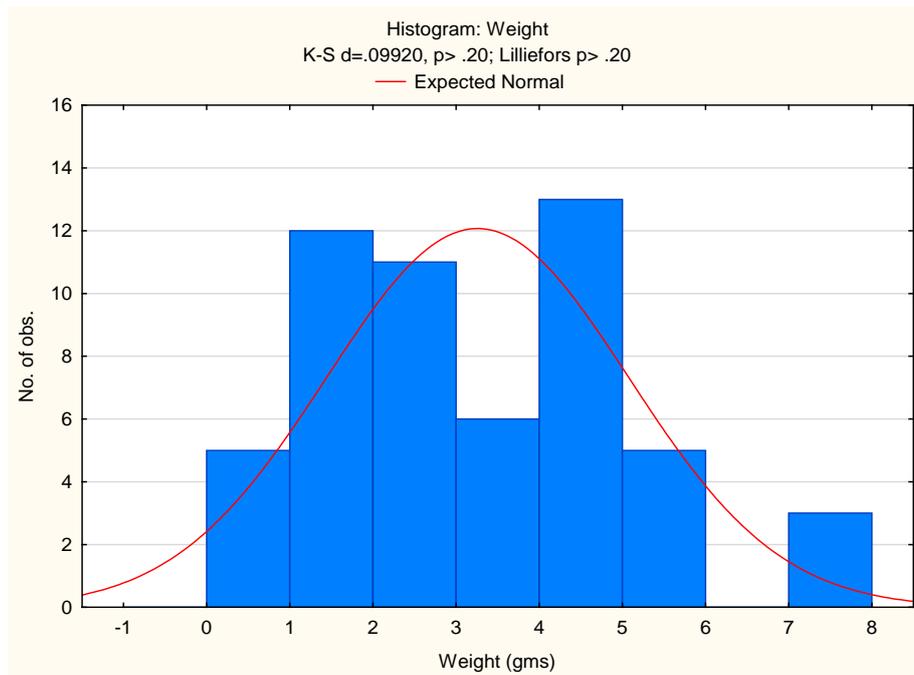


Figure 8: Weight variance of Female Sailfin Mollies collected from Tokaanu wetlands

For Sailfin Mollies, similar trends are seen between the males and females, with the females again having a far broader range of both weights and lengths than the males. Males range from 220 mm to 500 mm in length and 0.4 g to 1.8 g in weight. When this is compared to the females, which range from 100 mm to 800 mm in length and from <1 g to almost 8 g in weight, it shows a considerable difference in weight and length ranges. Although the females on average are the larger of the two sexes, with both higher weights and longer lengths, but they still show a far larger spread across the different measurements.

The Length-Weight relationship for Male Guppies is, $W=1.18 \times 10^{-6} \times L^{2.7130}$, and the Length-Weight relationship for Female Guppies is $W=4.49 \times 10^{-6} \times L^{3.7162}$, as shown in figures 9 and 10. As b is close to three, both the male and female guppies are growing at an isometric rate. This means that the guppies are growing at an equal rate both in terms of weight and length. This is important because isometric growth is one of the leading indicators for a healthy population.

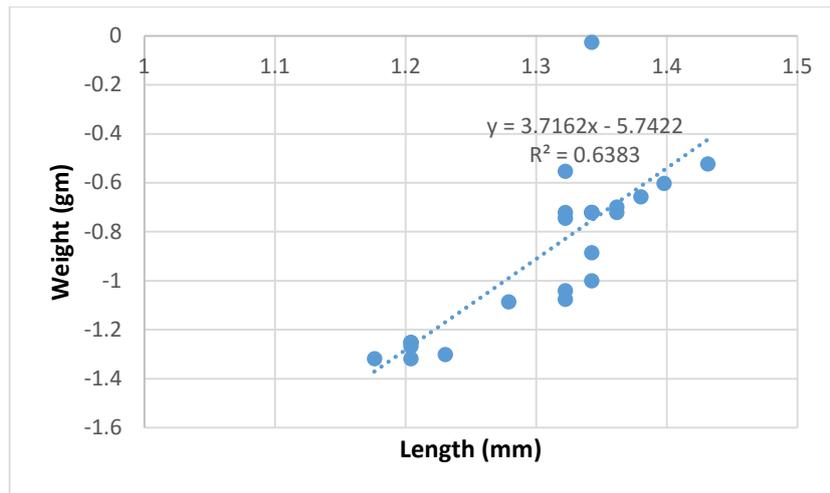


Figure 9: Weight-length relationships of Male Guppy

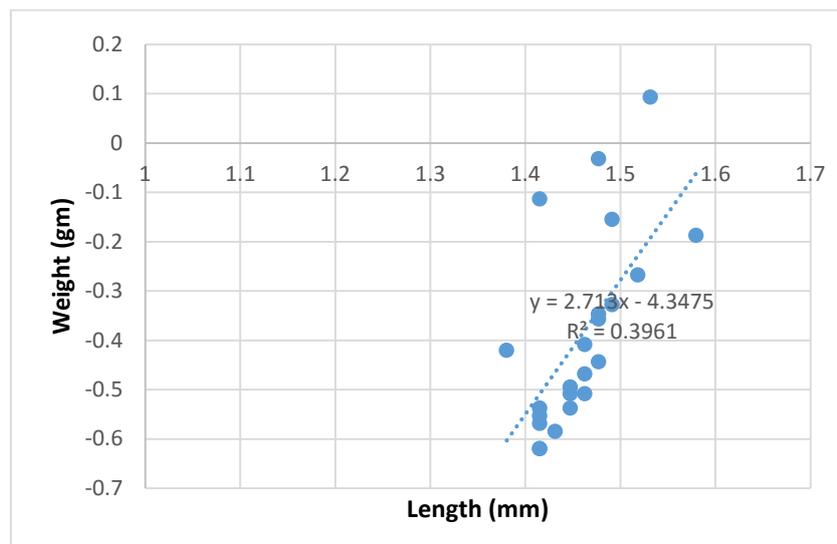


Figure 10: Weight-length relationship of Female Guppy

The Length-Weight relationship for female Sailfin Mollies is, $W=2.39 \times 10^{-6} \times L^{2.9657}$, as shown in figure 12 and the Weight/Length relationship for Male Sailfin Mollies is $W=1.68 \times 10^{-6} \times L^{2.8477}$, as seen in figure 11. Again, b is close to three and therefore indicates isometric growth meaning that the Sailfin Mollies are also a very healthy population. What this also shows for both species is that there is next to no difference in growth rates between the sexes, meaning that both the males and

females in each species are growing at equally healthy rates. With an R2 of 0.98, greatest confidence can be placed in the growth parameters for female Mollies.

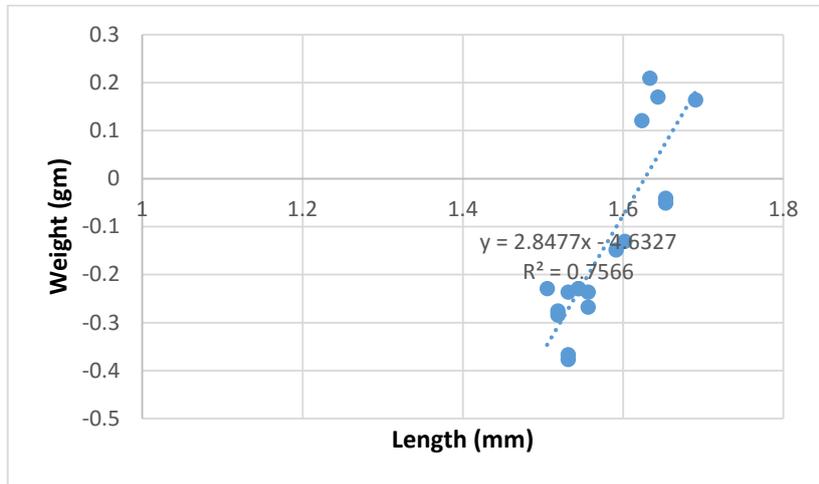


Figure 11: Weight-length relationship of Male Sailfin Molly

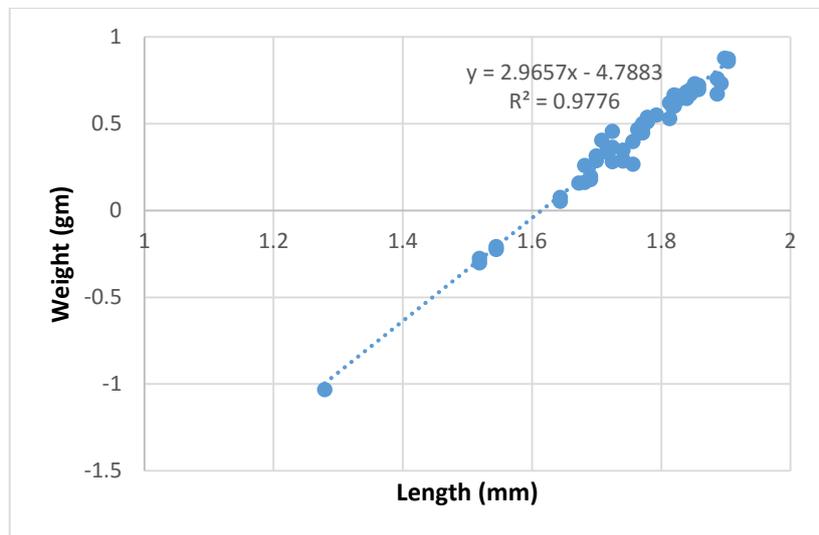


Figure 12: Weight-length relationship of Female Sailfin Molly

Fulton's condition factor was calculated for all individuals within each species and sex, and measurements averaged for the population for each sex. Both male and female Guppies had condition factors of 1.8, while the Sailfin Mollies at Tokaanu had condition factors of 1.3 and 1.4 for males and females, respectively.

Sailfin Mollies at Tokaanu had a population sex ratio of 1.6:1 in favour of the females. The total number of mollies caught for the population ratio measurement was 76 (29 males/47 females). The guppies at Golden Springs were found to have a 6:1 sex ratio in favour of males. The total number of guppies caught to work out the sex ratio was 91 (78 males/ 13 females).

Total population estimate for each species

Using the DeLury depletion technique an estimation of the total number of individuals in each population was calculated;

Fish capture attempts	No. of Sailfin Mollies (<i>Poecilia latipinna</i>)	No. of Guppies (<i>Poecilia reticulata</i>)
Attempt 1	44	24
Attempt 2	26	20
Attempt 3	44	19
Attempt 4	11	13
Attempt 5	9	7
Total population estimate	13,142	2076

Gut Analyses

The two poeciliid species were found to have contrasting diets. A gut analysis was carried out on 40 individuals of both species, comprising 20 males and 20 females in each. Sailfin mollies were found to consume mostly algae and other plant materials that either had fallen into the stream or were over hanging into the water. Due to the digestive process, species identification was generally impossible. Guppies at Golden Springs were found to have consumed invertebrates from a limited

number of both aquatic and terrestrial groups. The invertebrates found came from the Diptera, Chironomidae and Coleoptera orders, as well six individual Mollusca. Each invertebrate was identified to the lowest possible taxonomic level. However, due to partial digestion it was difficult to confirm exactly which species they were. All of the invertebrate groups found in the guts of these fish are known to live near or in thermal waters in New Zealand.

The four species identified to have been part of the guppies' diets were identified as being both terrestrial and aquatic;

Table 1: Prey species identified from *Poecilia reticulata* gut analysis.

Order	Chironomidae	Coleoptera	Diptera	Mollusca
Sub family	Chironominae	Hydrophilidae	Culicidae	Pulmonata
Genera	<i>Tanytarsus</i>	<i>Enochrus</i>	<i>Culex</i>	<i>Physella</i>
Species			<i>Culex rotoruae</i>	<i>Physa acuta</i>

Table 2: The percentages of *Poecilia reticulata* gut analysis/diet for Males versus Females, as well as total diet from terrestrial origin versus aquatic origin.

Prey Species	Male guppy	Female guppy	Aquatic	Terrestrial
Diptera	68%	50%		59%
Chironomidae	32%	40%	36%	
Coleoptera		4%		2%
Mollusca		6%	3%	

Discussion

Size differences between males and females

The lengths and weights of the males in both Guppies and Mollies were considerably smaller than the females. Several studies have shown that a disparity between male and female size in Poeciliids is apparent (Bisazza, 1993). Females require larger bodies in order to carry the fry, but also need to be large enough to carry a substantial number of young so that they will be able to sustain and grow the population; this means that the female body sizes will always be the larger when compared to males within the population (Deacon et al., 2011). The disparity between the male and female sizes also means that females require more food to reproduce, or the whole population may suffer.

The size and weight of the individual fish show that each of the poeciliid populations in New Zealand are more than just surviving but thriving, even given their restriction to thermal waters. Many populations of feral poeciliids are found to be surviving, and in fact thriving, throughout the globe. Examples from many hot springs in the USA and Canada show well established and healthy populations living in very isolated and resource limited conditions (Nelson & Paetz, 1992). With enough space and a large enough food source the potential growth of these species is only restricted by water temperature. Being as they are such survival specialists each of these species has well developed and reproductively successful populations (McDowall, 2005).

Length-weight relationships

The a (weight) and b (length) values for both species show positive isometric growth. This means the length and weight measurements are showing a positive response to the food sources available. Therefore, a continued ability to find enough food to survive not only when immature but also when more food is required as the body size increases (Garcia et al., 2008). The most important part of this is the fact that the growth in both sexes and both species is isometric. This means that the populations are growing at similar rates in both length and weight, and this is a very good indication of a healthy population (Garcia et al., 2008). This is especially important for the females as they

require not only enough sustenance for themselves but also the live young developing inside. As expected due to this the females of both species were on average far larger than the males and as such far heavier; often quite considerably larger in both the length and weight in comparison to the males found in these populations (Meffe & Snelson, 1989). However, the growth rates are still comparatively isometric even if overall the females are larger than the males.

Sex ratios

In New Zealand the population sex ratios for both species of poeciliid show interesting trends, especially given that they do not follow the expected ratios. The Sailfin Mollies were found to have a sex ratio of 1.6:1 in favour of the females (although statistically this was no different from 1:1); however, the guppies, in comparison had a male dominant population with a sex ratio of 6:1 in favour of the males. To understand why these sex ratios are interesting a comparison to other poeciliid populations must be made. Poecillids typically have heavily female dominated populations both in their home ranges and throughout the many feral populations found in hot springs across the globe (Székely, 2014). Poeciliid populations go through natural fluctuations in sex ratios, and this is attributed to numerous environmental or abiotic factors causing changes to the natural selection acting on the population (Pettersen *et al.*, 2004). In addition, individual fish within the population would be more likely to pass on their genes if they were to bias their offspring to the sex with fewer individuals, and therefore allow them to experience an increase in overall fitness (Bisazza & Pilastro, 1997). There are many other reasons that the sex ratios are biased towards females and they have a variety of explanations, the most important and fundamental being the ability to produce live young. The production of live young is highly beneficial for many reasons, including increased survival rates from predation, to the ability of the young to reach reproductive age more quickly than other fish species (Deacon *et al.*, 2013). Due to the increased rate of reproduction, females require far more food resources to produce the fully developed young, which increases the importance of the survival of females in the population. This therefore can potentially make it more important to have

increased numbers of females in a population than males, as they are the driving force behind the continued survival of the population (Pettersson *et al.*, 2004).

For Mollies, it has been shown that when more males are present in a population they will actively protect females from other males (Swanbrow-becker *et al.*, 2012). The males will often attempt to court the females through 'dance' and sometimes continued chasing of females in the hope of mating. This 'resource' protection and courtship acts means males have less time to forage for food, reducing physical fitness, and therefore their ability to defend and attract females (Makowicz & Schlupp, 2013). The other problem is often these displays require enough space to be performed meaning moving out of hiding spots, increasing the likelihood of being preyed on by both birds and other fish species (Trexler *et al.*, 1994). In addition, it's the larger males that are more likely to be performing courtship dances to attract females and they are normally far more colourful than the less mature small males (Trexler, 1994). They may be far more prone to predation from birds such as the White Faced Heron (*Egretta novaehollandiae*) (McDowell, 1990). The increased movement in the open combined with the brighter display colours may actually be increasing the likelihood that the larger males are being removed from the population therefore skewing the population slightly towards female dominance (Trexler, 1994). The other issue with the continued chasing of females by males is that not only does this mean the males are unable to feed, but also the females are often chased too much and so sometimes they do not have the physical strength to produce viable young. This type of harassment is detrimental to both the males and females physical fitness, and as such damaging to the population as a whole (Makowicz & Schlupp, 2013). In the New Zealand population, because the sex ratio is so even, these issues may not be arising. This means that all the individuals are able to achieve optimal fitness and produce the healthiest offspring at increased rates, as there is little to no competition for mates.

What this means in terms of population dynamics and structure is interesting. As stated, the average size of males was considerably smaller than females. This can have a lot to do with the courtship

strategies used by males and the amount of food resources needed to support the population. There are some interesting and complex interactions between male and female Sailfin mollies during courtship (Bisazza, 1993). In one particular study three sizes of males were recorded; large (7 cm+), medium (4-6 cm) and small (4 cm and under). It was observed that the largest males were most likely to perform courtship displays and protect females from other males, medium males were most likely to harass the females until mating occurred, and the smallest males used a further technique of sneaking up on females and mating with them without the larger males noticing (Bisazza, 1993). As a higher percentage of the males found in the New Zealand population are within the small bracket they would most likely be using a similar technique of sneaking up on the females in order to mate with them. This seems like the least energy intensive method of mating for both the males and females. What this means is that neither sex is expending any additional energy to reproduce than already needed. This keeps the physical fitness at the best possible for the females to produce the live young, and for the males to reproduce as often as possible all without having detrimental effects on their health (Bisazza, 1993). The other important thing about the overall smaller size of males is the reduced resource use as the smaller males require less food than larger ones and therefore potentially allowing higher numbers of them are able to survive within this population (Lange, 2013).

Sailfin mollies were seen to have relatively equal numbers of males to females; however, the physical size differences are more important when trying to determine the reason for this. This is because the males on average were considerable smaller than the females and therefore this allows for more of them to be present in this population. As explained, the mating strategy and/or courtship displays, or lack of, as well as the required food supply for the smaller male fish are what allows the more equal numbers of each sex to be present. The other possibility is that the population has gone through or is currently going through a change from female dominance or to female dominance and that is why the sex ratios are currently so similar (Swanbrow Becker et al., 2012).

With Guppies, the sex ratio heavily favoured males. This could be explained due to a decreased food availability, with only the smaller male fish having enough to eat in order to survive (Pettersson *et al.*, 2004). Therefore, more males were found than females, who need much more food in order to produce young. Another reason could be that the increased competition between males for mates will mean only the strongest will be able to breed with the females (Bisazza, 1993). Through this extended competition the females ensure that only the best possible genes are passed on to the next generation, thus increasing the overall survivability of the population as a whole. Therefore, males are more likely to be selected for to ensure the highest possible survival rates for future generations. A further reason suggested for why populations of poeciliids, and specifically guppies, can be heavily biased towards males is because the smaller males in greater numbers are more efficient at achieving mating and therefore reproducing when the females are unreceptive to conventional advances. This means that higher numbers of smaller males would be present in the population as they are more likely to achieve mating success (Bisazza & Pilastro, 1997). It could be one or a combination of all the previously mentioned reasons that have led to this male dominant population. It could mean that the overall dynamics have changed and this population will survive on the ability of the males to compete with other males to mate with the females (Jirotkulf, 1999). This could change if a perceivable advantage can be found in having fewer males and more females, but as said, it would depend on an increase in food supply in order to supply the bigger bodied females (Herdegen, 2014). Either way, it is most likely that this structure suits the guppies in this particular environment and is why it has developed this way in New Zealand.

Both of these population structures are different from what has been studied and is considered the norm for poeciliids; which is heavily female dominated populations. However, they do still follow several principles that apply to the Poeciliids as a group and which are a further contribution to the adaptability of these fish. Firstly, it is known that populations of poeciliids undergo changes in sex ratios depending on environment and ecological conditions (Brown, 1982). However, there is almost always a 'dominant' sex found within each population, although it is normally the females which

outnumber the males (Székely *et al.*, 2014). With the poeciliids in New Zealand the population structures of each species do represent this but in different ways.

The reason for this could be a change in resource availability and or food source due to a change in season and therefore light levels or water temperatures. These changing environmental conditions could be why there is need for these fish to either reduce population numbers or reduce the overall physical size of the fish during this time (Endler, 2011). This could be because as the temperature drops the thermal springs may only heat certain parts of the stream meaning that the mollies would have to move into these areas only during the colder months of the year. It could explain the reduction in size of the males and a reduction in the number of females, as fewer females would mean less young being produced and smaller males would mean less food needed to support the population (Courtney & Meffe, 1989).

Diet

The diet both species differed considerably. Gut analysis indicated the diet of Sailfin mollies was entirely made up of algae or vegetable matter, while guppies consumed a mix of terrestrial and aquatic invertebrates. Sailfin mollies are known herbivores and often prefer eating algae and other vegetable material where they are found naturally (McDowell, 2005). The algae species that do occur in the New Zealand thermal habitats are uncommon, and predation could lead to changes in species composition (McDowall, 2004). The mollies feed on algae entirely within the stream and as such means they are most likely having a large effect on the algal communities; however, this has no immediate implications as there is no known thermally endemic species of algae in New Zealand (McDowall, 2004).

Sailfin Mollies are currently only eating algae, which seems from physical observation to be plentiful in supply. However, they are known to be omnivores and will exploit any food sources that are available to them (Endler, 2011). Combined with this is the far larger population of Sailfin Mollies in New Zealand approximately 13,000 individuals; which creates the potential for mass environmental

and ecosystem damage. That Sailfin Mollies have been able to reach this population size in such isolation and in such a small area (~100-200 m), means that they are incredibly well suited to these restrictive conditions (Beatty & Morgan, 2013). With a change in environmental conditions or another incidental release, these fish could well be more destructive than the guppies. Even with the presence of other predatory fish in the wider waterways these fish have shown the ability to both survive and compete with these fish for both space and food (Scoppettone *et al.*, 1998).

Guppies were found to prey on a variety of invertebrate species; the Chironomidae found in the guts were all aquatic larvae, and have been sampled in similar thermally heated waters in New Zealand (Winterbourn & Gregson, 1989). Female guppies appear to consume more Chironomidae larvae than males, which may be due to the larger body sizes and or a larger gape allowing them to eat larger prey items; or a need for a larger required intake of food than compared to the smaller bodied males that would need less food. Coleopterans were found in several individuals, and were most likely terrestrial species that had fallen into the water from overhanging vegetation. The Coleopterans were all found in the larger females, which may provide further evidence that the larger females either require more food or are able to eat a wider variety of invertebrates due to their overall larger gapes. The mosquito species *Culex rotoruae* recorded were adults, and were found in both the males and females guts. These appeared to be the most widespread and common prey species and were found in almost every individual sampled. This particular species, *Culex rotoruae*, is a locally known species that inhabits thermal waters as larvae (Snell, 2005). The fact that only adults were found in the guts may mean that the larvae are living in slower moving or standing water nearby, and not in the stream that the guppies are living in at Golden Springs; as its flow rate is most likely too high. The *Physa acuta* snails found are not thought to be a regular part of the diet, as only four fish had eaten them. However, they were found in the guts of the larger female guppies and possibly indicates that they have a far broader diet than the smaller males. The two types of terrestrial invertebrates that were found to be making up the diet of the guppies, Diptera and Coleoptera, are both associated with the surrounding terrestrial environment of the thermal waters and are

therefore also not an unexpected find (Winterbourn & Gregson, 1989). Although some of the species of invertebrates, such as the Chironomidae species, have not been found in this particular stream before and so it was unknown they are a prey species for these fish (Forsyth, 1983). What this means in terms of potential impacts that the guppies will have on native invertebrates is important to the overall conservation of many aquatic invertebrate species. As shown the guppies are actually mainly feeding on terrestrial invertebrates, namely *Culex rotoruae*, that are either landing in the water or falling in from over hanging branches. However, due to the environmental factors associated with the thermal habitats such as the temperature or pH, it could be that only certain species of aquatic invertebrates, such as the Chironomidae found here, are able to survive in these conditions (Forsyth, 1983). What this means is that there is still the potential for this species to cause widespread damage to the many different aquatic ecosystems in New Zealand. There are many indigenous and specialised species of invertebrates found in New Zealand waters. On top of this with the increase in food supply and space, the establishment of feral populations could well become a far larger issue than currently thought (Deacon *et al.*, 2013). This makes a detailed assessment of diets and reproductive potential essential before judging if a notoriously invasive fish is disregarded as a threat to local species and ecosystems.

Climate Change and the implications for future invasions by Poecillid fish.

The two species of poecillids found in New Zealand are restricted to thermal waters and therefore further threats to most native species are minimised. This could change in the future if the global temperatures continue to rise at the predicted rates (Beatty & Morgan, 2014). The predicted average global temperature increase is roughly 2.8 °C in the next 30 years, with it possibly going up to 4.4 °C in the next 100 years. In comparison the predicted New Zealand average increase in the next 30 years is 2.0 °C, with it increasing by 5.7 °C in the next 100 years (Sammarco, 2009). This increase in water temperatures will allow these species access to the rest of New Zealand's waterways; which could spell disaster for both native species and economically important

introduced species (Klerks & Blaha, 2009). This temperature change and therefore increased risk of invasion is not only a problem for New Zealand but every other temperate country that have these species present in thermal waters (Bellard *et al.*, 2012). As stated both the Sailfin mollies and Guppies have generalist and very broad diets enabling them to easily colonise new habitats. This coupled with the highly specialised and effective reproductive strategy; which allows them to produce live young, which can be sexually mature in as little as six weeks means these two species are a considerable and potential threat to native ecosystems (Klerks & Blaha, 2009)

With this in mind it is important to understand that due to this potential for ecological damage by both these species of poecillids that effective management plans will have to be put in place. These will need to be ready if in fact the predicted climate change does increase; and therefore allow them to have increased home ranges in New Zealand. Currently invasive species are seen as one of the greatest threats to the health and sustainability of native ecosystems (Hellman *et al.*, 2008). This is especially relevant in the New Zealand freshwater environments, because as with the many terrestrial species the native fish and aquatic invertebrates have developed with little to no competition and far lower levels of predation (McDowall, 2004). They are therefore unequipped to deal with a highly invasive, highly competitive generalist fish species that is able to rapidly expand across most ecosystems and reproduce at a rate that will leave most if not all native species at a distinct disadvantage (Bellard *et al.*, 2013).

This means that an understanding of their current diets and population structure will be useful tools in developing management programs for these species. It is also important to be able to minimise economic costs in controlling these species. This means being able to take action before they are able to spread everywhere and keep them contained/eradicate them from these small thermal ecosystems (Rahel & Olden, 2008). In addition, the unknown damage to the native biodiversity that could be caused by these fish may well have extreme consequences with the potential to cause the

complete collapse of some native ecosystems. This issue is not only New Zealand's problem but also a global issue that may well affect many different species and ecosystems (Beatty & Morgan, 2013).

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