RELATIONSHIP OF HOCHSTETTER'S FROG (*LEIOPELMA HOCHSTETTERI)* POPULATION SIZE AND AGE STRUCTURE TO PEST MANAGEMENT

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Abstract

Hochstetter's frog (*Leiopelma hochstetteri)* is the most abundant of the four native frog species left in New Zealand, but little is known about the species' existence in the presence of invasive mammalian predators. We carried out surveys in the Waitakere Ranges in two catchment sites with varying pest management effort, in order to assess the effects of invasive predators on the Hochstetter's frog population and age structure. Results from our longitudinal study show that the total number of frogs and juveniles found in the site with limited pest management have been declining since 2007. The number of frogs found in the site with intensive pest control has shown fluctuations around a stable trend and now have surpassed the number of frogs found in the site with limited pest management as of April 2016. These findings are significant to the conservation of New Zealand native frog species and suggest high pest numbers can be detrimental to Hochstetter's frog populations.

Keywords: Hochstetter's frog (*Leiopelma hochstetteri)*, native amphibians, invasive species, pest management, New Zealand

1 Introduction

1.1 Overview of Native New Zealand Frog Species

Amphibians are experiencing global population declines due to habitat loss, invasive species, pathogens, and climate change (Newman, 1996). Monitoring population trends of amphibians, especially frogs, can tell us much about the health of an ecosystem and its speciess to (Pepeketua, 2006). Living in both terrestrial and aquatic ecosystems with highly permeable skin membranes that allow for passage of water-borne chemicals and toxins, frogs are essential ecosystem indicators of water quality, contamination, and riparian vegetation loss (Baber et. al. 2006).

New Zealand's amphibians have suffered the highest proportional biodiversity loss in the world (Wilson, 2004). Prior to human settlement, seven native frog species used to be widely dispersed and abundant throughout New Zealand. Now, there are only four native frog species left: Archey's frog (*Leiopelma archeyl*), Hochstetter's frog (*Leiopelma hochstetteri),* the Maud Island frog (*Leiopelma pakeka*), and Hamilton's frog (*Leiopelma hamiltoni*) (Wilson, 2004). The Maud Island frog and Hamilton's frog have suffered the largest population declines and are now considered critically endangered by the IUCN (Wilson, 2004). These two species' ranges have decreased drastically to the point where they have been eradicated from the mainland and are now constrained to small, predator-free offshore islands (Wilson, 2004). Archey's and Hochstetter's frog species are still present in fragmented forests in the northern half of the North Island in the Auckland and Waikato regions (Baber et. al. 2006). Hochstetter's frogs are also known to occur in the East Cape region (Baber et. al. 2006).

Hochstetter's frogs are found in predominantly broadleaf and temperate native forests, but can also survive in non-native forests such as exotic plantations (Easton, 2015). Unlike the other three native frog species, the Hochstetter's frog is semi-aquatic with a stream-dwelling larval stage (IUCN, 2015). It lays clutches of eggs under stones alongside streams and riparian vegetation, which is also where juveniles and mature adults can be found (IUCN, 2015).

1.2 Threats to Hochstetter's Frog Populations

Despite being one of New Zealand's four native frogs and its recently vulnerable status, little is known about Hochstetter's frog. Among other charismatic conservation species, this native frog is often overlooked and is seldom considered in pest control management plans. Isolated populations of Hochstetter's frogs are known to be present on the Waitakere and Hunua Ranges, where predation of frogs by rats and mustelids has been documented (Bradfield, 2005). Mammalian predation, habitat alteration and destruction by feral pigs and goats, and the spread of chytrid fungus (*Batrachochytrium*

dendrobatidis) pose serious threats to the Hochstetter's frog population (Bell et. al. 2004, Newman 1996).

Habitat fragmentation and modification from anthropogenic pressures are also threats to Hochstetter's frog populations. Forestry, agriculture, and development alter habitats by damaging riparian vegetation that is essential to Hochstetter's frogs (Department of Conservation, 2006). For example, Hochstetter's frogs are known to exist in non-native forest habitat such as pine plantations (IUCN, 2015). When sites are logged, small subpopulations with poor habitat connectivity face extinction from high levels of sediment runoff and mechanical disturbance (IUCN, 2015). Agriculture and development further fragment habitats and introduce pollutants, herbicides, and pesticides, which can be detrimental to these frogs with porous skin (Department of Conservation, 2006). In addition, by contributing to the loss of riparian vegetation, these activities can lower habitat quality by increasing UV radiation (Najera-Hillman, 2009).

1.3 Current Status of Hochstetter's Frog Populations

Despite these serious threats, Hochstetter's frogs have been recently listed as a species of "Least Concern" by the IUCN Red List of Threatened Species (IUCN, 2015). In 2010, the species was listed as "Vulnerable," but have been assessed as "Least Concern" because population reduction rates and population size have not yet met the threshold for the threatened category (IUCN, 2015). However, the population of about 100,000 individuals (Bishop et. al. 2013) is thought to have declined by 10% by the past three generations (Shaw, 1993; Douglas, 1998, 1999, 2001). Approximately, each generation length is estimated to be 12 years (IUCN, 2015). In addition, the frog's extent of occurrence of 68,594 km^2 and its area of occupancy of 9,032 km^2 is likely to decline by at least 10% in the next three generations due to habitat loss and degradation (Newman et. al. 2010).

1.4 Need of Conservation and Research of Hochstetter's Frog

Major conservation and research efforts are needed to further assess and to obtain a more accurate status of the Hochstetter's frog population trends (IUCN, 2015). Research on speciation within the species taxonomic group is necessary to define whether multiple separate species exists (IUCN, 2015). If significant genetic differences are found and the taxon group is split into several species, the conservation status of the Hochstetter's frog will have to be seriously reassessed (IUCN, 2015). In addition, further research on Hochstetter's frog life history and the benefits of non-native pest control is required for conservation planning (IUCN, 2015). Conservation actions, like the expansion of and more intensive non-native predator control, as well as habitat restoration of riparian vegetation, would benefit the survival of the species (IUCN, 2015). In addition, translocations of the frogs from active logging sites to pest-free areas could also be beneficial to the species (IUCN, 2015).

1.5 Objective of Study

The purpose of our study is to obtain data on habitat quality and the size and number of Hochstetter's frogs found in order to observe population trends and structure. Our study took place in an area (Ark in the Park) with intensive mammalian pest control and also in a reference area (Huia Catchment) with similar ecological conditions, but with minimal non-native mammalian pest control. We were able to find significant variations in the relative abundance and population structure (proportions of juveniles, sub adults, and adults) of the Ark in the Park and Huia populations, and therefore have assessed effects of varying pest control effort on Hochstetter's frog populations.

2 Methods

2.1 Site Description

Our study was carried out in the Waitakere Ranges located in the northwestern region of New Zealand's North Island. Approximately 16,000 hectares in size, the Waitakere Ranges is one of the only two large continuous forests of indigenous vegetation remaining in the mainland of the Auckland region (Regional Parks Management Plan, 2003). Surrounded by the Waitemata and Manukau Harbours and the Tasman Sea, the landscape is characterized by lowland coastal ecosystems with a rich diversity of indigenous flora and fauna (Regional Parks Management Plan, 2003). Many of the streams in the Waitakere Ranges are still intact and have retained much of their natural state with stable banks of dense riparian vegetation cover (Waitakere City Council, 2008). An elevated basalt plateau formed by ancient uplift volcanic uplift and coastal proximity, causes the Ranges to be frequented by large amounts of rainfall and storms from the Tasman Sea (Waitakere City Council, 2008). The annual average rainfall in the Ranges varies from 1397 to 2032 mm (Regional Parks Management Plan, 2003).

Half of the monitored streams were located in the Ark in the Park catchment, where pest management is intensive, and the other half of the monitoring was conducted at streams located in the Huia catchment, where pest control management is much less thorough. Streams in the Huia catchment were chosen with similar stream conditions and vegetation cover as to those in Ark in the Park.

2.2 Study Design and Timing

This long-term study is conducted during the months of November and April once every three years. In each month, 48 stream transects are surveyed, with half located in ARK and the other half located in the Huia Catchment. Streams were chosen on a random basis to ensure unbiased representation of the two study sites, however, accessibility and viable habitat for Hochstetter's frog were taken into consideration. Viable habitat characteristics that all streams were chosen for included: running water, predominantly closed canopies, and presence of cover objects, which were rocks, leaf litter, or down woody debris in which frogs can take refuge in or under.

2.3 Data Collection

2.3.1 Habitat Assessment

Data was collected using Visual Estimation Survey (VES) techniques with two-person teams comprised of a searcher and recorder. This process included an assessment of habitat suitability and quality of a 20 m stream transect. Habitat suitability was assessed by the searcher who classified the stream transect and its banks as “Optimal, Suitable, Marginal, or Not Suitable” by looking upstream for the presence of streamside frog habitat and suitable cover objects. Next, the searcher assessed habitat quality by ranking the transect on a 1 through 5 scale, where “1” was poor-quality habitat with a high amount of sunlight penetration contacting the stream, and a “5” was high-quality habitat with permanent shade and moist microhabitats. At 0, 10, and 20 m, the width of the stream was measured to the nearest 10 cm by the searcher.

We then assessed the presence and/or absence of cover objects at every meter point starting downstream at 0 m and working upstream to 20 m. At every meter, the left, right, or middle (if there was one) banks of the stream were assigned the letter, “X” for not suitable habitat, “S” for the presence of at least one suitable and searchable cover objects, and “U” for the presence of at least one suitable but unsearchable cover object. The size of cover objects ranged from approximately 4 to 30 cm in diameter.

2.3.2 Frog Assessment

Starting at 0 m, every consecutive meter on the bank within one square meter area or up to 60 cm in height (if the bank was steep) was searched. The searcher lifted and carefully placed rocks and down debris back to their original positions. The number of cover objects lifted was counted by the recorder, who also kept track of total searching time. Searching time was paused once a frog was found. During this time, the length of the frog from snout to urostyle was measured using a transparent millimeter ruler or estimated if the frog jumped away. The length in centimeters from where the frog was found to the stream edge was measured using a measuring pole. The meter at which the frog was found along the 20 m transect was recorded.

2.4 Biosecurity Protocols

No frogs were touched or handled during the data collection. Boots and equipment were washed and sprayed with TriGene Broad-spectrum disinfectant after each stream survey to ensure that there was no spread of chytrid fungus and kauri collar-rot between surveying sites.

2.5 Data Analysis

Data were analyzed using R version 3.0.2 (R Core team, 2013).

Differences in the number of cover objects searched in each study area were tested for by an Analysis of Variance, with number of cover objects per transect against study area. Habitat suitability was analyzed by two-sided t-tests of the percentage of habitat classed as “Suitable”, “Unsuitable” and “Suitable but Unsearchable” for the transects within each study area: these percentage data were arc-sine transformed before analysis to ensure normality.

Frog abundance data consisted of count data with a large number of zeros, and departed significantly from a normal distribution. This data was analyzed with generalized linear mixed effect models using a binomial response of frogs found by number of cover objects searched within each transect. Models were constructed with either a fixed effect of study site and random effects of year, and stream nested within year, or fixed effects of site, year, and their interaction, with stream as a random effect. To establish the importance of these effects, alternative models were constructed that omitted either stream or year, and Akaike Information Criteria used to compare these different models.

3 Results

The total number of objects lifted in the Huia and Ark in the Park Catchments was 5,927 and 6,221 respectively. The total number of frogs found in the Huia Catchment was 11, while in Ark the Park, 13 frogs were found. The total number of frogs found per cover object for each site was 0.0018 ±9.2 in Ark in the Park and 0.0022 ±9.2 in Huia. For April 2016, the total number of frogs found per cover object between the sites was not significantly different (Figure 1).

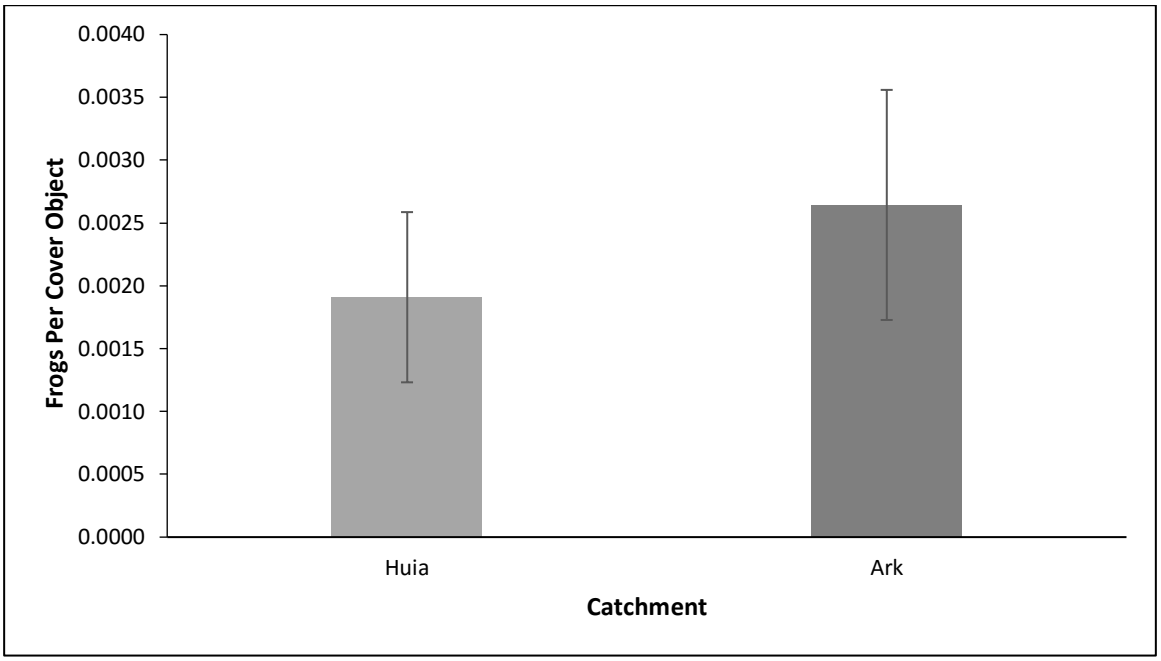

Figure 1. Frogs per cover object and ±SE in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=24 for Ark in the Park, n=24 for Huia, where n equals number of transects.

The number of cover objects lifted per whole site was not significantly different. Huia had a mean of 246.96 ±25.6 objects lifted and Ark in the Park had mean of 256.21 ±27.8 objects lifted (Figure 2).

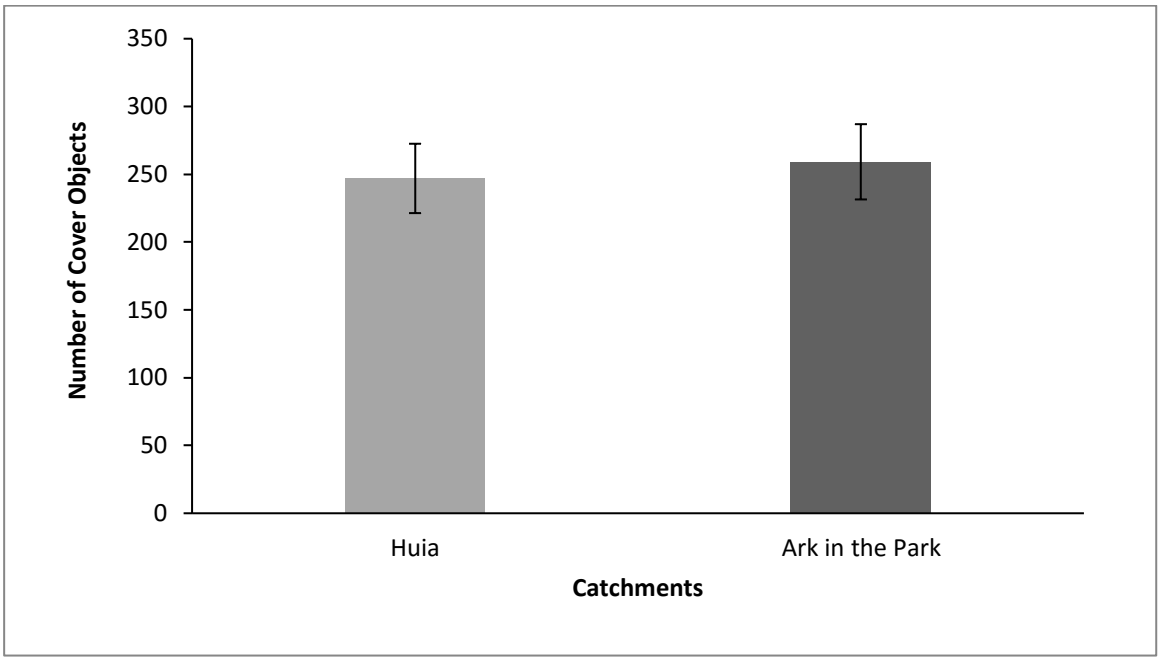

Figure 2. Mean and ±SE of cover objects lifted in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=24 for Ark in the Park, n=24 for Huia, where n equals number of transects.

The majority of the transect habitats and searching suitability among all transects in both sites was assessed as "suitable and searchable." Ark in the Park was 53% ±3.0 and Huia was 54% ±2.8 for "suitable and searchable." Ark in the Park had 29% ±3.2 as "unsuitable" and 18% ±2.2 as "suitable but unsearchable," while Huia had 26% ±2.7 as "unsuitable" and 20% ±2.5 as "suitable but unsearchable" (Figure 3).

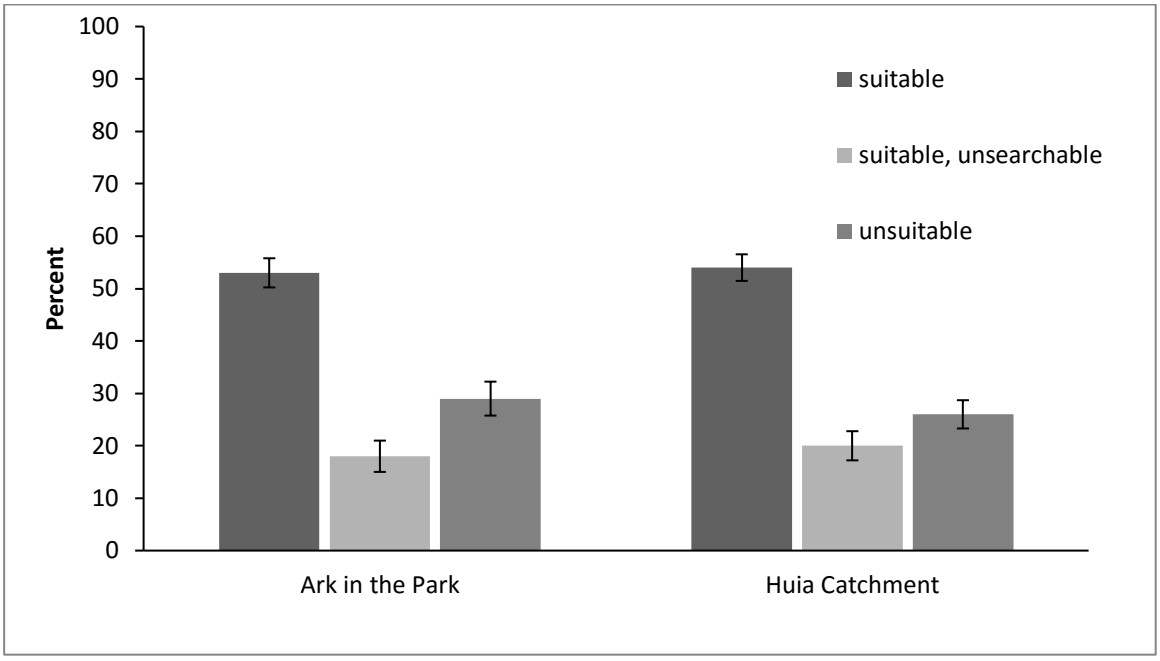

Figure 3. Mean ±SE of habitat and searching suitability in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=24 for Ark in the Park, n=24 for Huia, where n equals number of transects.

The most common whole site suitability category in both catchments was “suitable” at 24 stream transects in Huia and 20 stream transects in Ark in the Park. Huia had no other assessed categories. Two streams were assessed as "marginal" and another two were assessed as "optimal" in Ark in the Park (Figure 4).

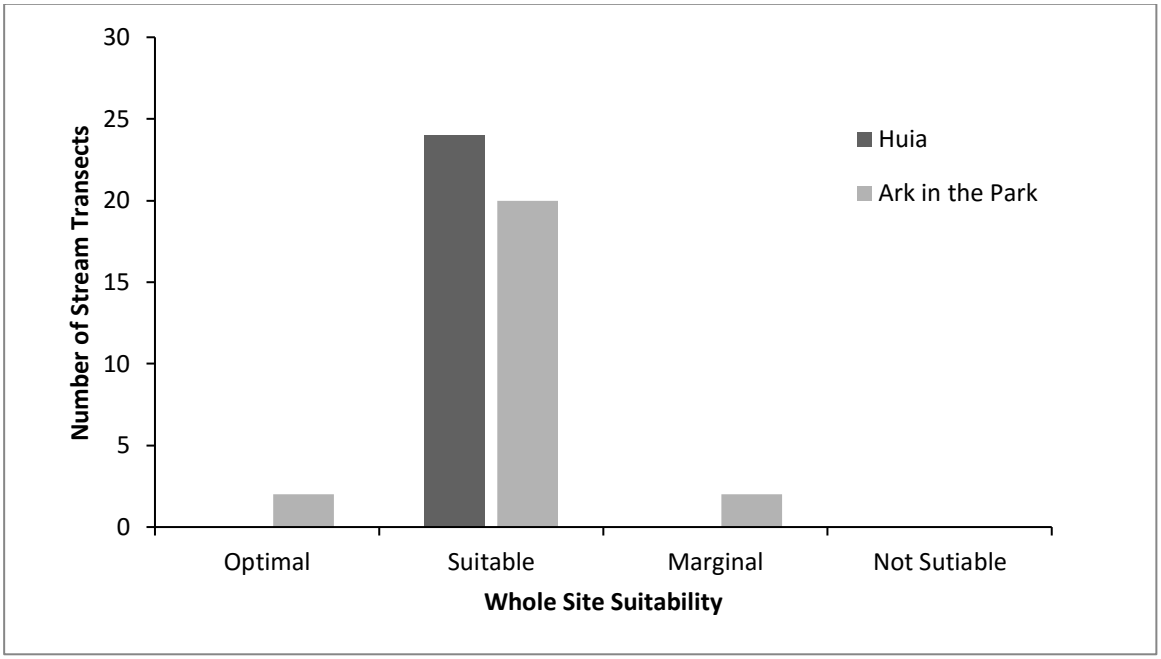

Figure 4. Whole site suitability of the stream transects in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=24 for Ark in the Park, n=24 for Huia, where n equals number of transects.

The overall stream width in Ark in the Park was greater than Huia. The overall stream width for Ark in the Park was 232.01 ±8.7 cm and the overall stream width for Huia was 193.27 cm ±5.1 cm. There was no significant difference between the two sites' overall stream width (Figure 5).

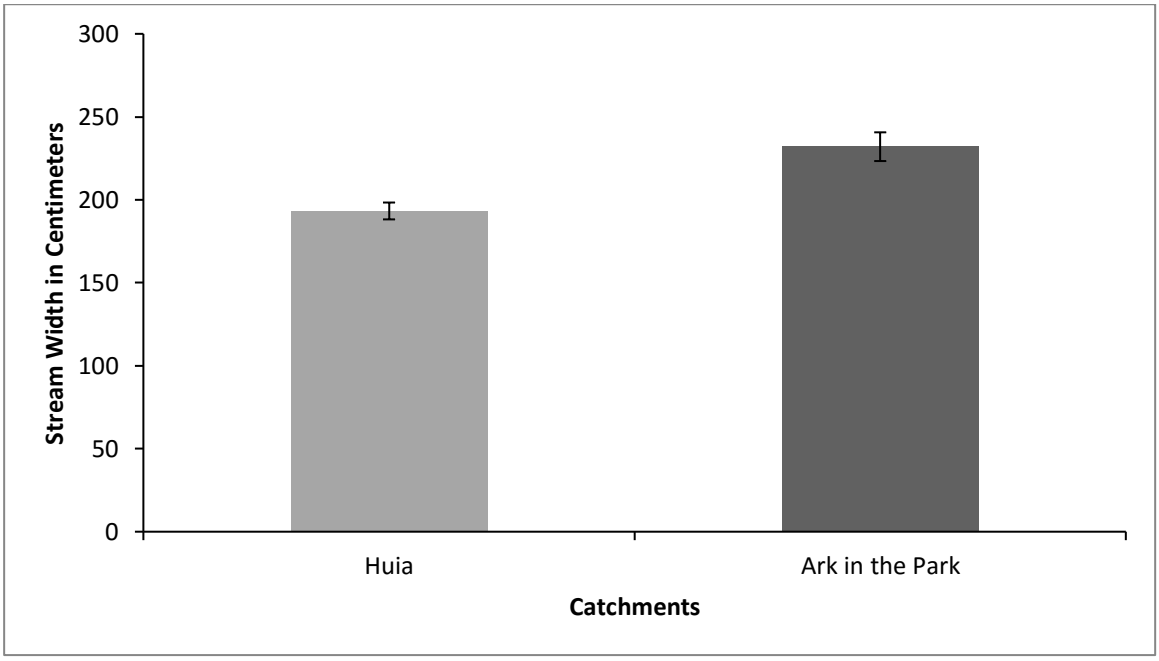

Figure 5. Mean and ±SE of stream width in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=24 for Ark in the Park, n=24 for Huia, where n equals of transects.

The greatest number of frogs found was 74 in Huia during April 2007, while the lowest number of frogs found was 2 in Ark in the Park during both seasons of April 2007 and November 2013. Overall, more frogs were found in Huia compared to Ark in the Park, except for the current season of April 2016. In April 2016, 13 frogs were found in Ark in the Park and 11 were found Huia. The total number of frogs found in Huia has been significantly declining since April 2007. The total number of frogs found in Ark in the Park has been experiencing slight fluctuations, but overall has been remaining steady throughout the years (Figure 6).

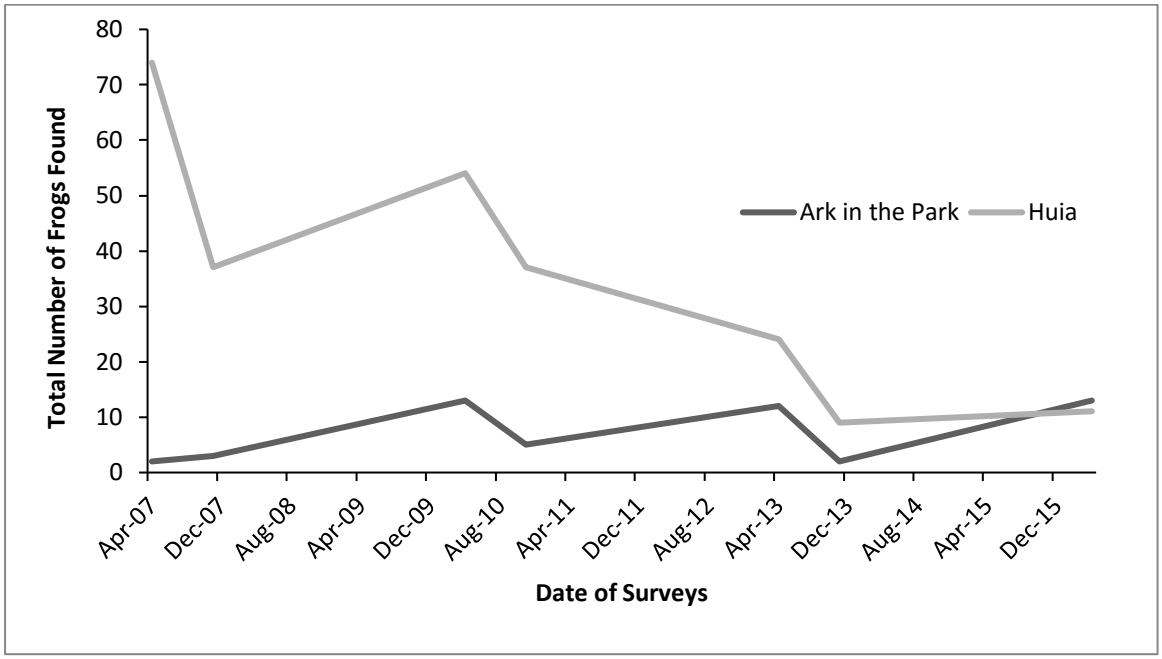

Figure 6. Total number of frogs found in Huia and Ark in the Park Catchments during the seasons of April 2007 n=47, November 2007 n=48, April 2010 n=47, November 2010 n=42, April 2013 n=48, November 2013 n=48, April 2016 n=48, where n equals number of transects.

The greatest number of frogs found per cover object was 0.021 during November 2010 in Huia, while the lowest number was 0.0006 during November 2013 in Ark in the Park. It should be noted that the spike in the number of frogs per cover object that occurred in November 2010 in Huia reflects fewer cover objects lifted, not more frogs found. Overall, Huia has had more frogs found per cover objects compared to Ark in the Park (Figure 7).

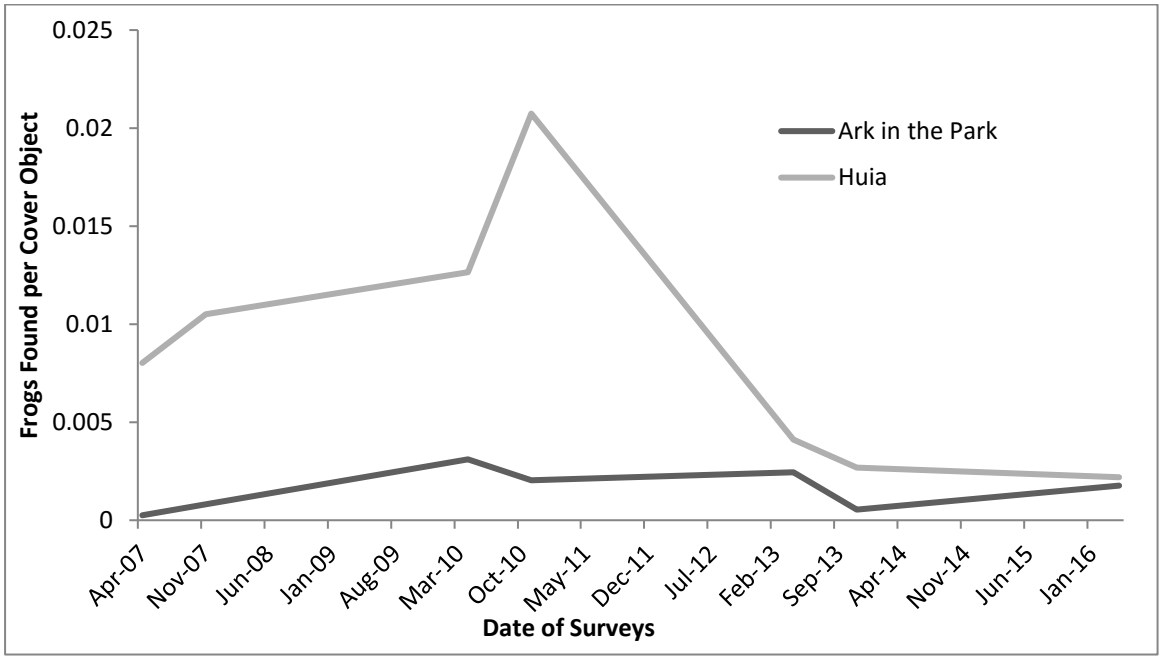

Figure 7. Frogs found per cover object in Huia and Ark in the Park Catchments, Waitakere Ranges in April 2007 n=47, November 2007 n=48, April 2010 n=47, November 2010 n=42, April 2013 n=48, November 2013 n=48, April 2016 n=48 in Huia and Ark in the Park, where n equals number of transects.

The age classes of all the frogs that were found differed in each site. Juveniles were considered to be 18 mm in length or less, sub-adults were 19 to 30 mm, and adults were 31 mm or more. Fifty-five percent of the frogs found in Huia were sub-adults and 45% were adults. Seventy-seven percent of the frogs found in Ark in the Park were adults and only 23% were sub-adults. No juveniles were found at either site in 2016 (Figure 8).

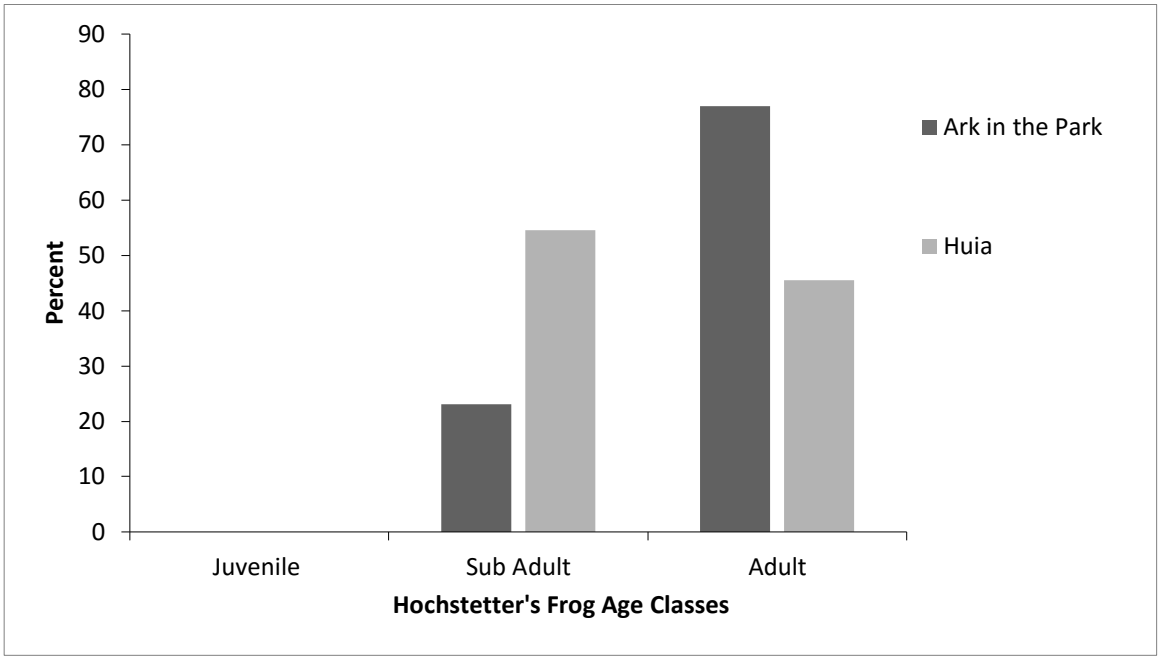

Figure 8. Percent of juveniles, sub-adults, and adults found in each of the 24 transects in the catchments of Ark in the Park and Huia, Waitakere Ranges, April 2016. n=13 for Ark in the Park, n=11 for Huia, where n equals number of frogs.

In April 2007, 2010, and 2013, the percentage of adults found was the greatest among all age classes of frogs found in the Huia Catchment. In 2013, 86% of all frogs found were adults, which was the greatest number of adults found in all transects. In 2016, 45% of all frogs found were adults, which was the smallest number of adults found in all transects. Sub-adults have been the second largest age class found with the greatest number at 54% of frogs found in all transects in April 2016. The smallest age class found has been juveniles at 3 to 4% of the frogs found in all transects, but in April 2013 and 2016, no juveniles were found (Figure 9).

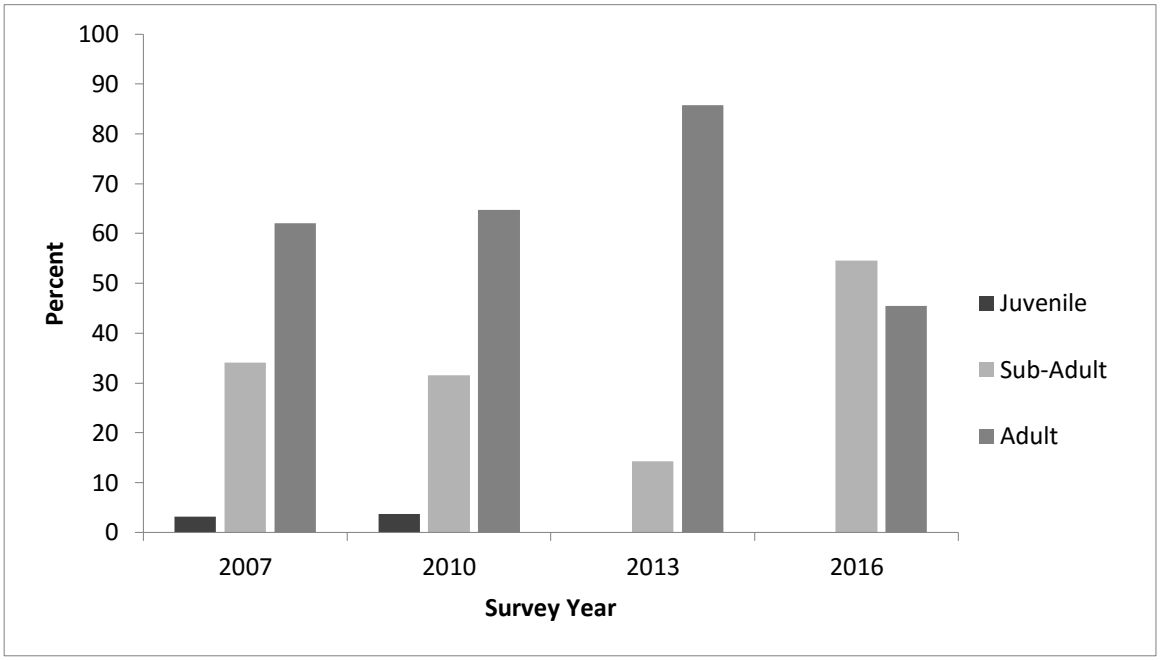

Figure 9. Percent of juveniles, sub-adults, and adults found in the Huia Catchment, Waitakere Ranges during the seasons of April 2007 n=94, 2010 n=54, 2013 n=21, and 2016 n=11, where n equals number of frogs.

Over all four survey years, the majority of the frogs found in Ark in the Park were adults. The percentage of adult frogs found were over 65% in all four years. Around 23 to 25% of frogs found in April 2010, 2013, and 2016 were sub-adults. There were no sub-adults or juveniles found in April 2007 in Ark in the Park. Only in April 2010 and 2013 were there juveniles found at around 8% of all the frogs found. No juveniles were found in 2007 and 2016 (Figure 10).

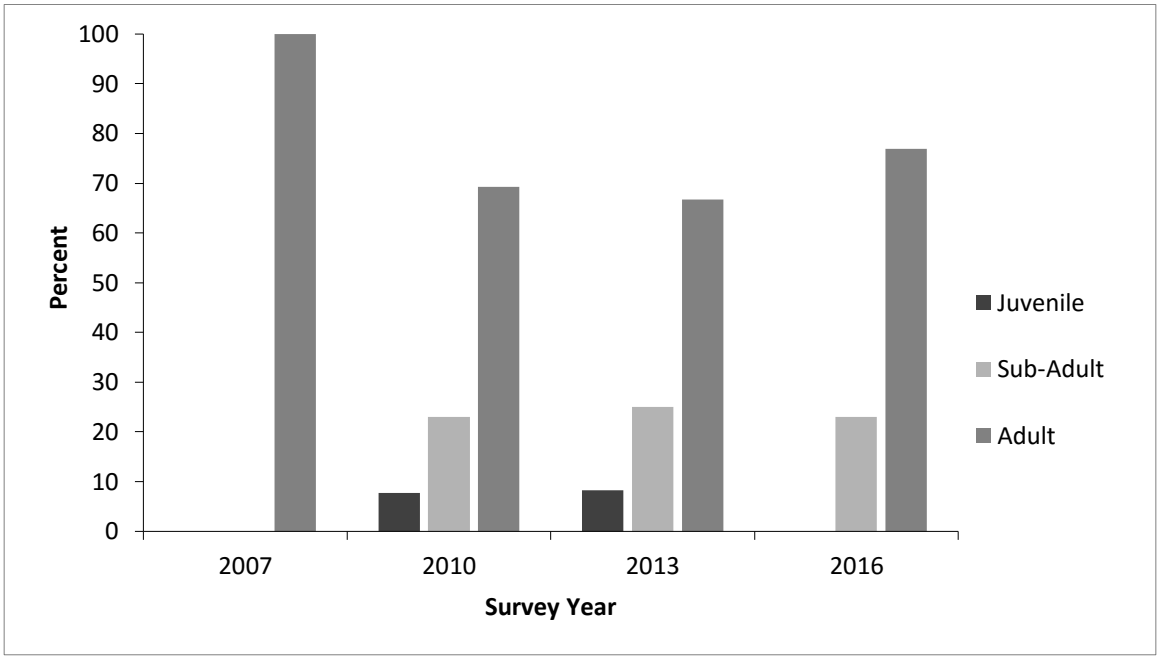

Figure 10. Percent of juveniles, sub-adults, and adults found in the Ark in the Park Catchment, Waitakere Ranges during the seasons of April 2007 n=2, 2010 n=13, 2013 n=12, and 2016 n=13, where n equals number of frogs.

4 Discussion

The purpose of our study was to find Hochstetter's frogs in the catchments of Huia and Ark in the Park in order to assess the effect that different intensities of pest management have on the Hochstetter's frog population in two sites with similar ecological conditions. There were no significant differences in the habitat aspects, such as mean stream width, transect habitat suitability, and whole site suitability, between the two sites during April 2016. This ensures that physical and ecological conditions that were assessed in our study did not vary significantly since 2007.

There was a total number of 24 frogs found between the catchments, with 13 in Huia and 11 in Ark in the Park. There was no significant difference between the total number of frogs per cover object between Huia and Ark in the Park for April 2016. However, there were significant differences in the total number of frogs found per object among the survey seasons from April 2007 to April 2016. A steady declining trend was evident in the number of frogs found per cover object in Huia. Overall, there were fewer frogs found in Ark in the Park, however, the frogs found in Ark in the Park exhibit a more stable trend with slight fluctuations, compared to Huia.

With similar and non-changing physical and ecological conditions, our results indicate that the declining trend is due the differing variable of non-native mammalian management efforts between the sites. Ark in the Park has undergone intensive pest control since 2003, while Huia receives minimal pest control every 6 years (Regional Parks Management Plan, 2003). The difference in pest management between the two sites contributes to varying predation pressure on Hochstetter's frogs. Our results indicate that less intense predator and pest control management is leading to a steady and significant decline in the number of frogs found in Huia. Where there is more intense pest management effort in Ark in the Park, the population of Hochstetter's frogs found is not showing a decline, presumably due to less predation pressure.

Other studies have shown similar findings. One study found that Hochstetter's frog populations substantially increased following the eradication of introduced predators (Longson et. al. in prep.). The rate of discovery did not only increase but also the spatial extent in which the frogs were found did too, indicating that both population numbers and distribution increased after invasive predator eradication (Longson et. al. in prep.).

Another study found that the distribution of native amphibians overlapped at several sites where pest management was occurring (Baber et. al. 2008). Even though pest management was implemented for the benefit of other threatened species, the study explained the control of introduced mammalian predators also benefited Hochstetter's frogs (Baber et. al. 2008). Frog abundance was significantly higher within the area with more intensive pest control than in the area with lower levels of pest control (Baber et. al. 2008).

The relation of predators and Hochstetter's frogs should be further analyzed by monitoring rodent and other pest populations in the study sites. In this way, fluctuations in pest and frog populations can be compared to see if there are any relations such as predator-prey lag effects. This research could give some explanations as to why we are seeing fluctuations in the number of frogs found between the sites. Fluctuations, like the ones seen in the Ark in the Park population, could also be due to other variables such as varying environmental conditions like severe storm and flooding events (Newman 1996). Whether the fluctuations are due to these variables or predation, the frog population in Ark in the Park is remaining stable, indicating that if predation was the cause of the fluctuations, it is not enough to cause a decline in the number of frogs found.

In April 2007, about 3% (n = 3 frogs) of the frogs found were juveniles and now this age class has declined to the point where no juveniles were found in April 2016. This change in the population age structure with the lack of juveniles could also be a factor behind the decline of frogs in Huia. This lack of juveniles can result in minimal recruitment of frogs for the next year, causing an overall population decline (Najera-Hillman, 2009). Other frog surveys have found a relatively low proportion of juvenile frogs in areas not controlled for mammalian pests (Baber et. al. 2008). For example, Bradfield (2005) recorded only 1.4% (n = 2 frogs) of the frogs as juveniles in the Waitakere Ranges (Bradfield, 2005).

The proportion of sub-adults in a population can be a better measure of recruitment than the proportion of juveniles (Whitaker and Alspach, 1999). This is because the distribution of small juveniles is more likely to reflect the patchy distribution of suitable nesting sites, which increases the chances of not finding individuals during surveys (Whitaker and Alspach, 1999). The percentage of sub-adults found has been in decline in Huia since 2007, with the exception of April 2016.

Hochstetter's frogs are long-lived and are adults for the majority of their life cycle (Longson et. al. in prep.). Due to this, adults make up the majority of the population (Longson et. al. in prep.). In Ark in the Park, all survey years had at least 65% of all frogs found as adults. However, in Huia, April 2016 was the first survey year that sub-adults exceeded adults. In 2013, adults made up 85% of the frogs found and in 2016, adults made up 45% of the frogs found. If adults keep declining in numbers, this would indicate an entire population decline.

This decrease in the proportion of juveniles and adults, and the declining number of frogs found in Huia may not be entirely a direct result of predation of invasive mammals. Other factors could be negatively affecting Hochstetter's frogs, such as land use practices that cause sedimentation or chemical runoff in the streams (IUCN, 2015). These factors may degrade viable habitat for Hochstetter's frog populations, however, introduced mammalian predators are likely to be the most serious threat to the species (Baber et. al. 2008).

5 Conclusions and Recommendations

The varying efforts of pest management between the sites have affected the number of frogs found in Huia and Ark in the Park. In Huia, where pest management is not as intensive as in Ark in the Park, the number of frogs found shows a steady decline. On the other hand, where pest management is rigorously controlled, the number of frogs found exhibits a stable trend and has now exceeded the number of frogs found in Huia for April 2016. Future monitoring is needed to continue to keep track of the Hochstetter's frog populations in the catchments of Ark in the Park and Huia. However, now that it is evident that lower levels of pest control are negatively affecting Hochstetter's frog populations, it is necessary to revise management practices in Huia and New Zealand to continue the conservation of this species.

Revisions to Huia's pest management strategy should include active baiting and monitoring of introduced mammalian predators, especially rodents, every year instead of every six years. Most pest management plans are implemented to benefit other threatened species, like native birds, however, this one should be designed to benefit native frogs, since they are often overlooked in management plans. Bait traps should be placed near streams to eliminate the predators near frog habitat first. Tracking tunnels, where tracks can be assessed and recorded, should be constructed to monitor rodent numbers (Ark in the Park, 2006). Finally, frog surveys should be conducted in a cycle of alternating surveyed streams on a yearly basis in order to track the progress of the pest management plan. Without future revisions and considerations, Hochstetter's frog subpopulations are likely to be extirpated in areas with low levels of pest management.

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