**Hypotheses for stagnant population growth of Hihi at Zealandia**

Hypothesis 1: predation by ruru (or falcons or kaka) is reducing adult survival.

1. Innes, J. I., D. Kelly, J. M. Overton, and C. Gillies. 2010. Predation and other factors currently limiting New Zealand forest birds. New Zealand Journal of Ecology 34:86–114.

Innes et al. (2010) reviews the roles of predation and other factors that may contribute to native bird declines in New Zealand. The authors suggest that predation by native species is unlikely to have a destabilizing effect on native birds unless other factors are involved, i.e., food supply, poor habitat, genetic effects, or disease.

1. Armstrong, D. P., C. Le Coeur, J. M. Thorne, J. Panfylova, T. G. Lovegrove, P. G. H. Frost, and J. G. Ewen. 2017. Using Bayesian mark-recapture modelling to quantify the strength and duration of post-release effects in reintroduced populations. Biological Conservation 215:39–45.
2. Panfylova, J., E. Bemelmans, C. Devine, P. Frost, and D. Armstrong. 2016. Post-release effects on reintroduced populations of hihi: Post-Release Effects in Reintroduced Populations. The Journal of Wildlife Management 80:970–977.

Both Panfylova et al. (2016) and Armstrong et al. (2017) report predation of Hihi by native species (Kārearea or Ruru) during the post-release period at Bushy Park. Panfylova et al. (2016) remarks on how predation events by native species may decrease with time after release, once Hihi have had time to adjust behavior and avoid local predators.

1. Barea, L. P., J. R. Waas, K. Thompson, and N. H. Hyde. 1999. Diet provided for chicks by New Zealand Falcons (*Falco novaeseelandiae*) nesting in forested habitat. Notornis 46:257–267.

Barea et al. (1999) describes the diet of chicks of two pairs of Kārearea in the Mapara Wildlife Management Reserve on the North Island. They report that the prey selected was in proportion to species abundance within Kārearea territories.

1. Kross, S. M., J. M. Tylianakis, and X. J. Nelson. 2013. Diet composition and prey choice of New Zealand Falcons nesting in anthropogenic and natural habitats. New Zealand Journal of Ecology 37:51–59.

Kross et al. (2013) investigates the diet composition of Kārearea on the South Island. Their findings suggest Kārearea select non-native prey at a higher rate than native prey in both human altered and natural habitats.

1. Kross, S. M., A. Tait, D. Raubenheimer, and X. J. Nelson. 2018. New Zealand Falcon prey selection may not be driven by preference based on prey nutritional content. New Zealand Journal of Ecology 42:58–64.

Building off the work of Kross et al. (2013), Kross et al. (2018) further assesses prey selection by Kārearea on the South Island. They hypothesized that prey is selected based on nutritional content (e.g., body mass). However, the results suggest that the relative abundance and endemicity (preference for introduced over native species) of species were key predictors in explaining prey choice by Kārearea, and not the hypothesized predictor of nutritional content. The selection of introduced prey over endemic prey may be explained by the habitat use of introduced prey or the anti-predator behaviors native species possess. Native species have co-evolved with native predators, so the observed preference for introduced species in non-native habitat may explain the observed preference for introduced prey in a Falcon’s diet.

1. Bell, D. 2017. Distribution of New Zealand Falcon (*Falco novaeseelandiae*): results of a 10-year survey 2006-2016. Notornis 64:234:238.

Bell (2017) reports the results of a 10-year survey effort to understand the distribution of Kārearea across New Zealand. Wellington observation records were the highest in New Zealand at the time of their work, although observation effects were not modeled or considered by this report.

1. Miskelly, C. M. 2018. Changes in the forest bird community of an urban sanctuary in response to pest mammal eradications and endemic bird reintroductions. Notornis 65:132–151.

Miskelly (2018) assesses the response of the forest bird community in Zealandia to mammal eradications and native species reintroductions to the site. They cite Kārearea as recolonizing Zealandia at some point before 2009 and as being present during surveys after native species were reintroduced.

1. Boyack, N. 2020, December. Kārearea soaring high in Wellington, even as they remain rare elsewhere in New Zealand. Stuff.

Boyack (2020) reports that Kārearea are regularly seen in Wellington but may be less common in other parts of New Zealand.

1. Busbridge, S., and J. R. Stewart. 2018. A video camera assessment of morepork (*Ninox novaeseelandiae*) diet and breeding success on Tiritiri Matangi Island. Notornis 65:187–195.

Busbridge and Stewart (2018) report on diet composition of Ruru during the 2016-2017 breeding season on Tiritiri Matangi Island. They sought to uncover if Ruru predation was a limiting factor for endemic bird species, including Hihi. They found that Ruru on Tiritiri Matangi Island were primarily insectivorous but there was evidence that they do predate Hihi (e.g., leg bands found in nests). However, the authors suggest that the potential for Ruru to pose a singular threat to Hihi populations is unlikely unless Hihi are experiencing other limiting factors (disease, post-release effects, genetic effects, etc.). Additionally, Ruru predation may be higher on offshore islands than on the mainland due to the limited prey availability on isolated islands.

Hypothesis 2: birds are moving outside of the fence into surrounding neighborhoods to feed and are being depredated, reducing adult survival.

Hypothesis 3: Birds are dispersing away from Zealandia and thus are lost to the population, functioning from the standpoint of the population as a reduction in survival.

1. Richardson, K., M. Hauber, J. Ewen, and D. Armstrong. 2010. Sex-specific shifts in natal dispersal dynamics in a reintroduced hihi population. Behaviour 147:1517–1532.

Richardson et al. (2010) examines natal dispersal of Hihi on Tiritiri Matangi Island, finding that females dispersed further than males. The dispersal distances they observed were suspected to be influenced by the sex ratio of the population, i.e., females dispersed further when the population is male biased. Males in the Tiritiri Matangi Island population showed a negative density dependent natal dispersal with the number of male juveniles.

1. Richardson, K. M., J. G. Ewen, P. Brekke, L. R. Doerr, K. A. Parker, and D. P. Armstrong. 2017. Behaviour during handling predicts male natal dispersal distances in an establishing reintroduced Hihi (*Notiomystis cincta*) population. Animal Conservation 20:135–143.

Richardson et al. (2017) investigates natal dispersal the Maungatautari population, which is restricted by unsuitable habitat outside of the reserve. They found that male natal dispersal was higher when the population was establishing, a similar trend to that of the Tiritiri Matangi Island population. Additionally, they suspect that personality or temperament types my facilitate dispersal, which can either benefit the population by expanding throughout a reserve or cost the population if dispersal is associated with mortality outside of the reserve. Genetic loss of dispersal behavior is possible when dispersal results in mortality, an important consideration in reintroduced and isolated populations.

1. Richardson, K. M., and J. G. Ewen. 2016. Habitat selection in a reintroduced population: social effects differ between natal and post-release dispersal. Animal Conservation 19:413–421.

Richardson and Ewen (2016) looks at the factors influencing habitat selection during natal and post-release dispersal in the Maungatautari population. They found a strong social effect in habitat selection of natal dispersers born at the release area, but no social effect was detected for juveniles translocated 2 years after the first releases occurred.

1. Richardson, K., V. Doerr, M. Ebrahimi, T. Lovegrove, and K. Parker. 2015. Considering dispersal in reintroduction and restoration planning. Pages 59–72 *in* D. P. Armstrong, M. Hayward, D. Moro, and P. Seddon, editors. Advances in reintroduction biology of Australian and New Zealand fauna. CSIRO.

Richardson et al. (2015) outlines the potential interactions between connectivity, dispersal propensity, and predator vulnerability following reintroduction. They describe Hihi as having a medium to high probability of dispersal related failure, since Hihi are vulnerable to non-native predators and dispersal is likely to equate to mortality.

1. McArthur, N., A. Harvey, and I. Flux. 2015. State and trends in the diversity, abundance and distribution of birds in Wellington City. Wildlife Management International Limited.

McArthur et al. (2015) reports on the distribution of birds in Wellington from 2011 to 2014 and provides citizen science observations of Hihi visiting reserves outside of Zealandia, but no Hihi were detected outside of the reserve during Wellington bird counts.

1. Rutschmann, A., P. de Villemereuil, P. Brekke, J. G. Ewen, N. Anderson, and A. W. Santure. 2020. Consequences of space sharing on individual phenotypes in the New Zealand Hihi. Evolutionary Ecology 34:821–839.

Rutschmann et al. (2020) investigates the genetics and dispersal patterns of Hihi at Zealandia to understand how birds establish their home ranges. They report that Hihi have been observed outside of the park, but they do not report any observed nesting attempts outside the reserve. Female fledglings travelled further than male fledglings, but adult males were observed dispersing further than adult females. Additionally, established adults were associated with high site fidelity within and between seasons.

1. Burge, O. R., J. G. Innes, N. Fitzgerald, J. Guo, T. R. Etherington, and S. J. Richardson. 2021. Assessing the habitat and functional connectivity around fenced ecosanctuaries in New Zealand. Biological Conservation 253:108896.

Burge et al. (2021) considers the potential for species to use habitat outside of fenced reserves by evaluating the level of habitat connectivity and species gap crossing abilities. At the time of their work, they report that Zealandia has a moderate level of high-quality habitat around the reserve, which may allow species to potentially disperse using habitat corridors.

Hypothesis 4: inbreeding depression is reducing survival or breeding success and thereby dampening population growth.

1. Brekke, P., P. M. Bennett, J. Wang, N. Pettorelli, and J. G. Ewen. 2010. Sensitive males: inbreeding depression in an endangered bird. Proceedings of the Royal Society B: Biological Sciences 277:3677–3684.

Brekke et al. (2010) assesses the level of inbreeding and inbreeding depression in the Tiritiri Matangi Island population. They describe the population as having a substantial genetic load (the decrease in fitness due to deleterious genes) during the period they examined. They also found evidence that inbreeding depresses long term survival, hatchling failure is higher when there is inbreeding, and report that related pairs produce more males than females.

1. Brekke, P., P. M. Bennett, A. W. Santure, and J. G. Ewen. 2011. High genetic diversity in the remnant island population of Hihi and the genetic consequences of re-introduction. Molecular Ecology 20:29–45.

Brekke et al. (2011) uses genetic data from the Hauturu population and reintroduced populations to uncover if there has been genetic diversity loss through reintroduction. The genetic diversity was not found to have decreased in reintroduced populations as compared to source populations. Through simulations they show that genetic loss in the future will be higher for populations with slow population growth and a small number of founders. However, they mention that the high levels of extra-pair copulation may help maintain genetic diversity. At the time of the study, Zealandia was shown to have substantial genetic diversity.

1. Brekke, P., J. Wang, P. M. Bennett, P. Cassey, D. A. Dawson, G. J. Horsburgh, and J. G. Ewen. 2012. Postcopulatory mechanisms of inbreeding avoidance in the island endemic Hihi (*Notiomystis cincta*). Behavioral Ecology 23:278–284.

Brekke et al. (2012) examines whether Hihi exhibit inbreeding avoidance in the Tiritiri Matangi Island population. They found that Hihi use postcopulatory mechanisms to avoid inbreeding, such as extra pair copulations. However, female social mate choices tended to be with closer relatives than random.

1. Brekke, P., J. G. Ewen, G. Clucas, and A. W. Santure. 2015. Determinants of male floating behaviour and floater reproduction in a threatened population of the Hihi (*Notiomystis cincta*). Evolutionary Applications 8:796–806.

Brekke et al. (2015) considers the role that breeding aged and unpaired individuals without a territory, i.e., floaters, play in the Hihi population on Tiritiri Matangi Island. Results indicate that floaters have an important role in population reproduction by increasing the number of breeders and introducing genetic variation.

1. de Villemereuil, P., A. Rutschmann, K. D. Lee, J. G. Ewen, P. Brekke, and A. W. Santure. 2019. Little adaptive potential in a threatened passerine bird. Current Biology 29:889-894.e3.

de Villemereuil et al. (2019) assessed the adaptive potential of Hihi in the Tiritiri Matangi Island and Hauturu population. They found that there is low genetic diversity and low adaptive potential. Their findings are opposed to those of Brekke et al. (2011).

1. Rutschmann, A., P. de Villemereuil, P. Brekke, J. G. Ewen, N. Anderson, and A. W. Santure. 2020. Consequences of space sharing on individual phenotypes in the New Zealand Hihi. Evolutionary Ecology 34:821–839.

Rutschmann et al. (2020) constructed a genetic pedigree and included genetic relatedness for the Zealandia population. They found a high ratio of extra pair paternity of around 64%. The average inbreeding coefficient between birds in the pedigree, 1095 birds across 7 generations, was 0.008 (SD = 0.028), implying that the probability that two copies of a gene variant have been inherited from a common ancestor to both female and male is 0.008. The authors mention that the dispersal patterns at Zealandia may safeguard against related individuals being clustered in space.

Hypothesis 5: a male-skewed sex ratio is resulting in harassment of females by males, which in turn reduces female survival or breeding success.

1. Ewen, J. G., D. P. Armstrong, B. Ebert, and L. H. Hansen. 2004. Extra-pair copulation and paternity defense in the Hihi (or Stitchbird) *Notiomystis cincta*. New Zealand Journal of Ecology 28:233–240.

Ewen et al. (2004) investigates reproductive behavior of Hihi on Tiritiri Matangi Island during the first two breeding seasons after reintroduction when the population was skewed male (3-1 and 2-1) because of low female survival after translocations. Females were reported to resist extra-pair copulation attempts by males.

1. Low, M. 2005. Female resistance and male force: context and patterns of copulation in the New Zealand Stitchbird (*Notiomystis cincta*). Journal of Avian Biology 36:436–448.

Low (2005) designed a study on Tiritiri Matangi Island to better understand the patterns of within pair and extra-pair copulations in Hihi. Their findings suggest that male Hihi gain benefits associated with forced extra-pair copulations, while females may not gain any fitness advantages. The author suggests that female resistance may be a test of male strength to judge male quality.

1. Donald, P. F. 2007. Adult sex ratios in wild bird populations. Ibis 149:671–692.

Donald (2007) provides a review of sex ratios in wild bird populations with a focus on adult sex ratio. Overall, it is common for males to outnumber females in bird populations and in threatened species this male skew is usually more severe. They further mention that in threatened populations, aggressive male competition can bare substantial costs for females which results in lower survival and increasing sex ratio skew. Other causes for male sex skew may be due to physiology, ecology, genetics, or behavior.

1. Ewen, J. G., R. Thorogood, and D. P. Armstrong. 2011. Demographic consequences of adult sex ratio in a reintroduced Hihi population. Journal of Animal Ecology 80:448–455.

Ewen et al. (2011) assesses the effects of fluctuating sex ratio of the Hihi population on Tiritiri Matangi Island and how aggressive male mating behavior impacts female survival and demographics. They found that a fluctuating adult sex ratio has little to no effect on adult female survival or fecundity. As the consequences of mating harassment behavior are not fully understood, the authors suggest caution in making decisions about removing excess males.

1. Brekke, P., P. Cassey, C. Ariani, and J. G. Ewen. 2013. Evolution of extreme-mating behaviour: patterns of extrapair paternity in a species with forced extrapair copulation. Behavioral Ecology and Sociobiology 67:963–972.

Brekke et al. (2013) explores the patterns of extrapair paternity where extrapair copulation is forced. On Tiritiri Matangi Island they report a 3-2 male biased sex ratio and found that female Hihi appear to avoid forced extra pair copulation, which can be costly and correlate with a higher chance of stress or injury. Another factor that may play into the skewed sex ratio is that females fledge later than males and may result in lower survival. The frequency of extrapair paternity on Tiritiri Matangi Island was reported to be high, which may have been the result of forced extrapair copulation.

Hypothesis 6: weather events - specifically cold weather early in the breeding season which reduces breeding success and potentially survival of females.

1. Chauvenet, A. L. M., J. G. Ewen, D. Armstrong, and N. Pettorelli. 2013. Saving the Hihi under climate change: a case for assisted colonization. Journal of Applied Ecology 50:1330–1340.

Chauvenet et al. (2013) develops a framework for identifying current and future sites that may be suitable for Hihi under climate change scenarios. Hihi cannot disperse naturally and there may be direct climate change impact on populations that cannot be controlled for by management actions. With Hihi’s lack of ability to naturally disperse and inability to control climate impacts in current populations through management, assisted colonization may be key to persistence in the future. Through their work, they identified that increased temperature impacts carrying capacity and temperature autocorrelation increases extinction probability. Northern populations were predicted to have the highest risk of impact and unsuitable climate conditions, for instance Hauturu and Tiritiri Matangi Island Hihi populations. Suitable habitat under climate change was predicted to occur on the South Island, where Hihi are not known to historically occur.

1. Correia, D. L. P., A. L. M. Chauvenet, J. M. Rowcliffe, and J. G. Ewen. 2015. Targeted management buffers negative impacts of climate change on the Hihi, a threatened New Zealand passerine. Biological Conservation 192:145–153.

Correia et al. (2015) conducts research to understand if supplemental feeding has the potential to buffer against impacts of climate change on Kapiti Island. Their findings suggest that supplemental feeding may help with persistence but is likely ineffective for increases in temperature. Additionally, since supplemental feeding for Hihi is not a balanced diet, other dietary requirements may be missing and need to be supplemented to match food availability and requirements under different climate change scenarios.

1. Toy, R., T. C. Greene, B. S. Greene, A. Warren, and R. Griffiths. 2018. Changes in density of Hihi (*Notiomystis cincta*), Tīeke (*Philesturnus rufusater*) and Tūī (*Prosthemadera novaeseelandiae*) on Little Barrier Island (Te Hauturu-o-Toi), Hauraki Gulf, Auckland, 2005–2013. New Zealand Journal of Ecology 42:149–157.

Toy et al. (2018) conducted distance sampling surveys on Hauturu from 2005 to 2013 to estimate Hihi density and trends. They report that there was variation from year to year and suspect it was caused by environmental variation and temporary loss of food resources during storms.

1. de Villemereuil, P., A. Rutschmann, K. D. Lee, J. G. Ewen, P. Brekke, and A. W. Santure. 2019. Little adaptive potential in a threatened passerine bird. Current Biology 29:889-894.e3.

de Villemereuil et al. (2019) examined the evolutionary aspects of lay date in Hihi on Tiritiri Matangi Island to understand the phenological response to climate change. They found a difference between optimum and observed lay date which implies maladaptive phenology. Despite the population having a strong population growth rate, a negative relationship between increased temperature and breeding success was reported. Both of these findings point towards Hihi having lack of adaptive potential and phenotypic plasticity. The authors also discuss the impacts of Hihi in immature habitat and how this may result in mismatches between phenology and resource availability.

1. Keegan, L. J., R. S. A. White, and C. Macinnis-Ng. 2022. Current knowledge and potential impacts of climate change on New Zealand’s biological heritage. New Zealand Journal of Ecology 46:1–24.

Keegan et al. (2022) discusses the potential effects of climate change on New Zealand species and ecosystems. Hihi are predicted to be threatened by warming and feeding interruptions during heavy rainfall. They also point out that invasive species survival may be facilitated in new places, potentially increasing competition or predation by native and non-native species.

Hypothesis 7: Disease, either aspergillosis or others (e.g., Toxoplasmosis, trematodes, Plasmodium sp., avian malaria, internal or external parasites), is reducing adult survival, fledgling survival, or the probability of fledging chicks (i.e., breeding success).

1. Ewen, J. G., R. Thorogood, C. Nicol, D. P. Armstrong, and M. Alley. 2007. *Salmonella* Typhimurium in Hihi, New Zealand. Emerging Infectious Diseases 13:788–790.

Ewen et al. (2007) reports on a *Salmonella* outbreak in 2006 on Tiritiri Matangi Island, work that offers an example to show that there is potential for diseases or pathogens to be novel and present in Hihi populations.

1. Rippon, R., M. Alley, and I. Castro. 2010. *Candida albicans* infection in free-living populations of Hihi (Stitchbird; *Notiomystis cincta*). New Zealand Veterinary Journal 58:299–306.

Rippon et al. (2010) investigates nestling mortality of Hihi at Zealandia and describes the prevalence of *Candida albicans* in nestlings. They report that survival to fledgling was not significantly different between nestlings that tested positive or negative for *Candida.* However, *Candidiasis* was associated with nestling mortality and infection may be passed from adult to young through feeding.

1. Perrott, J., and D. Armstrong. 2011. *Aspergillus fumigatus* densities in relation to forest succession and edge effects: implications for wildlife health in modified environments. EcoHealth 8:290–300.

Perrott and Armstrong (2011) assess whether *Aspergillus fumigatus* limits Hihi populations at 4 different Hihi sites: Hauturu, Tiritiri Matangi Island, Mokoia, and Mount Bruce. The highest spore densities were found in the spring, at the start of the Hihi breeding season. Seasonal changes in spore density were observed at Mokoia, and Hauturu always had lower spore counts than Mokoia. They postulate that highly modified habitat may present with higher spore counts.

1. Ewen, J. G., D. P. Armstrong, R. Empson, S. Jack, T. Makan, K. McInnes, K. A. Parker, K. Richardson, and M. Alley. 2012. Parasite management in translocations: lessons from a threatened New Zealand bird. Oryx 46:446–456.

Ewen et al. (2012) provides a retrospective review of parasite screening and what goes into assessing individuals for translocation.

1. Alley, M., and B. Gartrell. 2019. Wildlife diseases in New Zealand: recent findings and future challenges. New Zealand Veterinary Journal 67:1–11.

Alley and Gartrell (2019) review the main pathogenic agents that pose a threat to wildlife species in New Zealand. Specific pathogens mentioned in their review are mentioned by other resources above (i.e., *Aspergillus, Candida, Salmonella*). The authors suggest that effects of disease may not be obvious and direct effects but are more likely to be effects that influence the host’s ability to forage or cause immunosuppression, thereby increasing susceptibility to secondary infections, starvation, predation, or cause reproductive failure.

Hypothesis 8: Current habitat conditions result in poor nutrition (quality or quantity of food) and reduced adult survival.

1. Ewen, J. G., R. Thorogood, F. Karadas, A. C. Pappas, and P. F. Surai. 2006. Influences of carotenoid supplementation on the integrated antioxidant system of a free living endangered passerine, the Hihi (*Notiomystis cincta*). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 143:149–154.
2. Ewen, J. G., R. Thorogood, P. Brekke, P. Cassey, F. Karadas, and D. P. Armstrong. 2009. Maternally invested carotenoids compensate costly ectoparasitism in the Hihi. Proceedings of the National Academy of Sciences 106:12798–12802.

Ewen et al. (2006) describes the antioxidant concentrations in Hihi and Ewen et al. (2009) uncovers that supplementation may decrease parasitic effects in nestlings.

1. Walker, L. K., D. P. Armstrong, P. Brekke, A. L. M. Chauvenet, R. M. Kilner, and J. G. Ewen. 2013. Giving hihi a helping hand: assessment of alternative rearing diets in food supplemented populations of an endangered bird. Animal Conservation 16:538–545.

Walker et al. (2013) assesses the effects of neonatal supplementary feeding on nestling growth, nestling survival, and juvenile survival to breeding age of Hihi in the Tiritiri Matangi Island population. Utilizing an experimental design, they found that female nestlings had increased survival to fledgling when given a high protein diet, but males showed reduced survival to fledging under the same management. For females, they found that a carotenoid only treatment was beneficial for survival to fledgling, but not when provided with high protein. They were not able to identify any effects of nestling dietary treatment on survival from fledgling to recruitment.

1. Makan, T., I. Castro, A. W. Robertson, M. K. Joy, and M. Low. 2014. Habitat complexity and management intensity positively influence fledging success in the endangered Hihi (*Notiomystis cincta*). New Zealand Journal of Ecology 38:53–63.

Makan et al. (2014) examines Hihi island populations on Hauturu, Kapiti, Mokoia, and Tiritiri Matangi from 1992 to 2004 to understand the effects of habitat quality on fledgling success. They uncovered a positive relationship between habitat complexity and fledgling success, but report that supplementary feeding can compensate for lower quality habitat. They also cite that structure and diversity in the lower to middle sections of forest are potentially important for Hihi use.

1. Doerr, L. R., K. M. Richardson, J. G. Ewen, and D. P. Armstrong. 2017. Effect of supplementary feeding on reproductive success of Hihi (Stitchbird, *Notiomystis cincta*) at a mature forest reintroduction site. New Zealand Journal of Ecology 41:34–40.

Doerr et al. (2017) tests the effect of supplementary feeding on Hihi reproduction at Maungatautari by comparing females that used feeders with those that did not. Their results indicate that supplementary feeding has a significant impact on reproductive success in mature forest and females that used feeders were more likely to have reduced probability of nest failure.

1. Franks, V. R., and R. Thorogood. 2018. Older and wiser? Age differences in foraging and learning by an endangered passerine. Behavioural Processes 148:1–9.

Franks and Thorogood (2018) investigates the relationship between age and foraging cues of Hihi at Zealandia. Through varying feeding cues of supplementary feeders, they found that juveniles had a delayed reaction to changes when compared to adults and juveniles spent longer foraging than adults. This work indicates that both age classes use different strategies when foraging and juveniles appear to be less efficient. They caution that changing feeder locations may put juveniles at a disadvantage until they are able to learn appropriate cues.

Hypothesis 9: some interacting combination of factors:

* Hypothesis 9a: Weather events (Hypothesis 6) are causing females to approach feeders at a higher rate, where they are harassed by males (Hypothesis 5), which is reducing female survival and breeding success.
* Hypothesis 9b: Inbreeding depression (Hypothesis 4) is increasing the disease susceptibility of Hihi (Hypothesis 7), thereby reducing survival and breeding success.
* Hypothesis 9c: Weather events (Hypothesis 6) are causing stress to females, making them susceptible to disease (Hypothesis 7), reducing female survival.
* Hypothesis 9d: A male-skewed sex ratio (Hypothesis 5) is increasing the rate of female dispersal out of Zealandia (Hypotheses 2 and 3), thereby reducing female survival.
* Hypothesis 9e: The current habitat conditions (Hypothesis 8) are such that birds are dispersing out of Zealandia to find food (Hypotheses 2), reducing adult and fledgling survival.
* Hypothesis 9f: Current habitat conditions and poor nutrition (Hypothesis 8) are increasing Hihi’s susceptibility to disease (Hypothesis 7), reducing survival.

1. Low, M. 2010. Which factors limited Stitchbird population growth on Mokoia Island? New Zealand Journal of Ecology 34:269–271.

Low (2010) discusses the low adult survival rate of the Mokoia Island Hihi population in comparison to the Tiritiri Matangi Island population. Ultimately, the Mokoia population of Hihi was translocated to Kapiti Island in 2002 due to lack of population growth. Because there was not a comparison of the prevalence of aspergillosis between the two populations, the author suggests that other factors should be examined. Low remarks that there was no direct evidence that the rate of Aspergillosis was different between the two populations, but observations imply that Ruru density was higher on Mokoia than Tiritiri Matangi when Hihi were present. The author concludes that the likely cause of Hihi on Mokoia was due to a combination of factors, including aspergillosis, Ruru predation effects, and potentially other unknown causes.

1. Armstrong, D. P., I. Castro, J. K. Perrott, J. G. Ewen, and R. Thorogood. 2010. Impacts of pathogenic disease and native predators on threatened native species. New Zealand Journal of Ecology 34:272–273.

Armstrong et al. (2010) further discusses the ideas presented in Low (2010, reference directly above). The authors report that they expected the mouse eradication of 2001 on Mokoia to cause a Ruru population decline, thereby reducing Ruru predation of Hihi. The hypothesis that aspergillosis was the cause of deline of the Mokoia population was given greater weight due to the data collected on spore counts as reported by Perrott and Armstrong (2011), while information about Ruru densities was primarily anecdotal. The authors suggest that multiple hypotheses should be considered when trying to uncover causes of observed population trends.

1. Perrott, J., and D. Armstrong. 2011. Aspergillus fumigatus densities in relation to forest succession and edge effects: implications for wildlife health in modified environments. EcoHealth 8:290–300.

Perrott and Armstrong (2011) found that *A. fumigatus* spore densities were highest during the start of the Hihi breeding season. The authors postulate that stress on females due to forced extra pair copulation attempts by males may, in tandem with high *A. fumigatus* spore counts, result in the high incidence of aspergillosis in Hihi. They also mention that dry soil favors *A. fumigatus,* indicating that through climate change the density may increase. Further, the authors cite that genetic bottlenecks may play a role in limited immune health and contribute to greater incidence of aspergillosis mortality.

Hypothesis 10: Hihi get killed from hitting fences, reducing survival.

Unable to find any specific mention of Hihi killed in mouse traps or by hitting the fence but see Hypothesis 12 for other mammal traps.

Hypothesis 11: Hihi chicks are being fed wasps, causing internal trauma from stingers and leading to death, reducing overall survival of chicks.

1. Rippon, R. J., M. R. Alley, and I. Castro. 2013. Traumatic ventriculitis following consumption of introduced insect prey (*hymenoptera*) in nestling Hihi (*Notiomystis cincta*). Journal of Wildlife Diseases 49:80–90.

Rippon et al. (2013) investigates the causes of nestling mortality in Hihi at Zealandia. Of the 25 nestlings that died and were recovered for examination in their work, 7 of them died from ventriculitis which is associated with insect remains, most likely bees or wasps. The causes of death for the remaining chicks were emaciation and hypothermia. The authors suggest that Hihi parents may be maximizing foraging by selecting larger and available insects, but without the proper adaptations to process wasps or bees. They also mention that there is little information on the invertebrate diet of Hihi and whether fluctuations of invertebrate prey availability cause Hihi to select bees and wasps for nestlings.

Hypothesis 12: Hihi are consuming poisoned baits, either through primary or secondary poisoning, causing reduced adult survival.

1. Eason, C. T., and E. B. Spurr. 1995. Review of the toxicity and impacts of Brodifacoum on non‐target wildlife in New Zealand. New Zealand Journal of Zoology 22:371–379.

Eason and Spurr (1995) provide a review of the toxicity and effects of Brodifacoum in birds. They report that Hihi have potential, as insectivores, to eat invertebrates that have feed on toxic baits and could be at risk of secondary poisoning.

1. Empson, R. A., and C. M. Miskelly. 1999. The risks, costs and benefits of using Brodifacoum to eradicate rats from Kapiti Island, New Zealand. New Zealand Journal of Ecology 23:241–254.

Empson and Miskelly (1999) reports on work that monitored Hihi before and after a Brodifacoum application on Kapiti Island, but they detected no adverse effects from the application.

1. Alley, M., and N. J. Beausoleil. 2016. Predator-free New Zealand: welfare considerations and collateral damage to non- target species. Kokako 23:29–36.

Alley and Beausoleil (2016) discusses the potential for non-target poisoning in controlling invasive mammals and mention that ground dwelling birds are likely to be most affected.

Hypothesis 13: Hihi are being caught in mammalian traps and other control tools, reducing adult survival.

1. Warneford, A. D. 2011. Controlling pests in New Zealand sanctuaries: varying the spatial distribution of the standard grid system in a mainland conservation project. Massey University, Auckland, New Zealand.

Warneford (2011) reports that 3 Hihi were killed in traps designed to kill stoats, rats, ferrets, and weasels (DoC200 traps) during their thesis work at Arc in the Park to determine if bait density could be reduced. They cite that the traps may have resembled nest boxes used on Tiritiri Matangi Island where the birds were sourced from.

Hypothesis 14: Wasps are limiting nectar and insects, reducing adult survival.

1. Beggs, J. 2001. The ecological consequences of social wasps (Vespula spp.) invading an ecosystem that has an abundant carbohydrate resource. Biological Conservation 99:17–28.

Beggs (2001) reports on the impact of wasps in New Zealand beech forests that are infested with honeydew producing native scale insects on the South Island. The authors report that when wasp populations are supported by abundance carbohydrate food sources, wasps have been observed consuming large quantities of invertebrates. On the South Island, wasps have been observed competing with native birds for both honeydew and invertebrate food.

1. Harris, R. J. 1991. Diet of the wasps *Vespula vulgaris* and *V. germanica* in honeydew beech forest of the South Island, New Zealand. New Zealand Journal of Zoology 18:159–169.

Harris (1991) investigates the invertebrate diets of wasps at two beech forest sites on the South Island. Wasps were reported to have considerable dietary overlap with native insectivorous birds, with the amount of prey taken by wasps predicted as comparable to that of bird species.

1. Harris, R. J., and E. H. Oliver. 1993. Prey diets and population densities of the wasps *Vespula vulgaris* and *V. germanica* in scrubland-pasture. New Zealand Journal of Ecology 17:5–12.

Harris and Oliver (1993) examines the invertebrate prey diets of wasps at scrubland-pasture sites. They report that the prey biomass taken by wasps is lower in scrubland-pasture than the prey biomass taken in beech forests, although in some places the prey biomass taken was comparable to sites in beech forest. Due to lack of information about the prey population, the authors were unable to determine the impact of wasps in scrubland-pasture habitat.

1. Elliott, G. P., P. R. Wilson, R. H. Taylor, and J. R. Beggs. 2010. Declines in common, widespread native birds in a mature temperate forest. Biological Conservation 143:2119–2126.

Elliott et al. (2010) looks at the abundance of forest birds on the South Island using bird count data over a 30-year period. They report that the arrival of wasps and possums to the study area, in conjunction with rat and stoat predation, were responsible for the changes in bird abundance that were observed. The bird species that declined over the study period were entirely or partially insectivorous.

1. Lester, P. J., S. D. J. Brown, E. D. Edwards, G. I. Holwell, S. M. Pawson, D. F. Ward, and C. H. Watts. 2014. Critical issues facing New Zealand entomology. New Zealand Entomologist 37:1–13.

Lester et al. (2014) cites that invasive social wasps are widespread throughout New Zealand, which may put intense pressure on native invertebrates. However, the impact of invasive wasps and other non-native invertebrates on native species is not well understood.

Hypothesis 15: Competition with mice for insects and seeds is reducing adult survival.

1. Watts, C., J. Innes, D. Wilson, D. Thornburrow, S. Bartlam, N. Fitzgerald, V. Cave, M. Smale, G. Barker, and M. Padamsee. 2022. Do mice matter? Impacts of house mice alone on invertebrates, seedlings and fungi at Sanctuary Mountain Maungatautari. New Zealand Journal of Ecology.

Watts et al. (2022) examines the impacts of mice on the biodiversity at Maungatautari. They found evidence that mice reduce the abundance of ground-dwelling invertebrates. They also report an increase in earthworm biomass as mouse density decreased (through eradication).

1. Badan, D. 1986. Diet of the house mouse (*Mus musculus l.*) in two pine and a kauri forest. New Zealand Journal of Ecology 9:137–141.

Badan (1986) studied the diet of mice in exotic and native forests. In both forest types, mice generally fed on invertebrates and seeds, with the majority of their diet based on availability of either food type.

1. Russell, J. C., J. E. Peace, M. J. Houghton, S. J. Bury, and T. W. Bodey. 2020. Systematic prey preference by introduced mice exhausts the ecosystem on Antipodes Island. Biological Invasions 22:1265–1278.

Russell et al. (2020) studies the impacts of mice on Antipodes Island prior to mouse eradication. They found that invertebrates were the major food source for mice and they observed a reduction in invertebrate abundance due to mouse predation. They also found that land birds on the island fed lower on the food chain as a result of competition with mice for invertebrates. Once mice were eradicated, land birds showed a marked increase in recovery.

Hypothesis 16: Inter and intraspecific competition for supplemental feeding resources is reducing female survival.

1. Rasch, G., and J. L. Craig. 1988. Partitioning of nectar resources by New Zealand honeyeaters. New Zealand Journal of Zoology 15:185–190.

Rasch and Craig (1988) investigates intraspecific competition between tui, korimako, and hihi on Hauturu to determine which species dominated favored nectar sources. Through their work, they found that tui fed on the highest-ranking nectar flower sources, korimako fed on the intermediately ranked sources, and hihi fed on the lowest ranked sources but also sought access to high-ranking sources. Hihi were found to avoid resources that were used mainly by the bellbird.

1. Roper, M. 2012. Resource partitioning between two competitive species, the hihi (*Notiomystis cincta*) and bellbird (*Anthornis melanura*), during the non-breeding season on Tiritiri Matangi Island. Massey University, Albany, New Zealand.

Roper (2012) investigates the interaction between korimako and hihi at supplemental feeder sites, as well as interspecific interactions between male and female hihi on Tiritiri Matangi. They found that there was little competitive exclusion between male and female hihi at supplementary feeders. Female hihi were observed to decrease feeder visits when nectar resources were abundant, whereas male hihi increased use. Male hihi displacement behavior increased toward other male and female hihi in September, when their territorial mating defense behavior began. Male korimako were observed most frequently at the feeders.

Hypothesis 17: Hihi rearing is phenologically asynchronous with invertebrate prey availability, leading to poor nestling survival.

No specific research on invertebrate prey availability and/or hihi’s timing in relation to invertebrates.

1. Charmantier, A., and P. Gienapp. 2014. Climate change and timing of avian breeding and migration: evolutionary versus plastic changes. Evolutionary Applications 7:15–28.

Charmantier and Gienapp (2014) provides a review of concepts and how climate change may impact breeding timing.