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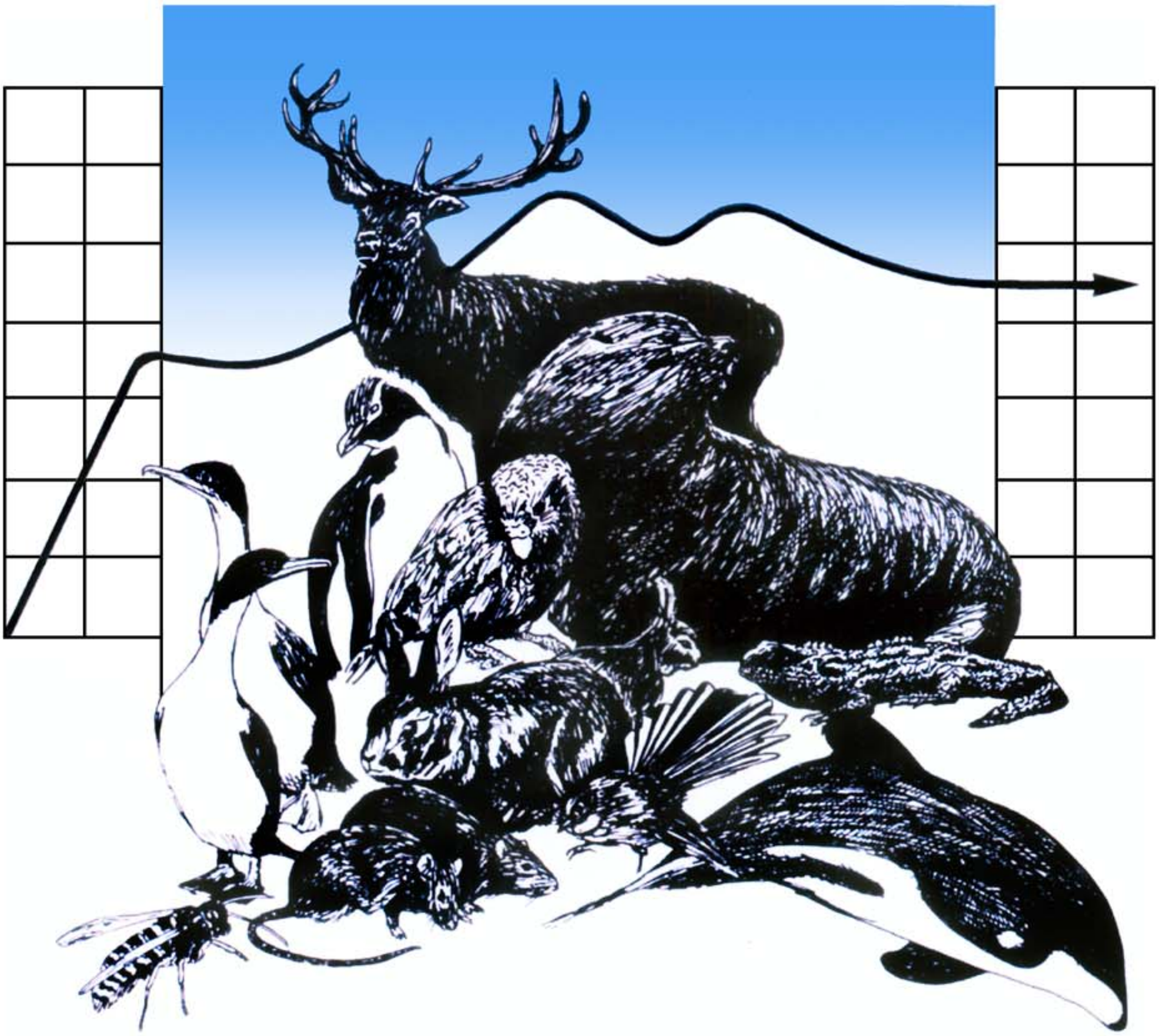

# WILDLIFE MANAGEMENT

# Kaki (Black Stilt) Cost-benefit analysis: When should egg-pulling cease?

**Alison Anker, Tammy Hanson, Benjamin Leutner, Kirsten Robertson**

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University of Otago
Department of Zoology
P.O. Box 56, Dunedin
New Zealand

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# Kaki (Black Stilt)

## *Himantopus novaezelandiae*


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## *COST BENEFIT ANALYSIS*

## *When should egg- pulling cease?*

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## ABSTRACT

The kaki *Himantopus novaezelandiae* are classified as critically endangered and have been undergoing intensive management since 1981, involving wild egg-pulling and captive rearing. They are restricted to the braided river system of the Upper Waitaki Basin. Annual egg-pulling is conducted by conservation managers at the Department of Conservation to prevent the species from facing extinction. Their aim is to reach a stable population size of 250 breeding individuals. The strategy of egg-pulling from the wild and captive breeding has relative costs and benefits to the species and the environment. This report will review the current management strategy, analyse population models to determine their effectiveness and identify three potential scenarios of kaki management and when to cease egg-pulling.

**Keywords: Kaki, Egg-pulling, Captive, Costs, Benefits**

## INTRODUCTION

The kaki *(Himantopus novaezelandiae)* is the rarest wading bird in the world and New Zealand's only non-migratory wading species. It is endemic to New Zealand and is listed as critically endangered by the International Union for Conservation of Nature (IUCN 2008).

The species was once distributed throughout the North and South Island of New Zealand. They are now restricted to the South Island's braided river systems of the Upper Waitaki Basin. The main reasons for the decline are habitat modification and predation predominantly by introduced species.

Since 1981, the Department of Conservation (Department of Conservation 2000) has been intensively managing the kaki. Strategies include: egg pulling from the wild, captive breeding, captive incubation, rearing, release and predator control. The population has grown from 23 adults in 1981 to the current population size of 82 adults (Department of Conservation 2007-2008; Maloney 2009). This has resulted in a population bottleneck and therefore there is a limited and vulnerable gene pool. Furthermore, due to the small founder population, inbreeding depression and hybridisation, there may be a decreased variability in the gene pool due and a loss of genetic representation of the species (Wallis and Conservancy 1999). For example, Wallis and Conservancy (1999) observed that survival rates of hybrids chicks are considerably lower than 'pure' chicks. This has lead to active management to reduce pied stilts pairing with kaki in the wild.

Objectives of the kaki management group are listed in the Recovery Plan 2000, with a main goal of increasing the population to 250 breeding pairs in the wild (Department of Conservation 2000). Without action taken by DOC to rear populations in captivity, it is highly likely the population would be extinct. This is evident from the low survival rates of wild birds between 1992 to 1999, of which only 4% reached reproductive age of two years (Department of Conservation 2000). As a result of intensive captive management there are only two birds which were reared in the wild.

Evaluation of management strategies is constrained. It takes two years to observe the outcomes of changes to management actions (Maloney 2009). Due to the vulnerability of the species and the amount of effort put into captive management, it is vital that any new management strategies considering relative costs and benefits are well thought out. These costs and benefits to the species and the public will be addressed and analysed in this report. This will provide us with a basis to address the question of: 'when or if egg pulling operations of kaki should cease?'

### Species Background

The kaki can be classified as juveniles until they are nine months old; sub-adults from nine months to two years; and adults from two or more years. They are a territorial species with a nesting territory ranging from 0.5 to 4 ha (Department of Conservation 2000). They are monogamous - pairing for life - and they breed for the first time at two to three years of age. Breeding occurs between August and September with a peak egg-laying period in October. Incubation lasts for 25 days and is carried out by both parents (Department of Conservation 2000). The clutch size ranges between three to four eggs per season. Clutches can be lost by flooding events, predation or by egg-pulling mimicking these events. If the clutches are lost, kaki have the ability to re-lay up to four clutches in a season. Although chicks are precocial (where the young are relatively mature and motile at birth), both parents are involved in brooding and guarding. Once the chicks have fledged (40 to 55 days old) they remain with their family group until the start of the next breeding season.

The fledging rate of chicks in the wild is very low. The current fledging rate is 32.5% and the current and breeding success is 10.8% (Department of Conservation 2000). These figures are based on predator control. This limited population growth is most likely due to breeding and recruitment failure as well as low life expectancy. Predation is considered to be the main factor for the limited population size. Nesting sites of the kaki are located on stable river banks within predator movement corridors. They additionally lack behavioural adaptation towards the introduced predators, increasing their vulnerability to predation.

## Habitat Background

Braided river systems are rare worldwide, existing in areas that have active uplift and erosion (Maloney, Rebergen et al. 1997). Typically the landscape consists of unstable gravel based channels, with sparse vegetated islands. They are subject to spring and summer flooding (Maloney, Rebergen et al. 1997). Various species utilise this unique habitat and restrict their available range to these specific areas.

The Upper Waitaki basin is a significant habitat to the kaki and other wading river birds dependent on this specific ecosystem. It is estimated to represent up to 50% of New Zealand's braided river habitat that is suitable to this species (Maloney, Rebergen et al. 1997). Management is restricted to these areas of suitable habitat. Re-establishing the species back into their former ranges is difficult for management in this braided river environment. Predator exclusion by boundaries is not feasible and there are currently no suitable offshore islands available for translocation.

## Current Management Strategy

The Department of Conservation's goal is to "*improve the status of kaki from critically endangered by increasing the population to more than 250 breeding individuals, with a mean annual recruitment rate that exceeds the mean annual adult mortality rate, by 2011*" (Department of Conservation 2000).

To achieve this goal, DOC is using the technique of captive management, which is a process involving a number of steps. As the response time to observe flow on effects of any changes made by management is two years, all implemented strategies should be carefully considered. The most critical steps that relate to management success of the wild population are outlined below.

1. *Egg- pulling*

Kaki pairs and their nests are located in the wild and the clutches are collected and incubated in the Twizel captive breeding facility. Pairs with eggs removed were able to multi clutch, enabling a total of 102 eggs to be collected from the wild kaki population in 2007 (Department of Conservation 2007-2008).

*2. Incubation Process*

The eggs are incubated in the DOC Twizel incubation facility. Conditions are optimised to improve hatching success. There is constant monitoring of egg temperature at 37.5˚C with the use of a temperature probe. Relative humidity is between 50 to 55% (van Heezik, Lei et al. 2005; Department of Conservation 2002). Once the eggs have begun pipping they are transferred to a hatcher. Following hatching they are placed into a brooder for 32 to 35 days and then relocated to an aviary (van Heezik, Lei et al. 2005). The total number of eggs incubated in 2007 was 101.

*3. Aviary Management*

On-going efforts have been made by the DOC Twizel office to improve the standard of the infrastructure and reduce injuries to birds. Suspended soft lined nettings have reduced injuries and fatalities due to birds flying into the aviary walls (van Heezik, Lei et al. 2005) Although there have been efforts by DOC to reduce injuries, occurrences of mortality or traumatic injuries from flying into the aviaries are still taking place (van Heezik, Lei et al. 2005). For example; in October 2007 a female (*Adult GR/BkW)* was found with a broken bill (Department of Conservation 2008).

*4. Disease Screening*

Protocols have been established by DOC staff to reduce the transfer of disease and to minimise the introduction of pathogens. Each bird is examined and evaluated to identify any associated risks. Their survival probability determines whether to treat or to euthanize (van Heezik, Lei et al. 2005). Prior to the release or transfer of all juveniles, sub-adults and adults birds, they are screened for disease (Department of Conservation 2008).

*5. Release of Kaki*

Every year both sub-adult and juvenile birds are released at the end of August. Although juveniles have a lower survival rate in the wild, the limited capacity at the Twizel aviary facility has meant that birds have been released before reaching two years of age (sub-adult). This increases the output of birds into the wild. In 2008 a total of 16 juveniles and 77 sub-adults were released (Department of Conservation 2008). All birds released from the captive unit are colour banded, enabling DOC staff to monitor through presence/absence surveys to determine survival rates.

## Species Comparison and Management

The ultimate goal of conservation management of endangered species is to increase the population size and attain a self-sustaining wild population (Maxwell and Jamieson 1997). Numerous recovery programmes have successfully restored small populations to self sustaining levels in the wild. Examples that use similar techniques as the kaki recovery plan include the takahe *(Notornis mantelli*) which have successfully increased the adult population in Fiordland. Also, the Mauritius Kestrel (*Falco punctatus)* which have re-established to 58-68 pairs from a critically small population size of only four individuals (Jones, Heck et al. 1995). Due to the success of their re-establishment, intensive management has ceased and the population continues to be monitored (Jones, Heck et al. 1995). However, this example is different to the kaki population as the identified cause of decline was pesticides and they were removed from the environment. Current kaki management has been unable to remove the main recognised threat of predators. Therefore, restoring species to their former ranges when the habitat continues to display attributes responsible to their initial decline is questionable (Maxwell and Jamieson 1997).

## PART A: COSTS & BENEFITS

There are a number of costs and benefits involved with producing and releasing captive reared kaki derived from egg-pulling in the wild. This section will discuss in detail the potential benefits and costs to the species.

### Benefits

1. *Survival*

As the kaki faces high predation rates and low survival rates, it is predicted that without captive rearing and egg-pulling the population would face eminent extinction. Management efforts have conserved a unique native species of New Zealand and increased the number of birds in the wild. In particular, through increasing egg productivity and improving fledging rates (by protecting kaki at their most vulnerable stage), the wild population has grown in size.

2. *Model Management Technique*

As there is a high turn-over with egg-pulling, the kaki recovery program could be considered a model management technique. These techniques could therefore be used for future model management design. For example, aviary structure can be improved with fine netting in the interior as well as ensuring a balanced diet in captivity. These techniques could be carried over to management of other species.

*3. Ecosystem Benefits*

Other associated benefits of the kaki recovery program include predator control in the braided river system. This can aid the conservation and recovery of other bird species found in these habitats and improve the overall function of the ecosystems (Keedwell, Maloney et al. 2002). However, the effectiveness of the current predator control is unknown. Further research and monitoring is required to evaluate these benefits (Keedwell, Maloney et al. 2002).

*4. Umbrella and Flagship Species*

Due to the difficulty and complexity of monitoring the biota of an area, it is common for conservation groups to focus their efforts on conserving a singular species. Such a species is the kaki. It primarily can be viewed as an umbrella species (Andelman and Fagan 2000) and secondly as a flagship species with the overall objective to substitute regional biota (Andelman and Fagan 2000). Umbrella species generally have a wide range and a large scale habitat requirement. There are flow-on effects to other species when a singular species is the main focus of management effort. Large scale habitat requirements and efforts to conserve these species directly benefit other flora and fauna in that ecosystem (Simberloff 1998; Andelman and Fagan 2000).

Flagship species can provide benefits to the general public, through increased knowledge, appreciation, awareness of species and conservation values and management organisations. These species can also benefit from the public through community involvement and funding. The kaki is one of the highest profile bird species in New Zealand. It is a public figure for the work going on and there is a statue of the kaki in the township of Twizel. Between 1999-2000, there were 1043 visitors to the captive facility to view kaki from the hide. The Forest and Bird Society have used the kaki image as their logo (Department of Conservation 2000). The image of the kaki is used on stamps and phone cards and other merchandise. They are also a significant species to the local iwi (Department of Conservation 2000).

However, managing a single species can often be very expensive and inefficient (Andelman and Fagan 2000). Conservation efforts to protect umbrella and flagship species have the added benefit of protecting and conserving other species. Kaki conservation provides improved management of other wading birds (including the black fronted tern and wry birds) and plant communities through habitat protection and predator control.

Management should recognise the emotional investment by the community when such programmes are established, and carefully consider which singular species that conservation efforts are placed into. How will the community respond if this species fail to respond to management? Perhaps, the community will lose interest and be disheartened with future projects run by conservation agencies (Simberloff 1998).

## Costs

Evaluating costs of captive rearing and egg -pulling to a species may be difficult, due to the possible long term effects and effort required to measure outcomes. The main costs that will be addressed in this section are directed towards kaki's long term viability.

1. *Financial*

There is a high cost associated with captive rearing and egg-pulling. The current (2009) total annual budget for the Kaki programme (includes all salaries and seasonal position wages) is $462,000. The breakdown is Wild: $120,000, Captive: $148,500 and Predator $193,500 (pers. com. Nelson 2009). The costs associated need to be carefully considered when designing management strategies.

2. *Behavioural*

*2.1. Temperament:*

Development, learning and evolution may influence both captive and wild populations in their temperament (McDougall, Réale et al. 2006). Variations in temperament traits include neophobia and exploration, boldness, tameness, activity, aggressiveness and sociability. These variations may impact on the way individuals respond to environments. Consequently, this may influence species Darwinian fitness (McDougall, Réale et al. 2006).

There is a tendency for breeding programs not to consider the risk of changes in temperament leading to domestication (McDougall, Réale et al. 2006). Consideration of this effect may improve conservation efforts for kaki management. In captivity, the kaki may be eating more food more often; and it may be better quality than what they would find in the wild. They do not need to actively search for their food in captivity, and they do not need to avoid predators (although they maybe on the look out for predators). There is no need to conserve energy in captivity to the same extent as in the wild. Perhaps the kaki have greater activity levels in captivity and once released, they may not adapt their behaviour accordingly. There may be a higher expenditure than necessary in the wild, leading to lower survival or reproductive rates (Mathews, Orros et al. 2005).

*2.2 Domestication*

Domestication refers to wildlife selectively adapting to a captive environment and to the presence of humans. This may result in changes to the genetic make-up of a species over generations (Price 1999). The transition from wild to domestic phenotypes is commonly in response to the availability of shelter, space, food and water and the lack of predator presence (Price 1999). Domesticated individuals may lack natural physiological and behavioural responses necessary for survival in the wild (Araki 2007). These changes can be linked to the presence or absence of key stimuli (i.e. predation); skills passed down from parents (i.e. foraging techniques) and human interaction (Frankham, Hemmer et al. 1986; Price 1999). This lack of parental involvement has been identified in some species to cause issues in mis-imprinting and their inability to develop appropriate predator avoidance. For example, captive reared species such as the Hazel grouse (*Bonasa bonasia*) fails to develop an appropriate alarm response, while the black grouse *(Tetrao tetrix)* displayed delayed reaction to predators (Curio 1993).

Domestication has also led to anatomical changes in species, such as the reduction in brain size of water fowl (Frankham, Hemmer et al. 1986). In addition, a constant supply of an ideal food source that would otherwise be unavailable in the wild has led to changes in gut morphology of captive bred partridges (Bagliacca, Profumo et al. 2004). Although it has been reported that kaki retain behaviours and skills that are necessary for survival in the wild (Galbraith, Sancha et al. 2007) further long term effects or changes to individuals should not be excluded. These behavioural changes may affect the overall fitness of a species.

*3. Fitness*

Multi clutching requires female birds to invest more energy into egg production, which may result in a cost to fitness. As seen in the case of the Lesser Black-backed Gulls *(Larus fuscus)*, increased egg production in one year can influence egg production in the following years and therefore future fitness (Nager, Monaghan et al. 2001). However, to date, there is no evidence that multi-clutching reduces fitness in the kaki (Maloney 2009). Keeping wildlife in captivity for many generations may also have negative effects on their ability to naturally reproduce in the wild (Araki, 2007). For example, Wild Turkeys in North America were unable to form wild populations following captivity for several years (Snyder, Derrickson et al. 1996).

Fitness levels of captive kaki may be reduced by factors such as stress in captivity. They are in close proximity in the aviaries, which may impact their ability to survive once released into the wild (van Heezik, Lei et al. 2005). Furthermore, alterations of selective forces compared to those in the wild may facilitate maintenance and development of non-adaptive genotypic traits within the kaki gene pool.

### Conclusion

It is vital that all of these associated costs and benefits are considered when deciding on appropriate management strategy options. However, it will be difficult to assess if these effects are impacting on the kaki as there are only two wild-reared birds to compare these behavioural changes to.

In addition the low genetic variability resulting from the bottleneck the population went through has to be considered. There is a serious risk of extinction or population crash with a disease outbreak. For example, the current decline in the tasmanian devil (*Sarcophilus arrisii)* is directly linked to the out-break of facial tumours. This vulnerability may be due to low genetic variability. However it is not running cost of the captive program itself but originates from the initial small population. Neverthe-less in the cost-benefit analysis this would appear as a risk, and subsequently accounts for a cost of the project.

## PART B: WHEN TO CEASE EGG PULLING OPERATIONS

The question is, why should we preserve the kaki when it is costing an extensive amount of money? A lot of time and effort is going into conserving this one particular species, when it could possibly be used more efficiently elsewhere. However, if DOC stops egg-pulling and gives up on the project it would generate negative publicity and result in a loss of public interest in DOC projects. The govern-ment, businesses and the public may be more hesitant to financially fund future projects. If we just ‘gave up’ on the kaki and stopped managing them, what future is there for other threatened species in the same circumstances? It is our job to try and conserve the endemic flora and fauna of New Zealand, no matter how critically endangered they are. Do we have a right just to give up on a species if we suspect there is no hope? Or should we continue to manage until the end?

A typical management method could be to translocate to offshore islands. If predators cannot be efficiently controlled on the mainland, then perhaps translocating them to predator-free offshore islands in the future would be an alternative option. However, there are no predator-free islands with suitable braided river habitat. Alternative management scenarios need to be identified.

In this section we will present the outcomes of a coupled management - population model, discuss scenarios of when to cease egg-pulling operations and recommendations of future management and research.

## Population Modelling

A way of projecting the likely and future status of a population is via modelling data using population viability analysis (PVA). This process is commonly used with collaboration between scientists and management to evaluate strategies for species management (Seddon, Armstrong et al. 2007). Using data derived from previous kaki management reports, we constructed a deterministic model to assess the development of the kaki population. This enables us to predict when the population is self-sustainable and egg -pulling operations can cease. However, these results are reliant on a number of assumptions; including the survival and reproductive rates of the wild bird population. The applied population model incorporates both the captive management and the wild kaki population. For further explanations of the model itself, please refer to the appendix. The initial parameters were taken from the 2008 population. However, it is important to be aware that there is no mortality because of age. Hence, the only source of death to the adult population is the mortality rate. This might favour a slight overestimation of the population sizes.

## When / Should we stop egg-pulling?

### *Scenario 1. Continue with egg-pulling*

The current management technique of egg-pulling is effective. It ensures the survival of the kaki population in the wild through the annual releases of juveniles and sub-adults. This process replaces loses in the wild kaki population due to mortality. The current strategy could be considered a model management technique as the population is increasing in the wild. However, at the current rates of fledging, survival, recruitment and releases from captivity, the model indicates that the population won't reach DOC's goal of 250 breeding individuals (baseline model). The baseline model (Fig. I) was run with the parameters listed in table 1. It assumes that all rates and variables remain constant with time. The numbers of released birds are allowed to vary within the captive management capacity. They are determined by the egg production of the wild population and the decision of which proportion of birds are released as juveniles (overall recruitment rate of 0.18) and which proportion are sub-adults (0.29 recruitment rate). In this model run it was set to 0.1, i.e. 10% of the available birds are released as juveniles and the rest as sub-adults, however, minus 10% losses in captivity. If the current survival and breeding success rates are maintained and captive management capacity is not increased, the population will approach a stable state (λ(2050)≈1) with a total number of 220 birds (180 being adults). Recent increased trapping efforts are not taken into account, as survival rates are derived from 2001 to 2005 data. The stabilization of the population is due to limited captive management capacity of 200 eggs, which results in 12 juveniles and 94 sub-adults to be released each year. Eventually the number of released and wild-bred animals substitutes exactly the number of birds which die. In other words, input equals output.

If captive management capacity was increased to 300 eggs, while the remaining parameters stay the same, the total population would reach 250 animals in 2016 converging against 330 individuals. Accordingly, the adult population would hit 250 in 2026 and end up at approximately 270 individuals. This would be achieved by releasing approximately 17 juveniles and 140 sub-adults per year.

If all survival rates increased by about 50%, i.e. 0.3 to 0.45 the total population would hit 250 individuals in 2013 and converge against 395. The adult population would reach 250 in 2018 and converge against 320 (Fig. 2). Releasing only sub-adults expectedly increases the overall population size owing to their higher recruitment rate. Only a low percentage of adult birds form pairs, approximately 50% of individuals from 2008's figures (Department of Conservation 2008). If this number was larger, the total population would be significantly greater. Since we can not directly influence pair formation it will not be taken into consideration.

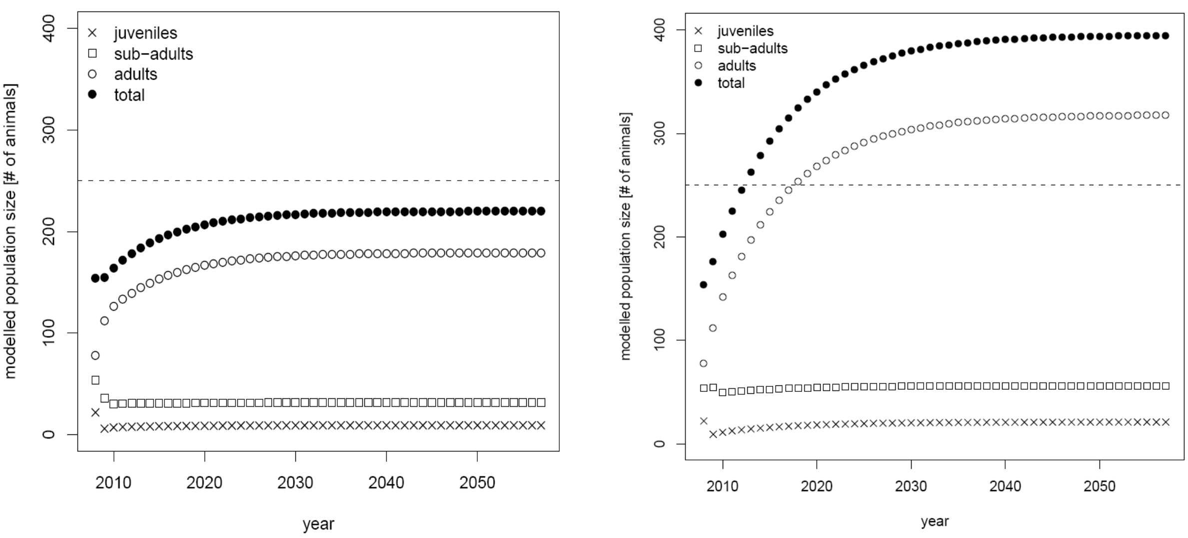

Figure 1 Population development obtained from the baseline projection.

Figure 2 Population development obtained from baseline projection, but with 50% increased survival rates.

Table 1 Initial parameters for the base-line model.

| **2008** | | | | | **Survival rates** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Population | | | Releases | | Released as juv. | | Released as s-ad. | Wild born juv. | Wild born s-ad. | Ad. |
| juv. | s-ad. | ad. | juv. | s-ad | $1^{st}$ yr. | $2^{nd}$ yr. | $1^{st}$ yr. | | | |
| 22 | 54 | 78 | 16 | 80 | 0.31 | 0.57 | 0.29 | 0.3 | 0.4 | 0.85 |

| | **Captivity** | | | | **Wild** | |
|---|---|---|---|---|---|---|
| pairing rate | capacity [eggs] | fledging success | chick mortality | juv. mortality | breeding success | pulled clutches |
| 0.25 | 200 | 0.63 | 0.09 | 0.09 | 0.108 | 3 |

*Scenario 2. Stop egg-pulling and have captive birds*

It is not possible for the kaki population to become self-sustaining unless survivorship rates improve. The rates could potentially be improved through further research and increased predator control (Department of Conservation 2002).

A sub-population of kaki could be brought into captivity and we would no longer try and maintain a population in the wild until the habitat is suitable. This is an option if the population cannot sustain itself in the wild without intensive management. Since the aviaries would soon reach capacity, the over-production could still be released into the wild. With the population bottleneck, a small population in captivity may represent the founder population well enough.

We need to ensure we have a representative sample of the population in captivity. There would need to be multiple captive sites in case disease affects all of the birds in a particular aviary. The goal would be to keep the birds in captivity until the reason for the decline is dealt with. This would involve removing the predators from the habitat, which might be possible in the future with advances in technology in predator control.

A private aviary called "Peacock Springs" in Christchurch already holds captive kaki and we could encourage other organisations to do this also. The problem with this strategy is there is a risk of public outrage if we stop intensively managing the wild population. Another problem is that other species benefiting from the kaki conservation efforts would no longer be supported by this umbrella species. The braided river system is very large and it is extremely difficult to control all of the predators in this habitat. There may be an increase of detrimental effects on the birds in captivity (negatively influencing behaviour and fitness) as discussed in part A of this report.

*Scenario 3. Continue egg-pulling but set a survival rate to stop*

In the future, if the predator control is improved, we may be able to cut back on the amount of egg-pulling from the wild. With predator control, the chicks will have an increased survival and it may allow the currently intensive management regime to be relaxed. If predators were completely controlled, then egg-pulling procedures could cease. Birds born in the wild have a 12% chance of reaching reproductive age (pers. com. Seddon). Released captive birds have a 17% chance whilst sub-adults have a 30% chance of reaching reproductive age (pers. com. Seddon). The model results show that if the complete captive management program was ceased in 2009, the birds would still breed in the wild; however, the population would decline rapidly, leading to extinction in the mid 2030's (see Figure 3.).

If survival rates of juveniles and sub-adults would improve significantly to 60% per year (instead of 30% and 40%) and breeding and nesting success would increase to 50% (compared to 10.8%) the population would be sustainable for the first time. It would increase slowly but surely, reaching about 200 birds in total, in the year 2030 (λ>1). Doubling of survival and breeding success rates would not be efficient enough to produce a sustainable population.

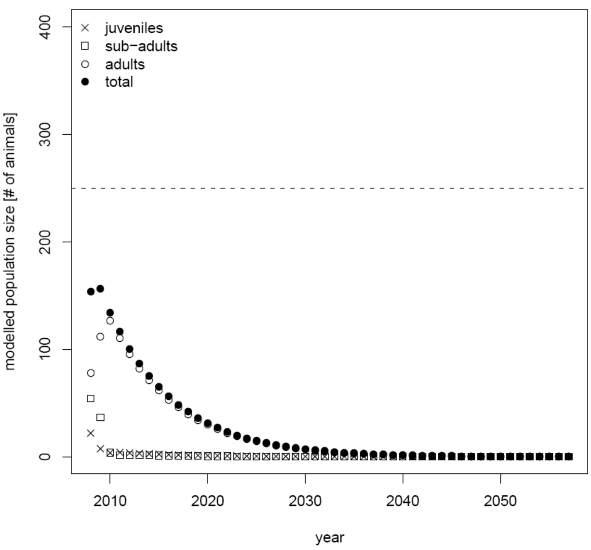


Figure 3 Population development, if captive management was completely stopped in 2009.

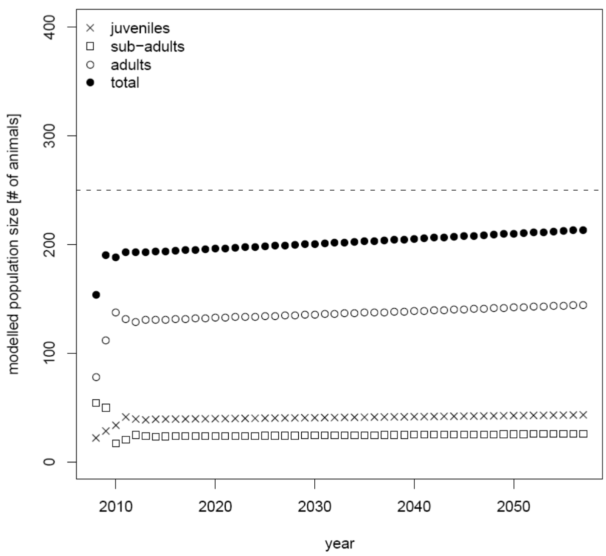


Figure 4 Population development without captive management, but improved survival rates (0.6 for both juveniles and sub-adults) and increased nesting and breeding success (0.5).

## Conclusion

Kaki is a unique species of the Upper Waitaki basin and we should continue to conserve and protect these species for the benefit of future generations. We propose that efforts into the protection and restoration of kaki in the wild are continued, primarily due to the amount of time, money and public interest put into the conservation of the species to date. We are therefore not in favour of scenario 2, which does not focus on management of the wild population.

Currently management is not meeting the set goal of 250 breeding pairs in the wild (scenario 1). Therefore, we suggest that alternative strategies are considered which increase the growth of the wild population and set a more realistic goal, focussing on increasing their survival rates. We would therefore recommend scenario 3: Continue egg-pulling but setting a survival rate to stop. Due to limited funding, it is probable that this scenario would need to decrease egg-pulling effort to enable an increase in trapping effort.

We recommend further research into predator avoidance to increase kaki survival rates. For example, research on the potential effectiveness of predator training. Feral cats were allowed to harass the cages of the Galapagos ground finch. This changed the behaviour and established a fear-based response to cats (Curio 1993). Teaching predator-recognition to a naïve bird may increase the survival rates of birds in the wild.

The way towards self-sustainability is clear. These increases in survival rates and breeding success may be hard to achieve, yet they appear to be the only determinants which can be directly influenced. Breeding-failure is massive and is greatly contributing to the critical situation of the kaki population. Further research should therefore be focused on how breeding success of wild kaki can be improved.

At the point when survival rates exceed mortality rates, egg-pulling effort will have fulfilled its primary purpose. Actual population numbers are theoretically not important for the population development. Nevertheless it makes sense to lift population numbers to a certain level in order to reinforce species resilience to disturbances.

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## REFERENCES

Andelman, S. and W. Fagan (2000). Umbrellas and flagships: efficient conservation surrogates or expensive mistakes?, National Acad Sciences. **97:** 5954-5959.

Araki, H. (2007). "Cooper, 8., Blouin, MS 2007. Genetic effects of captive breeding cause a rapid cumulative fitness decline in the wild." Science **318**: 100-103.

Bagliacca, M., A. Profumo, et al. (2004). "Egg-laying differences in two grey partridge (Perdix perdix L.) lines subject to different breeding technology: artificial egg hatch or mother egg hatch." European Journal of Wildlife Research **50**(3): 133-136.

Curio, E. (1993). "Proximate and developmental aspects of antipredator behavior." Advances in the Study of Behavior **22**: 135-238.

Department of Conservation (2000). "Kaki (Black Stilit) Recovery Plan." Draft Recovery Plan.

Department of Conservation (2002). "Kaki Recovery Report 2001-2002".

Department of Conservation (2008). "Kaki Annual report 2007-2008".

Faria, J. C. (2009). Resources of Tinn-R GUI/Editor for R Environment. Ilheus, Brasil, Uesc.

Frankham, R., H. Hemmer, et al. (1986). "Selection in captive populations." Zoo Biology **5**(2).

Galbraith, J., S. Sancha, et al. (2007). "Alarm responses are maintained during captive rearing in chicks of endangered kaki." Animal Conservation **10**(1): 103-109.

IUCN. (2008). "2008 IUCN Red List of Threatened Species." from www.iucnredlist.org

Jones, C., W. Heck, et al. (1995). "The restoration of the Mauritius kestrel Falco punctatus population." Ibis **137**: 173-180.

Keedwell, R., R. Maloney, et al. (2002). "Predator control for protecting kaki (Himantopus novaezelandiae)—lessons from 20 years of management." Biological Conservation **105**(3): 369-374.

Maloney, R. (April, 2009). Twizel Field Discussion.

Maloney, R., R. Rebergen, et al. (1997). "Bird density and diversity in braided river beds in the Upper Waitaki: Basin, South Island, New Zealand." Ornithological Society of New Zealand.

Mathews, F., M. Orros, et al. (2005). "Keeping fit on the ark: assessing the suitability of captive-bred animals for release." Biological Conservation **121**(4): 569-577.

Maxwell, J. and I. Jamieson (1997). "Survival and recruitment of captive-reared and wild-reared takahe in Fiordland, New Zealand." Conservation Biology: 683-691.

McDougall, P., D. Réale, et al. (2006). "Wildlife conservation and animal temperament: causes and consequences of evolutionary change for captive, reintroduced, and wild populations." Animal Conservation **9**(1): 39-48.

Nager, R., P. Monaghan, et al. (2001). "The cost of egg production: increased egg production reduces future fitness in gulls." Journal of Avian Biology: 159-166.

Nelson, D. Pers. com (April 2009).

Price, E. (1999). "Behavioral development in animals undergoing domestication." Applied Animal Behaviour Science **65**(3): 245-271.

R Development Core Team ( 2008). R: A language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing.

Seddon, P., D. Armstrong, et al. (2007). "Developing the Science of Reintroduction Biology." Conservation Biology **21**(2): 303.

Seddon, P., Personal Communications (May 2009)

Simberloff, D. (1998). "Flagships, umbrellas, and keystones: is single-species management passe in the landscape era?" Biological Conservation **83**(3): 247-257.

Snyder, N., S. Derrickson, et al. (1996). "Limitations of captive breeding in endangered species recovery." Conservation Biology **10**(2): 338-348.

van Heezik, Y., P. Lei, et al. (2005). "Captive breeding for reintroduction: influence of management practices and biological factors on survival of captive kaki (black stilt)." Zoo Biology **24**(5).

Wallis, G. and C. Conservancy (1999). Genetic status of New Zealand black stilt (Himantopus novaezelandiae) and impact of hybridisation, Dept. of Conservation.

## APPENDIX: The coupled management and population model.

The model was programmed in Tinn-R v.2.2.0.2 (Faria 2009) and executed in R v.2.8.1 (R Development Core Team 2008). It is a deterministic model, based on current population sizes of the different age classes and process rates derived from various, preferably recent, DOC reports (Department of Conservation 2008; Department of Conservation 2002). The R-code can be provided on request to benjamin.leutner@stmail.uni-bayreuth.de (variable names may differ slightly therein). This appendix provides some background information on the model, i.e. assumptions and limitations. Furthermore all included variables are listed as well as the actual equations which were used. Additionally Figure A1. provides a flow-chart visualizing the program sequence.

### Assumptions

Several assumptions are made, when applying this model.

First, the population is assumed to be closed, i.e. there are no immigrations or emigrations of animals. The population size is only determined directly by death and birth or release respectively. This assumption can be made, since the population was monitored to full extend without observing emigrations. And since the monitored population is the only existing one there is also no immigration.

Second, male-female ratio is assumed to be equal, which is given (KAKI07/08). Yet there would be even some leeway for unequal sex ratios owing to the fact that only 50% of the birds form breeding pairs.

Third, the survival rates remain constant over time. This might not be the case because on the one hand survival rates vary with changing environmental conditions as well as with chance. On the other hand it is unlikely that the current marginal survival rates remain that low also for significantly higher population sizes.

Fourth, there is no limiting carrying capacity in the wild. Theoretically this assumption is prone to be wrong considering the limited habitat for the kaki. However, at the small population sizes discussed in this report the assumption that the environment is not yet limiting the kaki population is feasible. Moreover fixing a certain carrying capacity would be pure speculation at this point. The logistic (growth) nature of the produced population scenarios results from the limited egg-processing capacity of the current management facilities.

Fifth, all pairs are assumed to be capable of laying three clutches per year, each containing four eggs.

### Limitations

First, the model does not incorporate egg-production by adult birds, which are currently held in captivity. That is to say if these were included, the wild kaki population could breed more eggs themselves.

Second, adult birds don't die because of age. This would require individual based modelling or at least splitting up of the adults in annual groups, which was not done in this modelling exercise. Nevertheless the model could be extended implementing the latter. The only source of death therefore remains the mortality rate. However, since it is quite high it can be expected that the resulting error is small but leads to a slight overestimation of population size.

Third, as this model is a deterministic one it is completely determined by the rates characterizing the processes. If these rates are wrong, than the model will not give matching predictions. The same is true if the rates vary over time. It could also be possible that the included rates are anomalies, differing from the true mean of the population (in the statistical sense). An approach to minimize such issues can be to apply probabilistic models. The existing model could also be extended in that regard, however it would require some more efforts put into it.

Fourth, the survival and breeding success rates of birds which were bred in the wild are derived from very few occasions (small sample size) and are therefore unsure. Furthermore the model does not give information about its uncertainty. One should always be aware of that, when interpreting the results.

**List of Variables:**

| | |
|---|---|
| *breed.success* | breeding success of wild pairs (nesting and fledging) |
| *capacity* | egg-processing capacity of the captive management facilities |
| *capt.f* | fledging success rate of eggs in captivity |
| *capt.prod* | number of chicks successfully produced in captivity |
| *capt.surv* | survival rate of juveniles or sub-adults in captivity |
| *eggs* | number of eggs produced by wild birds |
| *eggs.capt* | number of eggs for captive breeding |
| *eggs.wild* | number of eggs for wild breeding |
| *ew* | number of clutches to be left in the wild |
| *mate.prop* | proportion of the adult population, which forms breeding pairs |
| *N.ad.* | population of adults originating from captive management |
| *N.juv* | population of juveniles originating from captive management |
| *N.s-a.* | population of sub-adults originating from captive management |
| *N.total* | total population size, i.e. originating from wild and captive breeding |
| *N.total.ad* | total population of adults, i.e. originating from wild and captive breeding |
| *N.total.juv* | total population of juveniles, i.e. originating from wild and captive breeding |
| *N.total.s-a.* | total population of sub-adults, i.e. originating from wild and captive breeding |
| *p* | number of clutches pulled |
| *pairs* | number of breeding pairs |
| *prop.r* | proportion of captive offspring to be released as juveniles |
| *r.juv* | released number of juveniles |
| *r.s-a.* | released number of sub-adults (wild and captive bred) |
| *surv.rate(ad.)* | survival rate of adult birds |
| *surv.rate(juv)* | survival rate of released juveniles in the first year, i.e. until sub-adulthood |
| *surv.rate(juv.s-a.)* | survival rate of released juveniles in the second year, i.e. until adulthood |
| *surv.rate(s-a.)* | survival rate of released sub-adults to adulthood |
| *surv.rate(w.juv)* | survival rate of juveniles bred in the wild |
| *surv.rate(w.s-a.)* | survival rate of sub-adults bred in the wild |
| *t* | index indicating one time step with the length of one year. |
| *w.N.ad.* | population of adults originating from wild breeding pairs |
| *w.N.juv* | population of juveniles originating from wild breeding pairs |
| *w.N.s-a.* | population of sub-adults originating from wild breeding pairs |
| *wild.prod* | number of chicks successfully produced by wild pairs |
| $\lambda$ | ratio of population size at two subsequent time steps |

## Model Equations:

**Population size of birds originating from egg-pulling and captive management:**

$$N.juv(t) = r.juv(t-1) \cdot surv.rate(juv.)$$

$$N.s\text{-}a.(t) = N.juv(t-1) \cdot surv.rate(juv.s\text{-}a.) + r.s\text{-}a.(t) \cdot surv.rate(s\text{-}a.)$$

$$N.ad(t) = \left(N.ad(t-1) + N.s\text{-}a.(t-1)\right) \cdot surv.rate(ad.)$$

**Total population sizes, i.e. originating from wild and captive breeding:**

$$N.total.juv(t) = N.juv(t) + w.N.juv(t)$$

$$N.total.s\text{-}a.(t) = N.s\text{-}a.(t) + w.N.s\text{-}a.(t)$$

$$N.total.ad(t) = N.ad(t) + w.N.ad(t)$$

$$N.total(t) = N.total.ad(t) + N.total.s\text{-}a.(t) + N.total.juv(t)$$

**Eggs produced:**

$$pairs(t) = mate.prop \cdot total.ad(t)$$

$$eggs(t) = pairs * 4 * (p + ew)$$

$$ew = \begin{cases} 0 \text{ for } p = 3 \\ 1 \text{ for } p < 3 \end{cases}$$

** if three clutches are pulled there are no clutches to be left in the wild, otherwise its one clutch*

**Egg distribution**

$$eggs.capt(t) = \begin{cases} eggs(t) \cdot \dfrac{p}{p+ew} & if \quad < \quad capacity \\ capacity & if \quad > \quad capacity \end{cases}$$

** if eggs intended for captivity exceed the processing capacity of the captive breeding facilities, then the number is reduced to capacity*

$$eggs.wild(t) = \begin{cases} eggs(t) \cdot \frac{ew}{p + ew} & if \quad eggs.capt < capacity \\ eggs(t) \cdot \frac{ew}{p + ew} + \begin{cases} 4 \cdot pairs(t) & if \quad eggs - capacity > 4 \cdot pairs(t) \\ eggs - capacity & if \quad eggs - capacity < 4 \cdot pairs(t) \end{cases} & , \quad if \quad eggs.capt > capacity \end{cases}$$

** if there is excess of eggs from the captive breeding facilities, than these eggs are given to the wild. However, not more than 4 eggs per breeding pair.*

**Chick production**

$$wild.prod(t) = breed.success \cdot \begin{cases} eggs.wild(t) & if \quad eggs.wild(t) < 4 \cdot pairs(t) \\ 4 \cdot pairs(t) & if \quad eggs.wild(t) > 4 \cdot pairs(t) \end{cases}$$

** second reduction step correcting for possible overestimation in eggs.wild. If eggs + surplus are larger than 4 eggs per breeding pair, this is again reduced to 4 eggs per breeding pair.*

$$capt.prod(t) = capt.f \cdot eggs.capt(t) \cdot capt.surv$$

**Birds to release**

$$r.juv(t) = capt.prod(t) \cdot prop.r$$

$$r.s\text{-}a.(t) = \left(capt.prod(t-1) - r.juv(t-1)\right) \cdot capt.surv$$

**Population size of birds originating from the wild**

$$w.N.juv(t) = wild.prod(t) \cdot surv.rate(w.juv)$$

$$w.N.s\text{-}a.(t) = w.N.juv(t-1) \cdot surv.rate(w.s\text{-}a.)$$

$$w.N.ad(t) = \left(w.N.ad(t-1) + w.N.s\text{-}a.(t-1)\right) \cdot surv.rate(w.ad.)$$

**Population development indicator**

$$\lambda(t) = \frac{N.total(t)}{N.total(t-1)}$$

## Model Structure

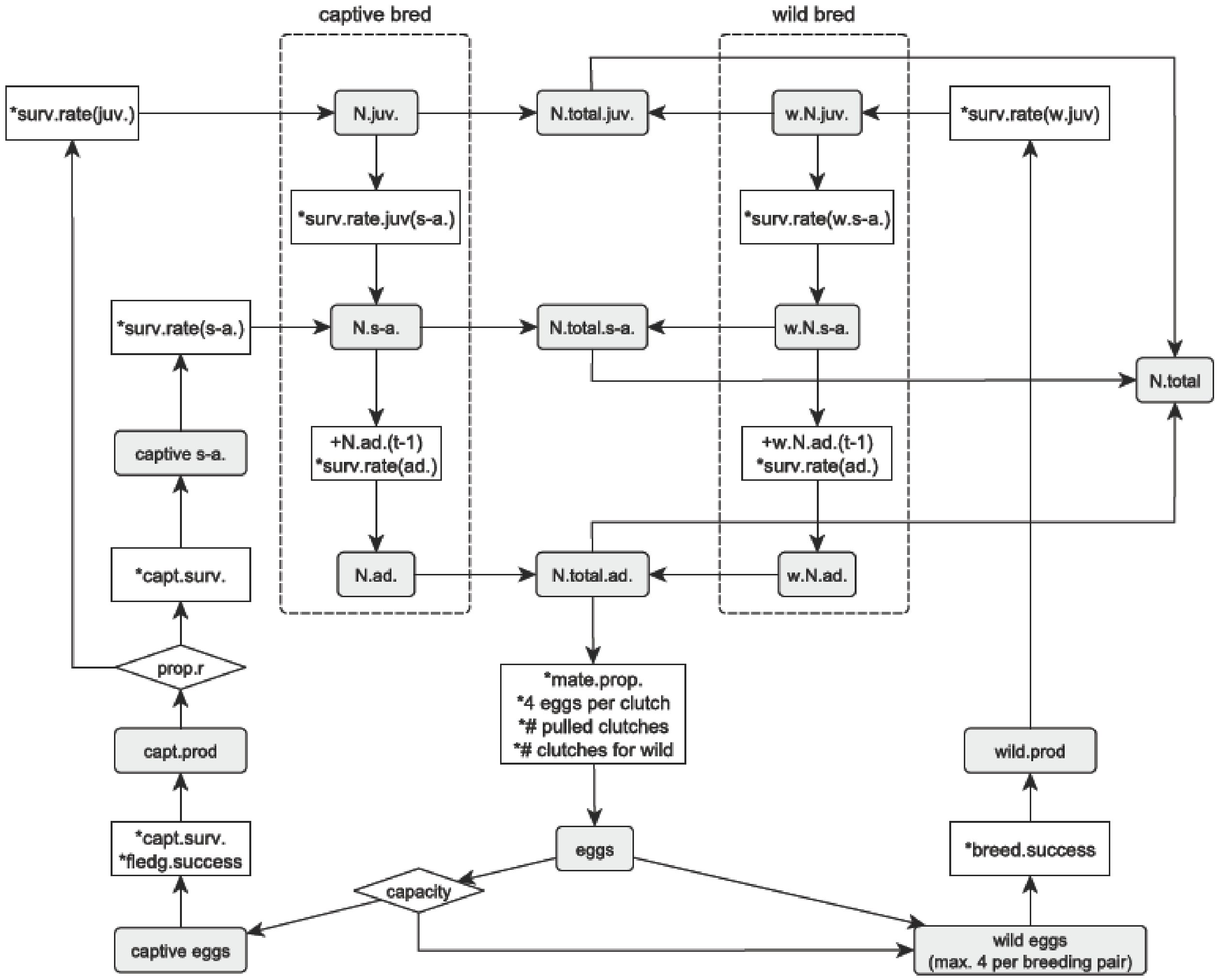


Figure A1: Flowchart of the coupled management and population model for the kaki. Abbreviations: Suffix “juv.” refers to juveniles, “s-a.” to sub-adults and “ad.” to adults. “N” are population numbers [# of individuals]. Prefix “w” stands for wild bred animals. “Surv.rate” are annual survival rates; “mate.prop” is the proportion of adult pairs who form breeding pairs; “capacity” is the limiting egg-processing capacity of the captive breeding facilities; “wild eggs” are those eggs left to wild pairs for breeding; “breed.success” is the nesting and fledging success of wild pairs; “capt.prod” is the chick production in captivity, “wild.prod” is the chick production in the wild; “capt.surv” are the annual survival rates of birds reared in captivity; “prop.r” is the proportion of captive juveniles which are released to the wild and determines the number of sub-adult releases in the following year. Items in grey boxes are variables, which are regulated by the processes in the blank boxes.