

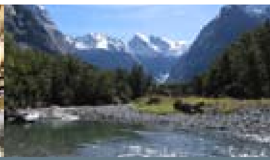
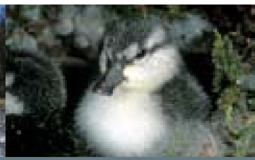

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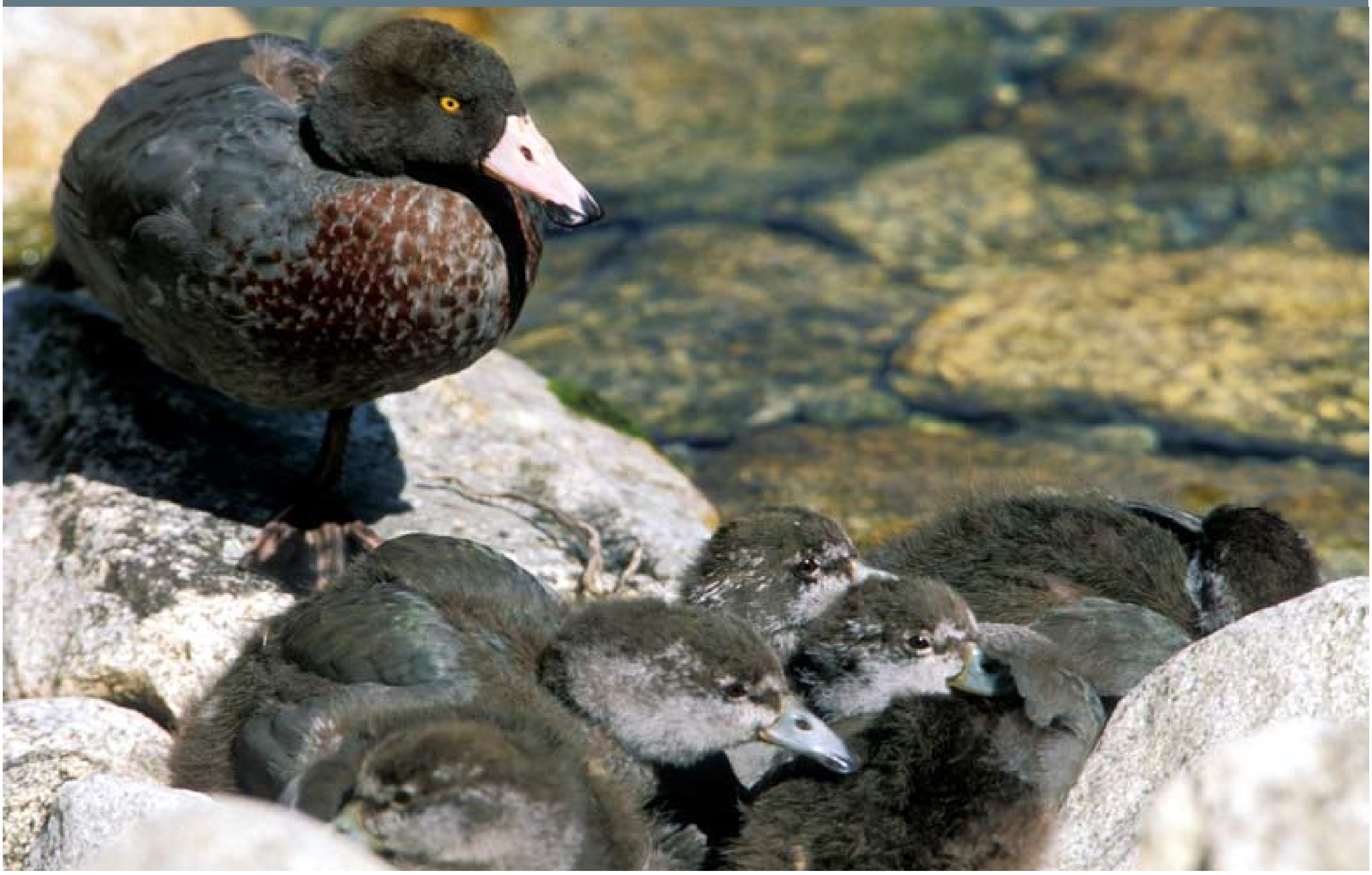
A review of productivity, survival and juvenile dispersal 2000-2006

JUNE 2007



Department of Conservation
Te Papa Atawhai

Status of blue duck (whio) populations in Fiordland, New Zealand, in response to stoat control

A review of productivity, survival and juvenile dispersal 2000 - 2006

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2007

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1. Summary

This report presents results from the six-year study on the productivity, juvenile recruitment, and survival of whio (blue duck, Hymenolaimus *malacorhynchos*) in Fiordland, in response to stoat control.

Whio populations were monitored in three catchments forming the study area - the Clinton, Arthur, and Cleddau – using an adaptive management framework. Stoat control, consisting of a single linear trapline along the valley floor, was established in the Clinton valley in 2000, while the Arthur valley was left untrapped. The Cleddau was included in the study after a community-initiated trapping regime was established in 2002, while stoat control in the Arthur valley commenced in March 2003. Whio were monitored within these catchments over the six-year study period to assess the impacts of stoat control on productivity, juvenile recruitment and survival.

Population models were created using the demographic data collected during the study period to estimate the population growth rate (λ) under the two management regimes. Predictions of future population size under a range of management scenarios were made to estimate the time required to reach a goal of 50 pairs within the study area.

In the absence of stoat control, whio experienced high nest failure due to stoat predation, while all adult female mortality was attributed to stoat predation. In comparison, nesting success improved significantly once stoat control was established and the proportion of females killed by stoats decreased. This demographic variation between the treatments translated into a significant difference in the associated population growth rates. Prior to stoat control, the population growth rate for whio in the Arthur was 0.91, indicating a declining population. In comparison, λ was equal to 1.14 after the establishment of stoat control.

Under current management conditions, the whio population in the study area is predicted to reach a median population size of 50 pairs in approximately 12 years. Additional stoat control has already been established in several neighbouring catchments and together with a planned trap expansion into the Neale Burn and upper North Branch of the Clinton, could see this time frame reduced to four years.

These findings have shown stoats to be the primary agent of decline for whio in a beech forest system. While single linear traplines are sufficient to ensure the population persistence of whio in steep-sided glacial river, we suggest that further expansion of the managed area in Fiordland is required to quickly reach the secure population size of 50 pairs advocated by the Blue Duck Recovery Group.

In general, we recommend that whio conservation should concentrate on stoat control, and that:

1. Single linear traplines should be used in steep-sided glacial valleys but that additional research be undertaken to assess the level of control required to protect whio in gentler terrain and in non-beech forest systems.
2. Stoat control for whio should be conducted on a continuing basis.
3. Managed sites should include the maximum practicable trapped area to secure whio populations.
4. Operation Nest Egg should be considered a valuable tool for boosting whio populations in areas where habitat is deemed to be suitable.
5. Whio conservation through corporate sponsorship and community driven initiatives should be encouraged and supported by the Department where appropriate.

2. Introduction

Threatened species management typically requires an immediate response to prevent population declines, yet is often hampered by a lack of information to make appropriate management decisions. An adaptive management approach to conservation can provide vital information regarding potential agents of decline and their impacts on the population demographics, while simultaneously managing the current needs of the system (Walters 1997, Parkes et al. 2006, McCarthy and Possingham, *In press*). This approach has previously been used in New Zealand to identify the primary agents of decline for kokako (*Callaeas cinerea wilsoni*) and mohua (*Mohoua ochrocephala*) (O'Donnell et al. 1996, Innes et al. 1999, Kelly et al. 2005), and to assess the effectiveness of a range of possum (*Trichosurus vulpecula*) control options (Parkes et al. 2006).

The blue duck (whio - *Hymenolaimus malacorhynchos* Gmelin) is a riverine waterfowl species, endemic to New Zealand. It is the sole member of its genus and one of only four species of specialised torrent birds in the world (c.f. Williams 1991). Sub-fossil and historical records show that whio were once widespread throughout both the North and South Islands, occurring from sea level to above tree line (Reischek 1885, Kear 1972). They are regarded by many as an iconic species of the backcountry (Young 2006).

However, it is well documented that whio populations have declined nationally in both distribution and abundance. Whio are now restricted to fragmented populations, mostly in the headwaters of rivers in the central North Island and western South Island (van Klink 2007). The declines have been attributed to habitat destruction through flow regulation and deforestation, predation by introduced mammals, and human disturbance (van Klink 2007). As a result, they are currently listed as “nationally endangered” (Hitchmough 2002, van Klink 2007).

The Fiordland population has not been immune to this trend. Survey and banding work that commenced in the early 1980s has provided conservation managers with a reliable measure of range restriction and population reduction for whio in the northern part of Fiordland National Park. By the late 1990s stretches of river that once contained healthy whio populations held very few (Torr and Coates 1999). It was generally thought that predation by stoats (*Mustela ermina* L.) was the major contributing factor to the decline in Fiordland, an area little impacted upon by the habitat degradation experienced in other parts of the country (Young 2006).

Stoat numbers vary significantly in Fiordland from year to year (King and McMillan 1982, Purdey et al. 2004), with very high stoat numbers associated with beech tree mast events (Figure 1) Beech masts, an event which produce a higher than normal seedfall, occur in autumn every three-to-five years and stoat numbers peak the following summer as a result of the greater food availability. Therefore, the predicted impact of a stoat plague on whio populations is on juvenile recruitment in late summer, and productivity and recruitment the following spring.

In 2000, following reports of serious decline in whio numbers in Fiordland (Torr and Coates 1999), an adaptive management approach to whio conservation was proposed for the Clinton and Arthur catchments. The purpose of adaptive management is to systematically acquire reliable information about system dynamics and potential monitoring uncertainties and then apply this knowledge to the process of making management decisions (Walters 1997). At the outset of this study, such an approach was rare in New Zealand conservation (c.f. O'Donnell et al. 1996, Innes et al. 1999) and had not previously been utilised for whio.

This study had three primary objectives:

1. To examine factors affecting adult survival and productivity of whio, with special emphasis on monitoring breeding success and recruitment of young birds into the breeding population.
2. To investigate whether the establishment of low intensity, long-term stoat control is sufficient to enable the whio population in these valleys to recover.
3. To study the dispersal of juvenile fledged birds at varying population densities to increase the understanding for future population management.

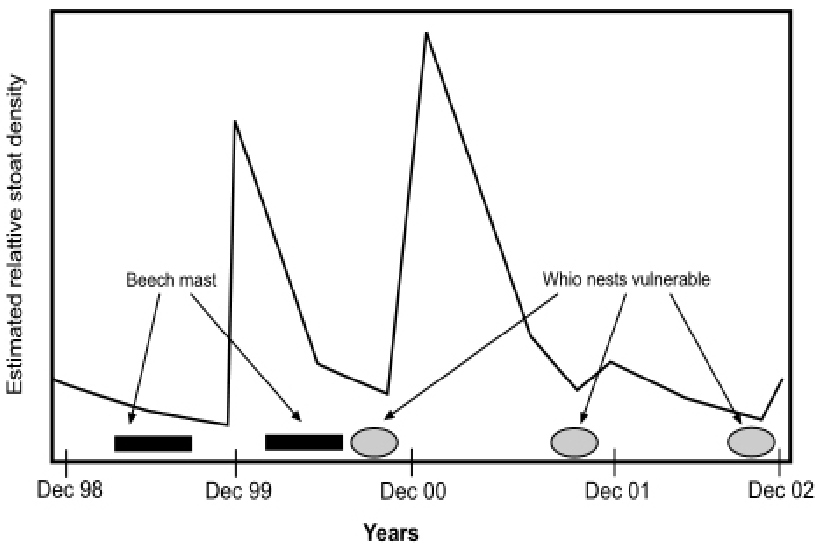


FIGURE 1. DIAGRAMMATIC REPRESENTATION OF RELATIVE STOAT DENSITY IN THE ARTHUR VALLEY THROUGH CONSECUTIVE STOAT PLAGUE YEARS.

It was proposed that stoat trapping should be conducted in the Clinton Valley for three seasons and that monitoring be undertaken in the Clinton and the Arthur Valleys to assess whio survival and recruitment, with the Arthur population serving as a control site. Stoat control would then be introduced into the Arthur Valley and intensive monitoring continued in both valleys for another year (Willans and Torr 2001). The initial proposal was extended to include an additional two years of monitoring to further investigate the impacts of stoat control and patterns of juvenile dispersal.

Trapping commenced in the Clinton Valley in 2000. Following a community driven initiative to control stoats in the vicinity of Milford Sound, a stoat trap line was also established along the Cleddau River and its major tributaries in October 2002 with monitoring of the whio population commencing in 2003. Finally trapping was initiated in the Arthur Valley in March 2003.

In 2006, following a technical review of the Whio Recovery Programme, the Whio Recovery Group set a new objective for whio conservation. This states that to ensure security for the species, a minimum of 50 pairs must be protected at eight core sites, four in the North Island and four in the South Island (van Klink 2007).

This report presents the findings of the six-year monitoring study. Population matrix models have been successfully used in ecological research to help estimate population growth rates and predict the potential effects of different management actions on a wide variety of organisms (i.e., sea turtles - Crouse et al. 1987, killer whales - Brault and Caswell 1993, red-cockaded woodpeckers - Heppell et al. 1994, palms - Olmsted and Alvarez-Buylla 1995, sturgeon - Gross et al. 2002). They are capable of modelling relatively complex systems (Heppell et al. 1994) and can be used with sparse datasets (Heppell et al. 2000). We provide population model predictions for reaching the 50-pair goal in Fiordland, based on the demographic data obtained in this study. A number of future management scenarios are assessed using these predictions and we make recommendations for whio conservation management.

3. Methods

3.1 STUDY AREA

The Clinton, Arthur and Cleddau valleys (Figure 2) were chosen for this study because they offer several important advantages over other locations in Fiordland.

1. All three catchments have held reasonable numbers of whio in the past and are considered a fair representation of whio habitat in the region. They also contain most of the other threatened species in the region, including kiwi, weka, kea, mohua and kaka.
2. The Milford Track runs the length of both the Clinton and Arthur valleys, providing excellent access to most of the river and good accommodation for field workers. In addition electricity, used to charge video batteries, was available at some sites. The Milford Road and side valley walking tracks give access to the Cleddau catchment and powered accommodation was available in the township.
3. Existing transport associated with track operations has provided inexpensive access to and from the study site for both personnel and equipment within the Great Walks Booking Season.
4. Recreation staff already working on the track and staff from local companies in Milford Sound have been able to assist with some tasks e.g. running stoat trap lines, monitoring whio, assisting with setting up cameras, changing batteries etc.
5. The large number of people walking the track annually (c.f. 13,000) and visiting Milford Sound (c.f. 450, 000) gives this project a high public profile, and offers good advocacy and educational opportunities for the Blue Duck Recovery Programme.

These valleys are predominantly silver beech (*Nothofagus menziesii*). However, red beech (*N. fusca*) is present in the lower reaches of the Clinton Valley. The lower reaches of the Arthur and Cleddau Valleys contain some rimu (*Dacrydium cupressinum*), totara (*Podocarpus hallii*), and miro (*Prumnopitys ferruginea*) forest.

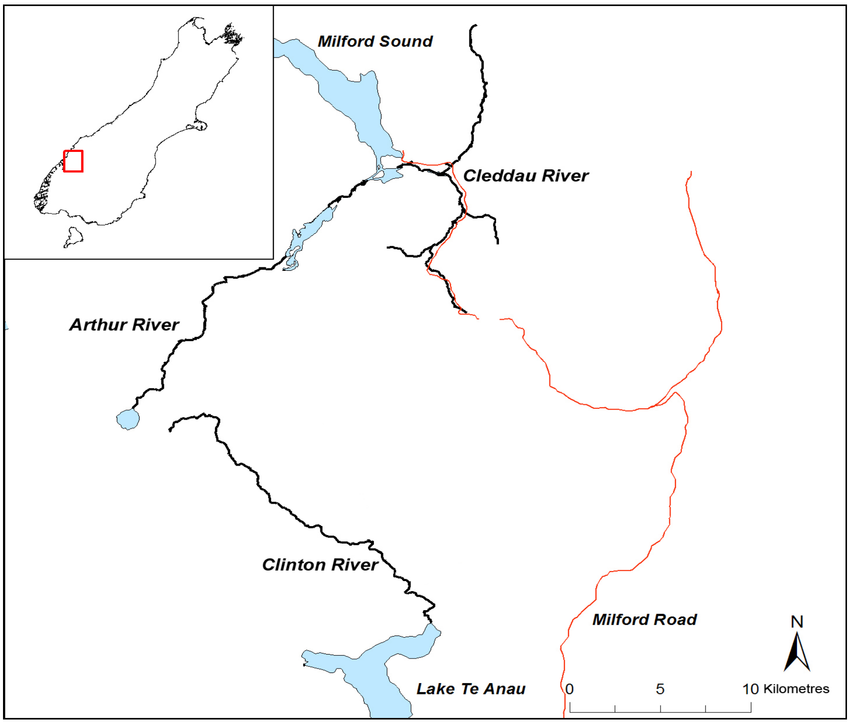


FIGURE 2. MAP OF CATCHMENTS IN THE STUDY AREA WHERE WHIO WERE MONITORED BETWEEN 2000 AND 2006.

3.2 STOAT CONTROL AND MONITORING

Stoat trap lines run adjacent to the rivers within the main study area. These were established in the Clinton Valley (33.5 km) in 2000, the Cleddau Valley (27 km) in 2002, and the Arthur Valley (27.5 km) in 2003. Additional trap lines were established by the Department of Conservation in the Joes Valley (9.6 km) and the Worsley Valley (26 km) by the Wapiti Foundation in the 2005 winter. All trap lines consist of double-set Mark IV Fenn™ traps in wooden tunnels at 200m spacings along either tracks or the Milford Road. Traps are baited with a single hen's egg and a piece of meat between the traps, and are checked and re-baited monthly.

Stoat and rodent abundance was also monitored in the Clinton, Arthur and Cleddau Valleys using tracking tunnel lines run three times per year. Further details of the stoat trapping and monitoring regime can be found in the 2005/2006 Operation Ark Annual Report for this area (Hill 2006).

3.3 MONITORING WHIO PRODUCTIVITY AND SURVIVAL

To make whio monitoring achievable, all adults within the three valleys were banded with a metal band and a double colour band combination. Adult females were fitted with radio transmitters using a standard backpack harness (Blue Duck Recovery Group 2004). Birds in the study area were monitored through the breeding season, with observers in the field from late September until late March. In the Clinton and Arthur Valleys, pairs were located weekly at the beginning of the season to establish when females appeared gravid and nesting commenced. Nests were then checked regularly to determine their outcome. In all seasons except 2005/2006, infrared nest cameras were also used to provide 24-hour surveillance of nests through incubation and hatching. Once the ducklings were observed on the river, family groups were monitored weekly until fledging.

Just prior to fledging, ducklings were caught and banded with a colour cohort band (distinct for each of the three catchments) and a stainless number band. During the 2003/2004 and 2004/2005 seasons, they were also fitted with radio-transmitters.

Monitoring in the Cleddau catchment was less intensive with whio pairs checked fortnightly. Video monitoring of nests was not undertaken but the nest contents would be inspected if a female was located off the nest during a visit.

An effort was also made to detect new birds and to keep track of unpaired banded birds in the study area. Detailed records of all whio sightings and activities were kept in a daily log in each valley and the location of each sighting recorded on maps. These records were also entered into Excel spreadsheets, and from 2004, an Access database, allowing for easy analysis and interpretation of the results.

Visits were made to all three areas from March to May for the purpose of changing transmitters and surveying the entire study area using walk-through river surveys. Three river surveys were typically carried out over each season. Staff walked riverbeds to locate as many whio as possible without using radio telemetry equipment. A trained whio dog was also used along some stretches of river. An initial survey was often carried out in September to determine the number of pairs prior to the breeding season. However, high avalanche risk prevented the September survey from occurring in the 2004/2005 and 2005/2006 seasons. A late November survey was conducted to determine duckling productivity and one in mid March to determine duckling survivorship to fledging.

Male and female survival rates were calculated using Program Mark (Pryde 2003, Cooch and White 2006). Male survival was calculated using mark-recapture data in an age-structured Cormack-Jolly-Seber model, with catchment and year as co-variables. Female survival was calculated separately for the two treatments, using mark-recapture, re-sighting and recovery data in an age-structured Barker model. Year and catchment were included as co-variables.

3.3.1 Juvenile Dispersal and Recruitment

Juvenile whio were fitted with transmitters in the 2003/2004 and 2004/2005 seasons. These birds were closely monitored in subsequent years to determine dispersal patterns. Monitoring involved monthly radio telemetry from a helicopter flying along the main rivers and major tributaries of the study area to locate transmitterised juveniles. Additional locations of juveniles, including those without transmitters, were recorded during routine ground radio tracking and river surveys, and also observations of banded birds from hunters or trampers. A larger flight was undertaken in February 2006, covering approximately 600 km of river from the Iris Burn north to the Hollyford River (Map 17 - Whitehead and Smart 2006), to locate transmitterised juveniles that may have moved outside the study area. Opportunistic recoveries were also made by taking radio telemetry equipment on flights going into other catchments for different work.

Juvenile whio were also closely monitored to determine how many were recruited into the study area. Juvenile recruitment was considered to have occurred when a bird was observed to be holding a territory with a mate. Juveniles were located by ground-radio tracking and by helicopter throughout the summer season. If individuals died or moved outside the study area, they were no longer followed as part of the recruitment study and transmitters were removed.

3.4 PREDICTIVE POPULATION MODELLING

3.4.1 Mean population growth rate (λ)

The demographic parameters calculated from the population study were incorporated into a three-stage pre-breeding Leslie matrix to model the potential effects of stoat control on whio populations. Population projection matrices typically take the form

$$n_{t+1} = An_t$$

or

$$\begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_{s1} \end{bmatrix}_{t+1} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1s} \\ a_{21} & a_{22} & \cdots & a_{2s} \\ \vdots & \vdots & \ddots & \vdots \\ a_{s1} & a_{s1} & \cdots & a_{ss} \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_{s1} \end{bmatrix}_t$$

where n_t is the abundance of individuals in a particular life stage at time t, and s denotes the final stage (Leslie 1945). A is the transition matrix that describes the number of individuals in each stage that survive from one period to the next. In addition, it characterizes the number of offspring produced by each stage within a given time period. The dominant eigenvalue λ of A is equal to e^r, where r is the intrinsic rate of increase of the population for $N_t = N_0 e^{rt}$ at the stable stage distribution. Therefore, if $\lambda = e^r = 1$, then $r = 0$, and the population is stationary. If $\lambda < 1$, the population is in decline, while $\lambda > 1$ represents an increasing population.

There are typically more males than females in existing whio populations (van Klink 2007), so males can be considered an unlimited resource. Consequently, all models were confined to modelling female population dynamics which can be used to estimate the number of pairs within a given population. The models make a number of other assumptions and these are listed below:

1. Females have a fixed age at maturity.
2. All females attempt to breed annually.
3. The population dynamics are not regulated by density dependant factors.
4. No immigration or emigration occurs in this population.
5. The models contain no spatial parameters.

Modelling was conducted using R (R Development Core Team 2005) and the PopTools add-in for Microsoft Excel (Hood 2006) with the demographic parameters calculated in Section 0. Demographic stochasticity was incorporated through the random generation of parameters on an annual basis.

Whio are particularly vulnerable to stoat predation during the incubation period when both eggs and adult females are at risk (McMurtrie et al. 2004, Whitehead et al. 2006). To assess the contribution that these demographic rates make to the overall population growth rate (λ), the basic model structure was initially used to predict λ under a range of nest survival and adult female survival rates while holding the remaining parameters constant.

3.4.2 Predicting population size

The Blue Duck Recovery Plan states that a secure population of whio should consist of a minimum of 50 pairs and it is a key objective of the recovery plan that this goal be met in each of the secure sites by 2010 (van Klink 2007). The probability of reaching this goal in the managed site within Fiordland National Park was calculated by predicting the population size over time under two management regimes. These models are not spatially explicit and do not include the potential effects of density dependant factors that may become important as the number of whio present within a catchment increases. However, over a short time frame, they offer a good indication of how management may affect these populations.

4. Results

4.1 STOAT CONTROL AND MONITORING

A total of 828 rats and 1056 stoats were caught in the Clinton and Arthur Valleys during the study period, with the highest trap captures occurring during the initial knockdown period in each valley (Figure 3). There was no significant difference in number of rats or stoats caught per 100 traps nights between the Clinton and Arthur valleys (rats - $F_{1,86} = 0.001$, $p = 0.975$; stoats - $F_{1,86} = 0.9688$, $p = 0.328$). No reliable information on trap captures is available for the Cleddau catchment.

The establishment of stoat control significantly lowered the mean tracking rate for stoats ($F_{1,32} = 409$, $p<0.000$) in all three catchments but lead to a significant increase in the mean tracking rate for rats ($F_{1,32} = 9.04$, $p=0.001$; Figure 4). However, there was no significant difference in the tracking rates recorded across the three catchments for either species (rats - $F_{2,32} = 0.09$, $p=0.913$; stoats - $F_{2,32} = 0.50$, $p=0.609$).

Three beech mast events occurred in Fiordland National Park just prior to or during the six-year study of whio productivity. Two consecutive masting events occurred in the 1999/2000 and 2000/2001 seasons, while a significant seedfall event was recorded during the 2005/2006 season. These events corresponded with high rat numbers in the immediate period following seedfall and elevated numbers of stoats in the following summers. While no seedfall data is available for the 2003/2004 season, elevated rat numbers in the Clinton suggest that a partial beech mast may have also occurred during this period.

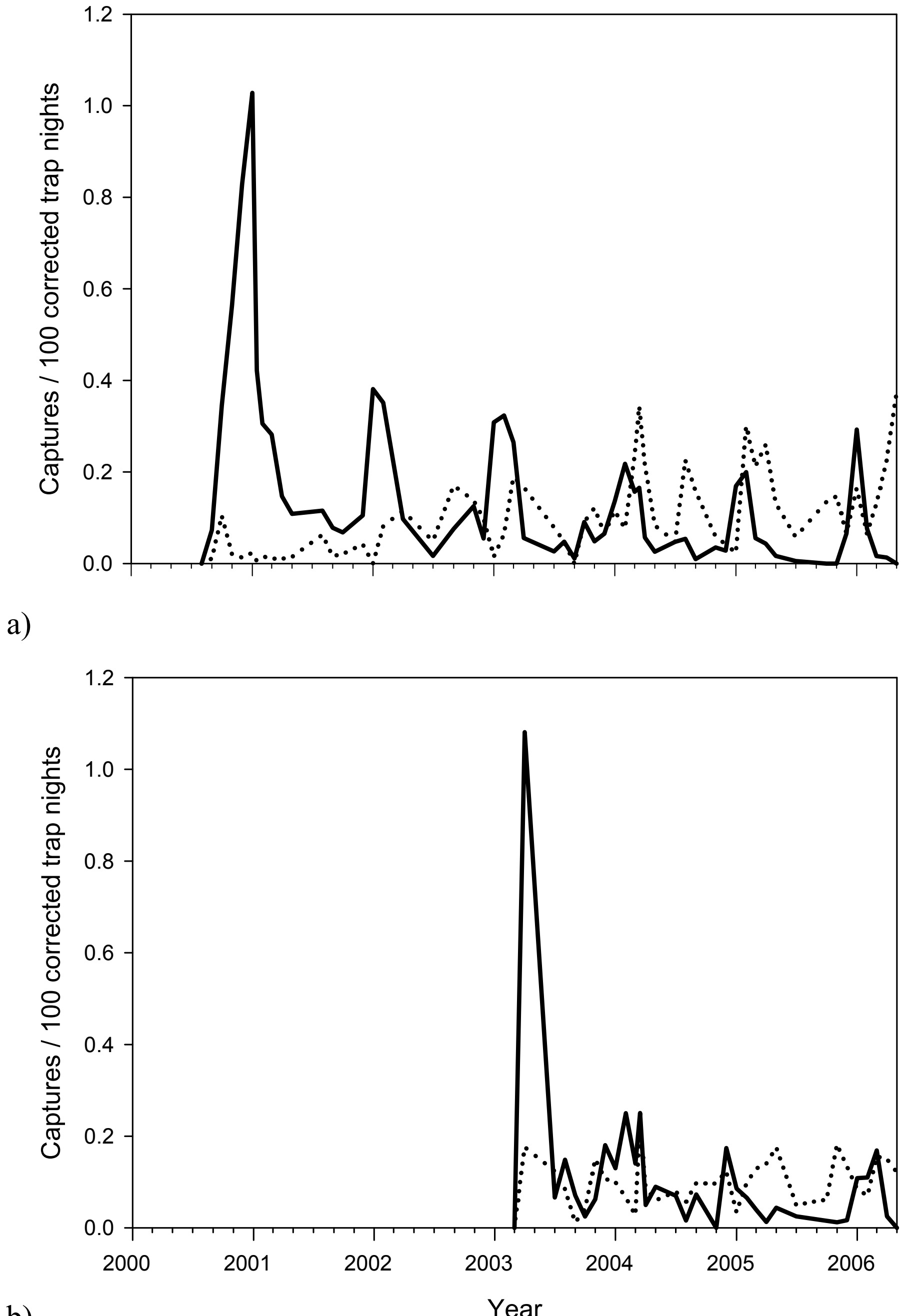


FIGURE 3. RAT (DOTTED LINE) AND STOAT (SOLID LINE) CAPTURES IN THE A) CLINTON AND B) ARTHUR CATCHMENTS BETWEEN 2000 AND 2006. STOAT TRAPPING BEGAN IN THE CLINTON VALLEY IN SEPTEMBER 2000 AND THE ARTHUR VALLEY IN APRIL 2003.

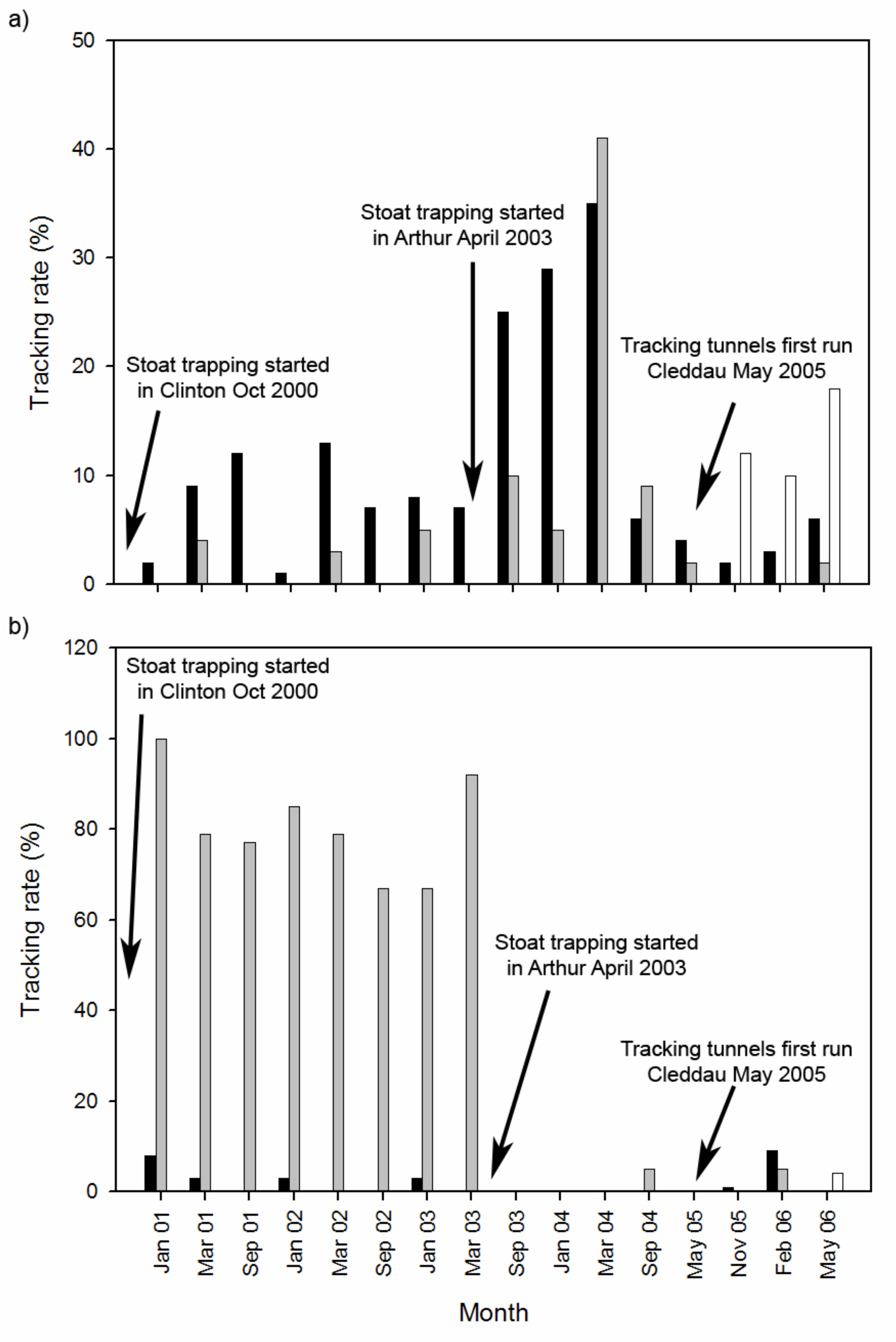


FIGURE 4. TRACKING TUNNEL RATES FOR A) RATS AND B) STOATS IN THE CLINTON (BLACK BARS), ARTHUR (GREY BARS) AND CLEDDAU (WHITE BARS) CATCHMENTS BETWEEN 2001 AND 2006.

4.2 WHIO MONITORING

A total of 115 whio were banded in the Clinton, Arthur, and Cleddau catchments over the six-year duration of the study (Table 1).

The initial sex ratio of whio in the Clinton Valley was heavily skewed towards high numbers of males (Figure 5), indicating that this population was not as healthy as originally thought in 1999 (Torr and Coates 1999). Male whio were significantly heavier than females with average weights of 0.97 ± 0.01 kg and 0.79 ± 0.01 kg respectively ($F_{2, 88}$=38.4, $p < 0.001$).

TABLE 1. SUMMARY OF BANDED WHIO IN THE STUDY AREA BETWEEN 2000 AND 2006

Catchment	Banded whio	Banded as juveniles	Female
Clinton	60	48 %	39 %
Arthur	37	44 %	55 %
Cleddau	18	17 %	50 %
Total	*115*	*41 %*	*46 %*

A total of 57 banded whio were known to be alive in the Clinton, Arthur and Cleddau catchments at the end of the 2005/2006 season (Table 2). It should be noted that it is possible a number of banded birds may still be alive outside the core study area although they remain within the trapped area. Indeed, several males that had been missing for up to five years were re-sighted in 2006. However, for the purpose of this study, individuals which move outside the core study area are excluded from our analysis as they no longer contribute to the productivity of the monitored population.

TABLE 2. SUMMARY OF BANDED WHIO IN FIORDLAND NATIONAL PARK KNOWN TO BE ALIVE IN 2006

Catchment	Banded whio	Banded as juveniles	Female
Clinton	29	63 %	34 %
Arthur	17	53 %	47 %
Cleddau	11	0 %	36 %
Total	*57*	*29 %*	*40 %*

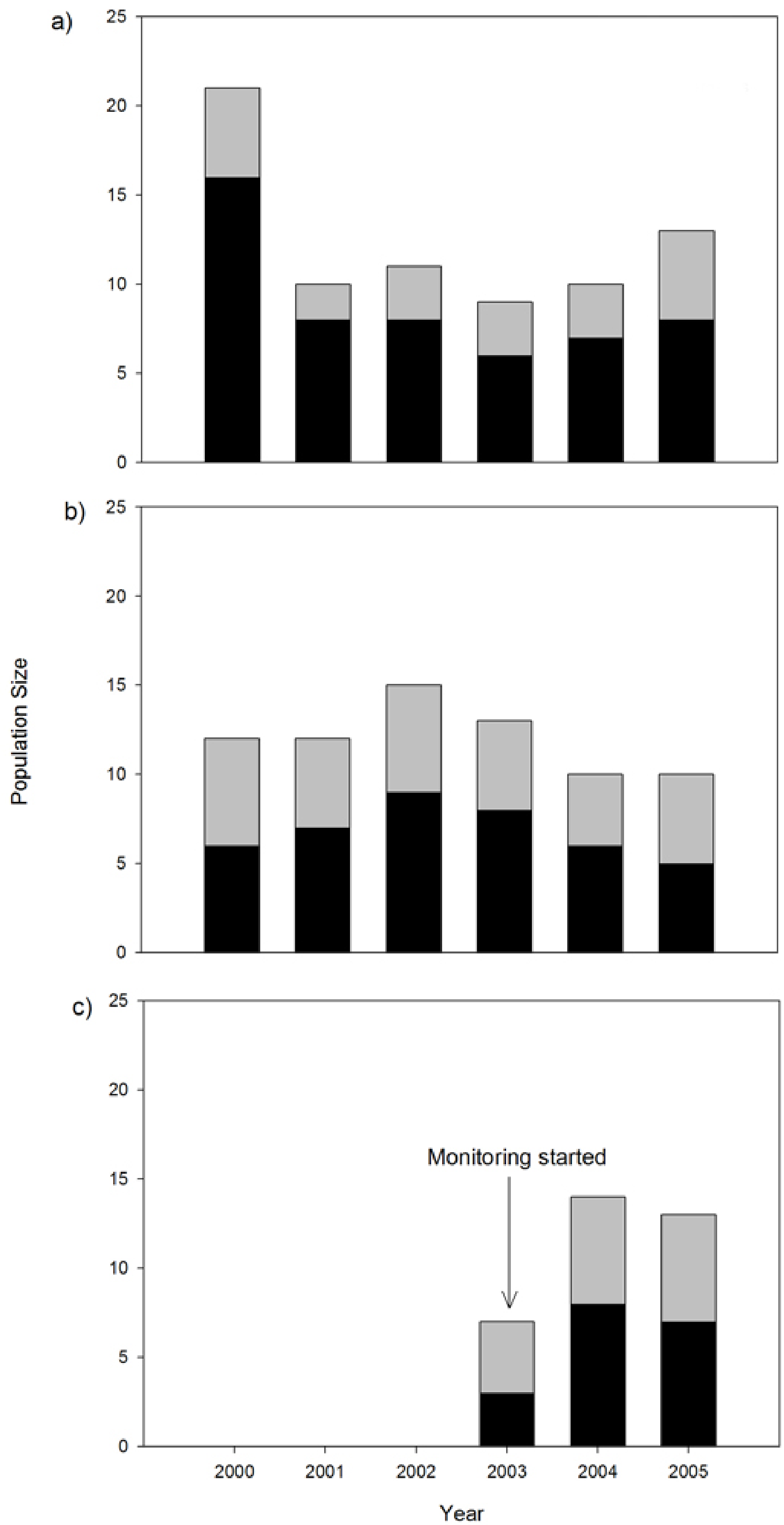


FIGURE 5. NUMBER OF ALIVE BANDED WHIO IN THE A) CLINTON, B) ARTHUR AND C) CLEDDAU CATCHMENTS BETWEEN 2000 AND 2006. MALES ARE SHOWN IN BLACK, AND FEMALES IN GREY.

4.3 WHIO REPRODUCTIVE SUCCESS

4.3.1 Breeding Pairs

A minimum of 47 different adult-adult and adult-juvenile pairings were observed in the Clinton, Arthur and Cleddau catchments over the six-year study. The number of pairs present in the Arthur has remained relatively constant throughout the study period (Table 3). There was an initial decline in the number of pairs present in the Clinton, although they have been steadily increasing since the 2003/2004 season. Most individuals had only one mate (71 %), although others had up to four mates during the period of this study (mean = 1.4 ± 0.75).

The formation of new pairs appears to have been driven by several factors:

1. Death of a female during the breeding season,
2. New territories established by single males, or
3. Mate switching due to divorce.

In addition, both male and females were observed to switch partners several times during a season. This was common during the moult, perhaps when males were less able to defend a territory against a non-breeding male. Therefore, different pairings during this period may not represent a true pairing.

TABLE 3. THE NUMBER OF WHIO PAIRS PRESENT IN THE STUDY AREA BETWEEN 2000 AND 2006

	Clinton	Arthur	Cleddau*
2000/2001	5	6	-
2001/2002	4	6	-
2002/2003	3	6	-
2003/2004	4	5	5
2004/2005	5	6	4
2005/2006	7	6	6

* Whio monitoring did not begin in the Cleddau catchment until the 2003/2004 season.

While pair composition changed quite frequently in some parts of the study area, the occupied territories have remained relatively constant. This pattern, strongest on the Arthur River, suggests that these territories may contain more suitable habitat than unoccupied or less frequently utilised stretches of river. Mean territory length in the study area was approximately 1.7 ± 0.1 km, with no significant difference between years. However, the Clinton Valley contained significantly longer territories (2.1 ± 0.2 km) than the Arthur (1.5 ± 0.1 km) and Cleddau (1.5 ± 0.2 km) valleys ($F_{2, 50} = 6.4$, $p = 0.003$).

4.3.2 Nesting Success

A total of 50 nesting attempts were observed

Table 4), containing an average of 4.3 ± 0.2 eggs (max = 6). Of these, 49 % successfully hatched at least one duckling. However, there was a significant difference in nest survival between the trapped and non-trapped valleys (Figure 6). In the absence of stoat control, approximately 10% of whio nests survived to hatch at least one duckling. In comparison, 54% of whio nests survived to hatching in areas where stoat control was in place. Interestingly, no infertile eggs have been found in any of the monitored nests during the study period (c.f. Briskie and Mackintosh 2004).

The video monitoring of nests provided good data about interactions between incubating females and potential nest predators. Stoats were the primary biotic cause of nest failure, often predating both the eggs and the incubating female. In the absence of stoat control, 50 % of nest failure was due to stoat predation. In comparison, 26 % of nest failure was attributable to stoats in the presence of stoat control. Other nest predators included weka and kea, causing 11 % and 4 % of nest failures respectively. Possums were observed visiting a number of nests but none of these visitations resulted in predation. Floods and avalanches also lead to nest failure on two occasions.

TABLE 4. SUMMARY OF MONITORED WHIO NESTS IN FIORDLAND NATIONAL PARK BETWEEN 2000 AND 2006

Catchment	Nesting Attempts	Successful Nests	Ducklings	Fledglings
Arthur*	12	8 %	4	0
Arthur†	12	66 %	42	20
Clinton†	16	56 %	32	25
Cleddau†	10	50 %	20	14
Total	*50*	*45 %*	*98*	*59*

* No stoat trapping
† Stoat trapping

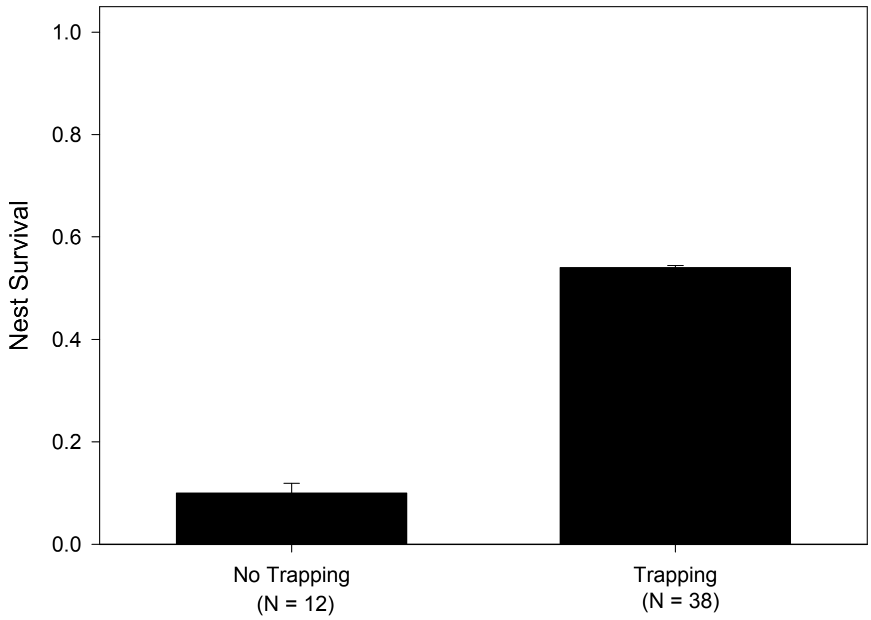


FIGURE 6. WHIO NEST SURVIVAL IN THE STUDY AREA IN RESPONSE TO STOAT CONTROL

4.3.3 Duckling Survival

A total of 98 ducklings were known to have hatched from 50 nesting attempts (

Table 4). However, only four ducklings from one nesting attempt hatched prior to the establishment of predator control in the Arthur Valley. These ducklings, as well as the adult female, were killed by a stoat within three days of hatching. After stoat control was put in place, 65% of ducklings survived to fledging. The most vulnerable duckling stage is during the Class I phase when ducklings are just a few weeks old. It is often difficult to identify the cause of death of ducklings as bodies are rarely found and it was not possible to ascertain the impacts of predation on this life history stage. However, the frequent disappearance of small ducklings at times of high water flow suggests that they probably succumbed to flood events.

4.3.4 Juvenile Survival

A total of 51 juvenile whio were banded in the study area. Of these, 28 were known to be alive in May 2006 (Table 5).

TABLE 5. LIFE HISTORY TABLE FOR JUVENILE WHIO BANDED WITHIN THE STUDY AREA

Year banded	Number alive					
	2000	2001	2002	2003	2004	2005
2000	0	0	0	0	0	0
2001	-	4	2	1	1	1
2002	-	-	4	1	0	0
2003	-	-	-	14	6	5
2004	-	-	-	-	15	8
2005	-	-	-	-	-	14

It is not possible to assess the impact of stoat control on juvenile whio as no ducklings fledged prior to stoat control being established in the Arthur Valley.

In the presence of stoat control, 46 % of juveniles survived their first year. However, there was a significant difference between the sexes, with male and female survival rates of 29 ± 13 % and 80 ± 9 % respectively. It is important to note that a number of juvenile males dispersed outside the management area (see Section 4.3.5) and were subsequently lost to the population. However, several of these were re-sighted during the 2006/2007 as adults (A. Smart, *pers. comm.*). Therefore, the actual juvenile male survival rate is probably much higher than suggested here. Predation appears to be a contributing factor to juvenile mortality, with at least one killed by a stoat. The remains of another three juveniles suggested predation but it was not possible to determine the predator, or if in fact the carcass had been scavenged after the animal had died due to some other cause. Interestingly, it appears that at least two juvenile males were killed by avalanches during the harsh 2004 winter and this may be linked to their dispersal into high alpine valleys.

4.3.5 Juvenile Dispersal and Recruitment

Juvenile dispersal within the Clinton, Arthur and Cleddau catchments appears to be differentiated by sex, with males moving significantly further from their natal territory ($F_{1,20}$=4.72, p = 0.043). Eighty-seven percent of females remained in their natal catchment, moving an average of 3.84 ± 0.60 km. In comparison, only 40 % of juvenile males have remained in their natal catchment, with a mean dispersal distance of 8.77 ± 2.05 km. The greatest juvenile dispersal movement observed was made by a male moving from the

Arthur Valley to the Glaisnock River, a distance of approximately 24 km. Fifty-six percent of the 2005/2006 Clinton juveniles are thought to have dispersed into other catchments but the use of cohort banding means that it is not possible to determine which birds have moved and exactly how many. Therefore, the statistics quoted above do not include data from these individuals. However, it appears that the patterns of dispersal are similar to those that have occurred over past seasons.

Eight females banded as juveniles have been recruited to territories within the study area. Of these, five have attempted to breed at least once and one successfully bred as a one-year-old bird. In comparison, none of the male whio banded as juveniles are known to have formed pairs to date.

However, it is important to note that a number of juveniles have not been relocated since they were first banded. While transmitter failure was a considerable problem in some years, it seems likely that any of these birds remaining alive within the core area would have been relocated during routine monitoring or river surveys in the surrounding catchments. Therefore, these individuals can be discounted from any subsequent survival analysis as they are no longer contributing to the growth of the population within the study area.

4.3.6 Adult Survival

Female

Adult female survival was estimated to be 77 ± 9.8 % prior to trapping and 71 ± 6.6 % after trapping was established (Figure 7), although these values were not significantly different. There were also no significant effects of catchment or year, making it difficult to identify any impacts that high densities of stoats may have had on adult female survival during the 2000/2001 stoat plague. However, while all adult female mortality prior to trapping was attributed to stoat predation, only 25 % of adult females that died once trapping was established were killed by stoats.

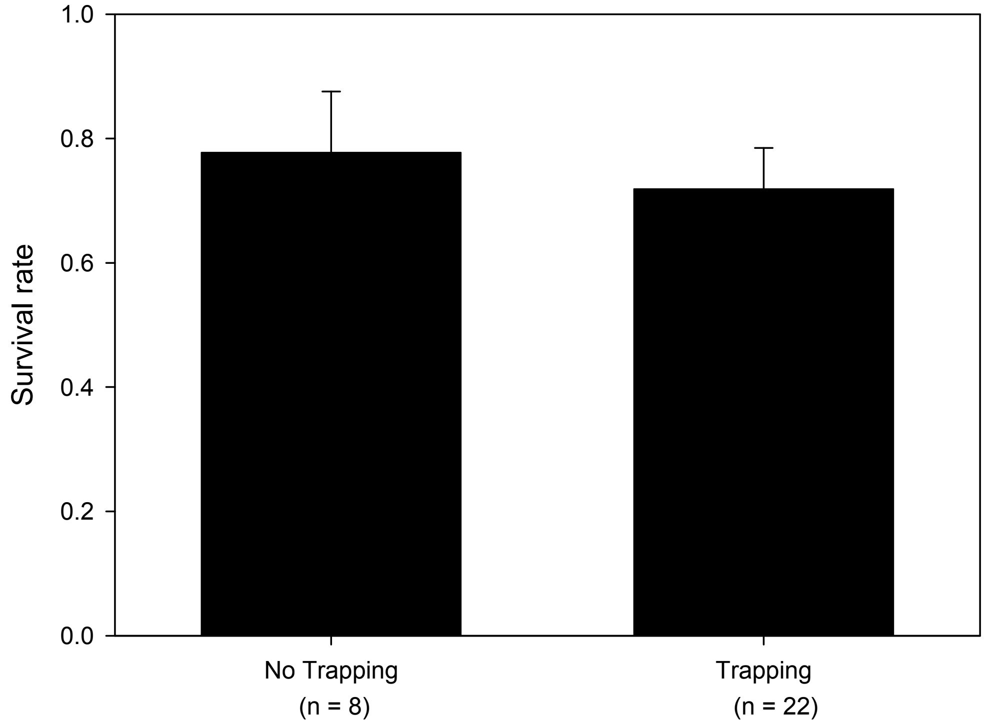


FIGURE 7. SURVIVAL RATE FOR ADULT FEMALE WHIO IN FIORDLAND NATIONAL PARK IN RESPONSE TO STOAT CONTROL.

Male

Actual adult male mortality (and the cause thereof) is more difficult to determine as adult males were not fitted with transmitters. However, the estimated adult male survival rate with stoat trapping, based on mark-recapture data, is approximately 82 ± 5 %. A number of males have been known to disappear for several seasons and then be relocated, so it is likely that this is a conservative estimate of adult male survival. Only a small number of males (n = 9) were monitored in the Arthur Valley prior to trapping and all of these birds survived. Therefore, we are unable to determine the impact of stoat control on adult male survival, although it appears that it may have little impact.

4.4 OPERATION NEST EGG (ONE)

The removal of whio eggs from nests in Fiordland began in 2002 when four eggs were removed from two nests at threat from further stoat predation in the Arthur (i.e. the nest had already lost an egg/eggs to stoat predation). Three of these eggs from the same nest hatched successfully, while the fourth failed to hatch. Eggs were hatched at the takahe rearing facilities at Burwood Bush and ducklings raised at the Te Anau Wildlife Park. They were subsequently released in the Clinton Valley in February 2003.

One clutch at risk from avalanches was removed in 2003 and three of the five eggs subsequently hatched at Burwood Bush. The ducklings were reared at the Te Anau Wildlife Park and were released in the Clinton Valley in February 2004.

Following the apparent success of this technique, ONE was used in 2005 to supplement the whio population in the Murchison Mountains, Fiordland National Park (Whitehead and Smart 2006).

4.5 PREDICTIVE POPULATION MODELLING

4.5.1 Mean population growth rate (λ)

The demographic parameters used to construct the population models are shown in Table 6.

TABLE 6. MEAN (± SE) DEMOGRAPHIC PARAMETERS INCORPORATED INTO STOCHASTIC FEMALE POPULATION MODELS OF WHIO UNDER DIFFERENT MANAGEMENT REGIMES.

Model Parameters	No trapping	Trapping	Distribution
Number of eggs	4.8 ± 0.98	4.8 ± 0.98	Binomial
Nest survival	0.1044 ± 0.0004	0.5400 ± 0.00002	Beta
Fledging rate	0.6992 ± 0.0447	0.6992 ± 0.0447	Beta
Juvenile survival	0.8040 ± 0.0083	0.8040 ± 0.0083	Beta
Adult survival	0.7778 ± 0.0096	0.7189 ± 0.0096	Beta

The population growth rate increased with increasing nest success and adult female survival, with both variables appearing to make an equal contribution (Figure 8). The mean (± se) predicted population growth rate in the Arthur valley prior to the establishment of trapping was 0.91 ± 0.01, indicating a population that was in rapid decline. In comparison, the predicted population growth rate in the Clinton, Arthur and Cleddau catchments under the current trapping regime was 1.14 ± 0.01. This represents a population that is growing strongly.

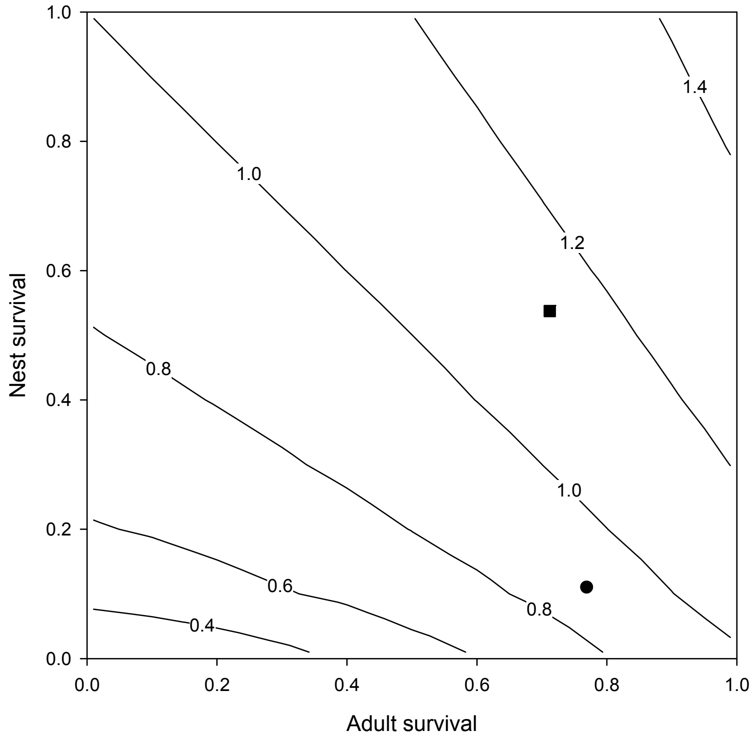


FIGURE 8. CONTOUR PLOT OF THE MEAN POPULATION GROWTH RATE (λ) ASSOCIATED WITH DIFFERENT COMBINATIONS OF MEAN ADULT FEMALE SURVIVAL AND MEAN NEST SUCCESS RATES, WHERE λ=1 INDICATES A STABLE POPULATION. THE MEAN LAMBDA VALUES FOR THE TWO MANAGEMENT REGIMES (NO TRAPPING - ●; TRAPPING - ■) ARE SHOWN.

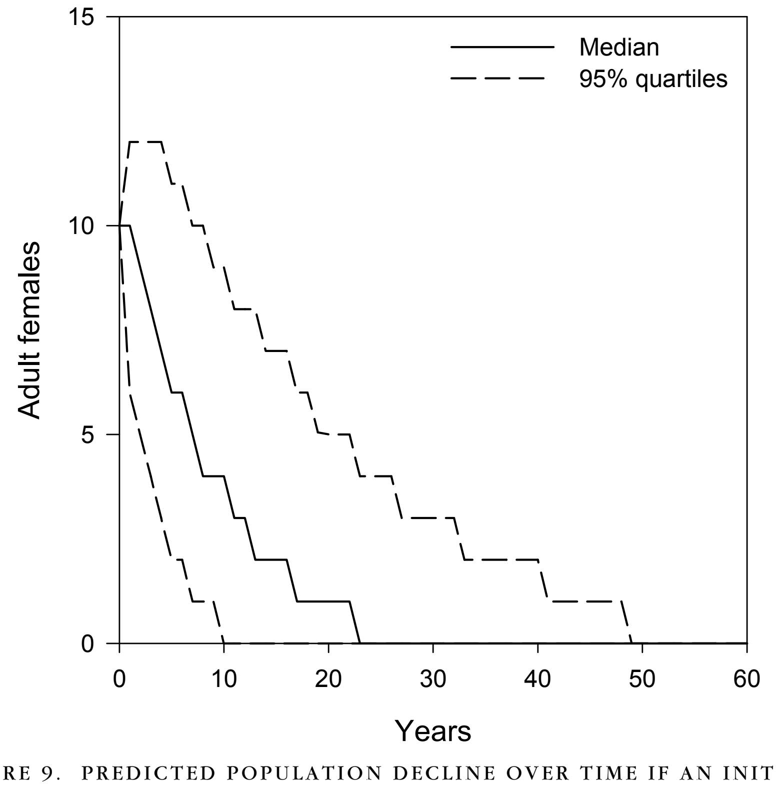


FIGURE 9. PREDICTED POPULATION DECLINE OVER TIME IF AN INITIAL POPULATION OF TEN PAIRS OF WHIO WAS LEFT UNMANAGED.

4.5.2 Predicting population size

When whio monitoring was initiated in the Clinton, Arthur and Cleddau catchments in 2000, a total of ten pairs were present. If trapping had not been established, the population may have become functionally extinct (i.e. no females would have been present) within approximately 22 years (Figure 9).

The current management regime consists of 88 km of linear trapline (Figure 2), protecting 16 whio pairs. This population is predicted to increase and reach the recovery group goal of 50 pairs in approximately 12 years (Figure 11a). Since 2005, the current stoat trapping regime has been expanded to include the Joes and Worsley catchments (Figure 10). Together with a proposed trap expansion into the Neale Burn and upper North Branch of the Clinton, this will increase the managed area to 143 km of trapped river, currently protecting 31 pairs of whio. This population is predicted to increase and reach the recovery group goal of 50 pairs in approximately 4 YEARS (Figure 11b).

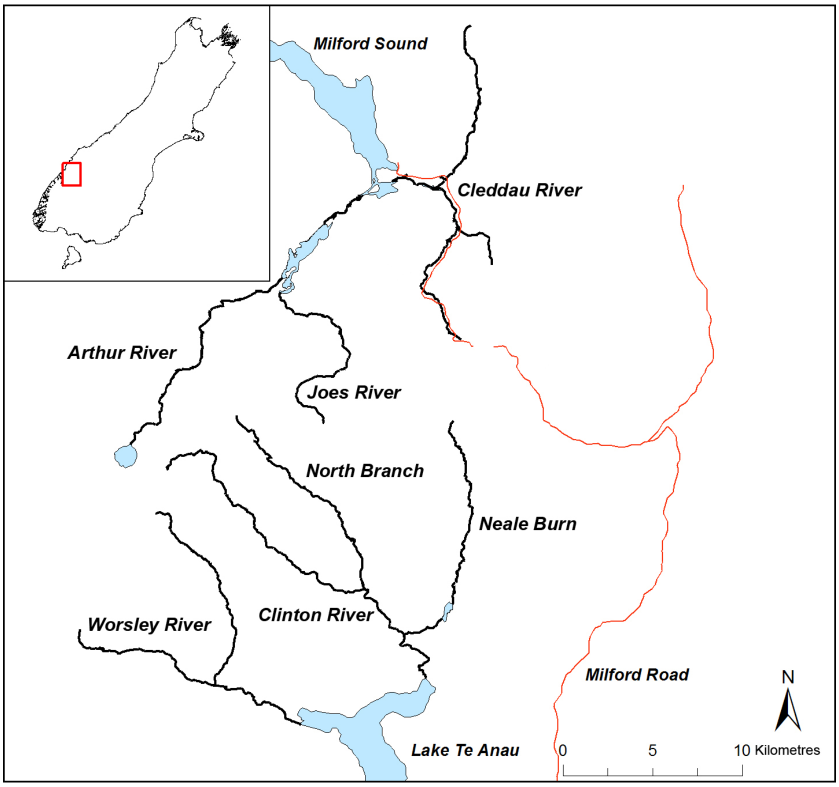
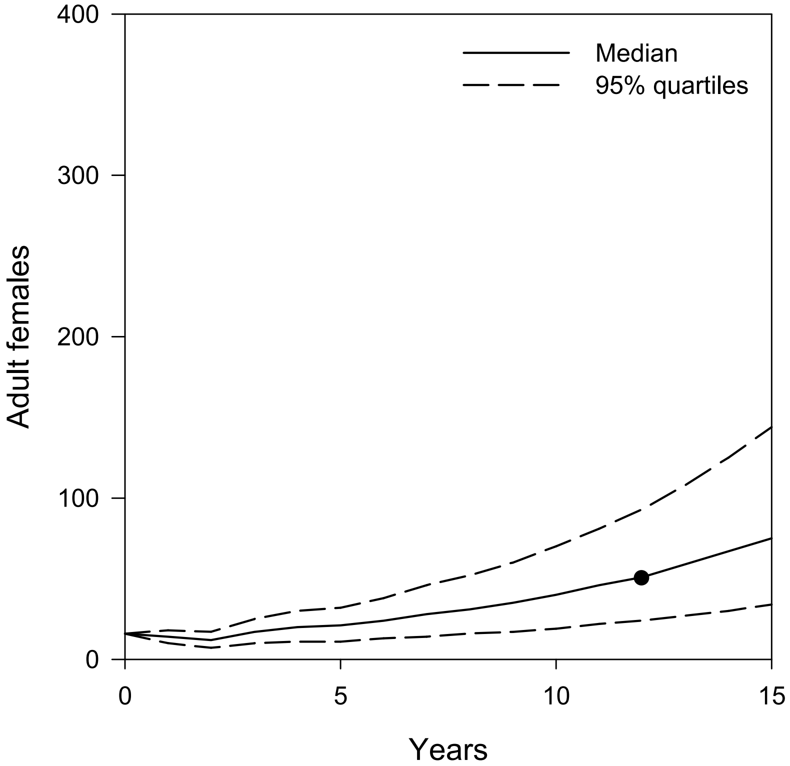


FIGURE 10. MAP DEPICTING EXPANDED MANAGEMENT AREA FOR WHIO IN FIORDLAND NATIONAL PARK.

a)



b)

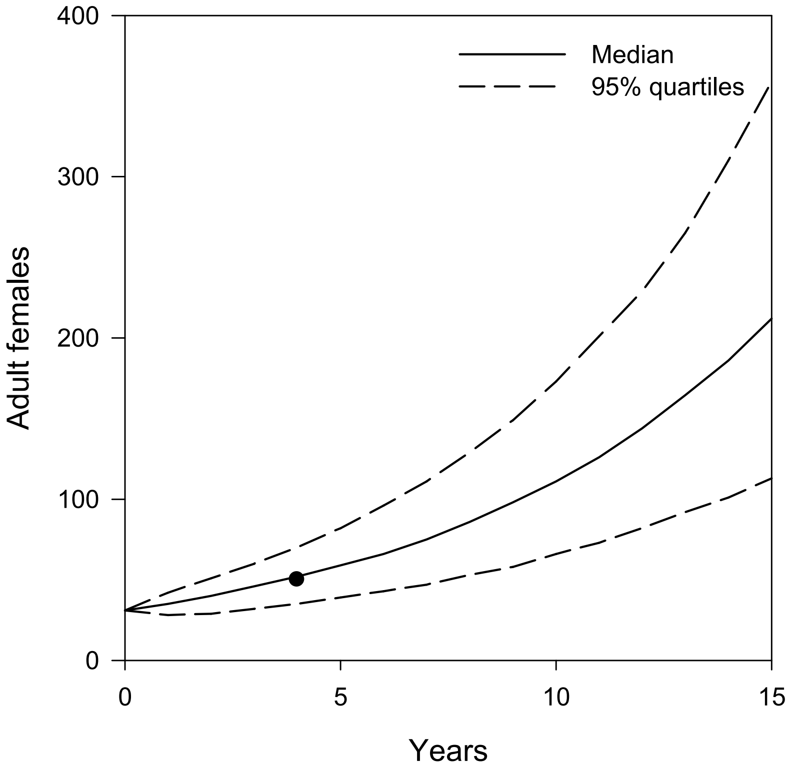


FIGURE 11. PREDICTED POPULATION SIZE OVER TIME IF AN INITIAL POPULATION OF A) 16 PAIRS AND B) 31 PAIRS OF WHIO IS MANAGED UNDER THE CURRENT TRAPPING REGIME. BLACK CIRCLES INDICATE THE POINT AT WHICH 50 PAIRS IS REACHED.

5. Discussion

It has been recognised for some time that whio populations have been declining in distribution and abundance across New Zealand (van Klink 2007). In many cases, these declines have been attributed to predation by stoats but evidence has been largely anecdotal. However, the current study has confirmed that whio populations in Fiordland are threatened by stoat predation.

5.1 ARE STOATS AN AGENT OF DECLINE FOR WHIO?

In the absence of stoat control, whio in the study area experienced very low nest success, with only four ducklings hatching from 12 nesting attempts. Video footage identified stoat predation as the primary cause of nest failure, with both eggs and young ducklings predated. No ducklings fledged during this period and stoat predation was suspected as the sole cause of duckling mortality. In addition, stoat predation was identified as the cause of all adult female mortality during this period.

Stoats are known to predate a wide range of New Zealand bird species (Moors 1983) and they have been identified as important agents of decline for mohua, kaka (*Nestor meridionalis*) and yellow-crowned parakeets (*Cyanoramphus auriceps*) (Elliott 1996b, Elliott et al. 1996, Moorhouse et al. 2003). O'Donnell (1996) suggested that these species may be particularly vulnerable to stoat predation because

1. they nest in tree holes with one entrance, which puts the incubating female at risk of predation as well as the eggs and chicks;
2. only the females incubate, resulting in a biased sex ratio due to nest predation;
3. they have long incubation and nestling periods which increases the predation risk; and
4. the chicks are noisy just prior to fledging which may attract nest predators.

Whio exhibit some similar behavioural traits which may make them vulnerable to stoat predation. Whio are ground-nesters (Williams 1991) which suggests that nests should be easy for mammalian predators to locate and access. Only the females are involved in incubation (Williams 1991) and male-biased sex ratios have been observed in almost all catchments that have been intensively studied (van Klink 2007, current study). In addition, the laying and incubation period for whio can last for up to 45 days (Williams 1991, current study), placing both the eggs and adult females at risk for an extended period of time. However, whio ducklings are precocial and typically leave the nest within 48 hours of hatching (Williams 1991, current study). While this behaviour may help to reduce duckling mortality, little information is known about the level of predation that occurs between hatching and fledging.

5.2 WILL LINEAR STOAT CONTROL ENSURE POPULATION PERSISTENCE?

Whio nesting success in the study areas was significantly higher in the presence of stoat control, although a small number of nests were still lost to stoat predation. While there was no significant difference in adult female survival between the two treatments, some adult female mortality, as well as juvenile mortality, was attributed to stoat predation even after trapping commenced. In other studies, stoat control has also been found to have positive impacts on the nesting success and adult survival rates of mohua, kaka, bellbirds (*Anthornis melanura*) and short-tailed bats (*Chalinolobus tuberculatus*), as well as improved juvenile recruitment for North Island brown kiwi (*Apteryx mantelli*). With one exception, all of these species are present in the stoat trapped area.

The demographic variation observed between the treatments in this study translated into a significant difference in the associated population growth rates. Prior to stoat control, the population growth rate for whio in the Arthur was 0.91, indicating a declining population that would have been functionally extinct within 20 years. In comparison $\lambda=1.14$ after the establishment of stoat control. Therefore, the presence of stoat control is sufficient to halt the decline of whio under the conditions observed in this study.

While two consecutive stoat plagues were observed within the study area during the six-year period, insufficient data was available to determine the impact that such events have on whio demographics. However, preliminary results following the 2006/2007 stoat plague also suggest that whio were not negatively impacted in the presence of stoat control (A. Smart, *pers. comm.*). This outcome may be because the whio nesting period, when eggs and females are most vulnerable to predation, finishes prior to peak stoat densities in plague years (King 1983, Williams 1991).

Population viability analyses for mohua and long-tailed bats in the Eglinton Valley, Fiordland, suggest that frequent stoat plague events would lead to a high probability of extinction within a 50-100 year time frame (Elliott 1996a, Pryde et al. 2005). However, these populations were predicted to remain extant if stoat control was place during irruption years. Interestingly, these studies observed little or no stoat predation in years when stoat densities were low (O'Donnell et al. 1996, Pryde et al. 2005). This finding is in direct contrast with the current study where all life history stages of whio experienced some degree of stoat predation in the presence of stoat control. Although stoat predation was significantly lower than that observed when stoat control was absent, it suggests that a pulsed approach to stoat control may be inappropriate for whio.

It is important to note that, while the current study found single linear traplines are sufficient to ensure the population persistence of whio in steep-sided glacial river valleys, such levels of control may not be sufficient for catchments with gentler terrain, where immigration from neighbouring areas may be high (Dilks et al. 2003). In addition, because the demographic data used in the models came exclusively from beech forests, caution should be exercised in extending these results to whio populations in other habitats. However, stoat control targeted at whio conservation is also likely to have wider community benefits, with a number of species known to respond positively to reduced stoat numbers (O'Donnell 1996, O'Donnell et al. 1996, Dilks et al. 2003, Kelly et al. 2005, Smith et al. 2005).

5.3 HOW LONG WILL IT TAKE TO REACH A SECURE POPULATION?

Under current management conditions, the whio population in the study area is predicted to reach a median population size of 50 pairs in approximately 12 years. While the population projection models suggest that the current level of management is sufficient to ensure the persistence of these populations, they also indicate that expanding the managed area will secure the goal of 50 pairs more rapidly. Additional stoat control has already been established in several neighbouring catchments and together with a planned expansion into the Neale Burn and upper North Branch of the Clinton, could see this time frame reduced to four years. The inclusion of the Neale Burn and the North Branch will protect an additional 18 km of whio habitat, providing immediate protection for an additional four pairs (A. Smart, *pers. comm.*). More importantly, these river segments lie in the centre of the core area (Figure 10). A number of juveniles produced in the study area are known to have dispersed into these catchments, suggesting that protecting this area may help to further boost the population size through increased juvenile recruitment. Therefore, it appears that this expanded management regime will lead to reaching a secure population within the Recovery Group's timeframe, even in the presence of stoat plague events.

5.4 MODEL LIMITATIONS

It is important to note that the population models described in this report do not consider the impacts of density dependence, meaning that the populations grow without limit. While this approach ignored the limiting effects social and extrinsic factors would have on whio density, we were more interested in the time a recovering population took to reach 50 pairs, than in the size this population might attain in the longer term. While density dependent recruitment and survival functions have been noted for whio on the Maunganui a te ao River (Henderson 1994), this assumption probably holds for the Fiordland populations at the time of this study as no evidence of density dependence was observed. However, dispersal patterns may change as more pairs become established within the study area and this information should be incorporated into future population predictions as it becomes available.

The models also assume a closed population with no immigration or emigration. However, juvenile whio in Fiordland are capable of dispersing considerable distances from their natal catchment and several moved outside the managed area during the study period. Males typically dispersed to neighbouring catchments soon after fledging and similar results were noted in the Murchison Mountains, with one juvenile male moving over 27km (Whitehead and Smart 2006). In comparison, females tended to remain within their natal catchment and often formed pairs with single males soon after fledging. Because the models only consider the female population dynamics, it is unlikely that the current juvenile dispersal patterns will have a significant impact on population dynamics when the density of pairs within the study area is low. However, these are likely to change as the number of available territories decreases (Carr et al. In Press) and this information should be incorporated into the models as it becomes available to ensure that decisions are made within an adaptive management framework. It is interesting to note that these dispersal patterns are in contrast to those observed by Williams (1991) on the Manganui a te ao River, where only one inter-catchment dispersal event was observed in a ten-year period.

Such variation in the dispersal patterns in different areas needs to be carefully considered when making management decisions.

While there is often some uncertainty associated with the results of population models, they offer a platform from which managers can explore population dynamics and make informed management decisions. More accurate estimates of population viability would require better demographic information, however the time taken to collect this may lead to further declines for threatened populations. Despite the limitations of these models, there is sufficient empirical evidence to suggest that their predictions are approximately correct. Whio populations in the absence of stoat control have declined in abundance around the country, while population increases have been observed where stoat control is in place. Therefore, the primary aim of whio conservation should be to reduce the impacts of stoat control on whio populations.

5.5 CONCLUSIONS AND RECOMMENDATIONS

This study has identified stoat predation as a primary agent of decline for whio in beech forest systems. Therefore conservation management for whio should concentrate on reducing stoat densities through ongoing predator control programmes. We suggest that such predator control meet the following recommendations.

1. Single linear traplines should be used in steep-sided glacial valleys but that additional research be undertaken to assess the level of control required to protect whio in gentler terrain and in non-beech forest systems.
2. Stoat control for whio should be conducted on a continuous basis.
3. Managed sites should include the maximum practicable trapped area to secure whio populations.
4. Operation Nest Egg should be considered a valuable tool for boosting whio populations in areas where habitat is deemed to be suitable.
5. Whio conservation through corporate sponsorship and community driven initiatives should be encouraged and supported by the Department where appropriate.

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