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Home ranges and dispersal patterns of Great Spotted Kiwi *(Apteryx haastii)* subadults

by

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Abstract

Since human arrival in New Zealand a number of different species have become extinct or endangered mainly through mammalian predation or competition. The nocturnal, flight less bird great spotted Kiwi (GSK) *(Apteryx haastii)* is an example for this biodiversity threat. For this reason the GSK is supported by the Operation Nest Egg™ (ONE) program. Within the ONE program five GSK chicks were artificially hatched and raised in a predator free area until they reached a weight, which increases the chances of the chicks being able to defend themselves in the wild.

These particular subadults were released into the Arthurs Pass National Park on the South Island of New Zealand. The aim of the study is to determine the home range size, to assess the movement and activity pattern of those birds. This was made possible using radio telemetry to track and determine the location of the birds through triangulation. These locations were used to calculate the home range size with the Minimum Convex Polygon and Harmonic Mean methods.

The activity and weight data shows that the birds were able to sustain themselves in the wild after release. The size of the home range varied between birds and method. Beside that some locations of the birds were in open grassland and sometimes close to human infrastructure. Unfortunately three of the five birds died during the project. One bird died of avian malaria, one of fungal pneumonia and one of predation.

These results show the potential of the ONE program and their capacity to improve their success. Also this study could improve the knowledge about subadult GSK, and also raise some new questions.

Zusammenfassung

Seit der Ankunft des Menschen und der durch ihn eingeführten Säugetiere ist in Neuseeland eine hohe Anzahl von einheimischen Arten ausgestorben oder vom Aussterben bedroht. Der nachtaktive, flugunfähige Vogel, Haastkiwi oder Großer Fleckenkiwi (GSK) *(Apteryx haastii)* ist ein Beispiel für diese Bedrohung der Artenvielfalt. Das Programm „Operation Nest Egg^TM (ONE) unterstützt den Erhalt des GSK. Innerhalb dieses Programms wurden fünf GSK Küken künstlich ausgebrütet und in einer säugetierfreien Umgebung aufgezogen. Denn ab einem Gewicht von ungefähr 1200g sind die Vögel eher zu gross für die Säugetiere wie Wiesel oder Marder und können ausgewildert werden.

Diese fünf juvenilen Vögel wurden in den Arthurs Pass Nationalpark auf der Südinsel von Neuseeland ausgesetzt. Das Ziel der vorliegenden Studie ist es, die Reviergröße, die Wanderungen und die Rate der Aktivität der Vögel zu bestimmen. Um die Positionen der Vögel mittels Triangulation bestimmen zu können, wurde die Technik der Radio Telemetrie angewendet. Mit Hilfe der ermittelten Positionen konnte anschließend mit der Minimum Convex Polygon und der Harmonic Mean Methode die Reviergröße berechnet werden.

Die ermittelten Daten von Gewicht und Aktivität zeigen die Fähigkeit der ausgewilderten Vögel, sich selbst zu versorgen. Die Reviergröße schwankt je nach Vogel und angewendeter Methode. Einige Positionen der Vögel sind im offenen Grasland und nahe menschlichen Infrastrukturen. Leider sind in der Zwischenzeit drei der fünf ausgewilderten Vögel gestorben. Ein Vogel erlag der Vogelmalaria, einer der Pilzpneumie und ein Vogel starb aufgrund Prädation.

Die Resultate der Studie zeigen die Stärken und das Verbesserungspotential des ONE Programmes auf. Ebenfalls konnte die Studie das Wissen über die GSK vertiefen und gleichzeitig wurden neue Fragen aufgeworfen.

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1 Introduction

Kiwi species abundance has declined since the arrival of Europeans to New Zealand. Findings and historical evidence shows that kiwis were more abundant in the past (DOC, 2004). The great spotted kiwis (GSK) for example has seen a population decrease by 30% (McLennan and McCann, 2002).

One of the main reasons for this decline was habitat loss through intensive forest clearance to establish agricultural land (Holzapfel et al., 2008). Another reason for the decreasing numbers of kiwi species was and are the introduction of mammalian predators. The agents of decline are: stoat *(Mustela erminea)*, ferret *(Mustela furo)*, weasel *(Mustela nivalis vulgari)*, feral cat *(Felis catus)*, dog *(Canis familiaris)*, pig *(Sus scrofa)* and possum *(Trichosurus vulpecula)* (Basse et al., 1999, Holzapfel et al., 2008, McLennan et al., 1996, Murphy et al., 2008, Pierce and Westbrooke, 2003). The impact of these agents is varied and the impact of ferret and dog, the main predators of adult kiwi, can be both high (Taborsky, 1988) and low (McLennan et al., 1996). This depends on the life stage and number of predators but the impact remains both unpredictable and episodic (McLennan et al., 1996).

The main reason why the introduced predators have had such an impact on kiwi, is that young kiwis show no natural defence behaviour (McLennan et al., 1996). The study of McLennan et al. (1996) found that at least 8% of chicks, 45% of juveniles and possibly 60% of all young kiwi were killed by predation of stoat and feral cat. Eggs and juvenile kiwis are more at risk than adults and the mortality of young kiwi is significantly higher on NZ mainland than on the predator-free Kapiti Island (McLennan and Potter, 1993).

1.1 Family of the Kiwi *(Apteryx spp.)*

The family of the kiwi is very unique in the class of the birds *(Aves)*. Kiwis are members of the order *Struthioniformes* and their genera *Apteryx* consists of five species (Peat, 2006, Holzapfel et al., 2008, Sales, 2005, IUCN, 2010):

- North Island brown kiwi *(Apteryx mantelli),* Status: Endangered
- Great spotted kiwi *(Apteryx haastii),* Status: Vulnerable
- Little spotted kiwi *(Apteryx owenii),* Status: Near Threatened
- Okarito rowi *(Apteryx rowi),* Status: Critically Endangered
- Southern brown Kiwi /Tokoeka *(Apteryx australis)* Status: Vulnerable

All species are endemic to the three main islands of New Zealand (Sales, 2005). The five species of kiwis are different compared to most other birds even in the same order.

For example, they have a relatively low body temperature (about 38°C), their use of burrows in the ground, they have an excellent sense of smell, the paired ovaries in females combined with a slow metabolism, they are flightless and have only vestigial wings (Sales, 2005). These differences make the kiwi more related to small mammals than to birds. They have strong legs and are good runners, even capable of swimming through rivers (Holzapfel et al., 2008).

One unique speciality of kiwis is their very sensitive bill tip, which is used to detect prey movement along with their olfactory sense (Cunningham et al., 2009, 2007). Their prey consists mainly of soil/litter invertebrates and fruits. The main part of their diet is invertebrates and limited vegetable matter (Sales, 2005, Holzapfel et al., 2008, Colbourne and Powlesland, 1988).

Adult kiwis are monogamous and actively territorial. This means that kiwi normally stay together as a pair for life, which can between 25 and 50 years, and defend their territory (Sales, 2005, Taborsky and Taborsky, 1999, Holzapfel et al., 2008).

1.2   The Great Spotted Kiwi *(Apteryx haastii)*

The GSK lives in different types of habitat and is mainly located in subalpine to alpine areas up to 1500m above sea level (a.s.l.) (BirdLife International, 2010). The preferred types of habitat are (Marchant et al., 1990):

- Tussock grassland
- Damp, mossy beech forest
- Dry, alluvial podocarp and hardwood forest
- Scrub covered coastal pasture

Sometimes they can reside on the farmland edge, but the highest population density is normally in mossy beech (*Nothofagus spp.*) forest. This because there is a thick ground level of moss and lichens (Marchant et al., 1990). The more recent study of McLennan and McCann (2002) found the most dense populations of GSK in areas with high rainfall and high altitude.

The total estimated GSK population is 22,000 (+/-25%) individuals and spreads over an area of 6,000-8,500 km^2 in the South Island (BirdLife International, 2010, McLennan and McCann, 2002). In the report of Holzapfel et al. (2008) an estimate of the total GSK population is 16,000 individuals. These differences show that the exact population numbers remains uncertain. The stronghold of the total GSK population is in north-west of Nelson with about 50% residing in this area (Robertson et al., 2005). The rest of the population occurs in the Paparoa Range and Arthur's Pass-Hurunui district (Robertson et al., 2005). The current population in the Nelson Lakes National Park (see Figure 1), is a result of a recent relocation program (Gasson, 2005).
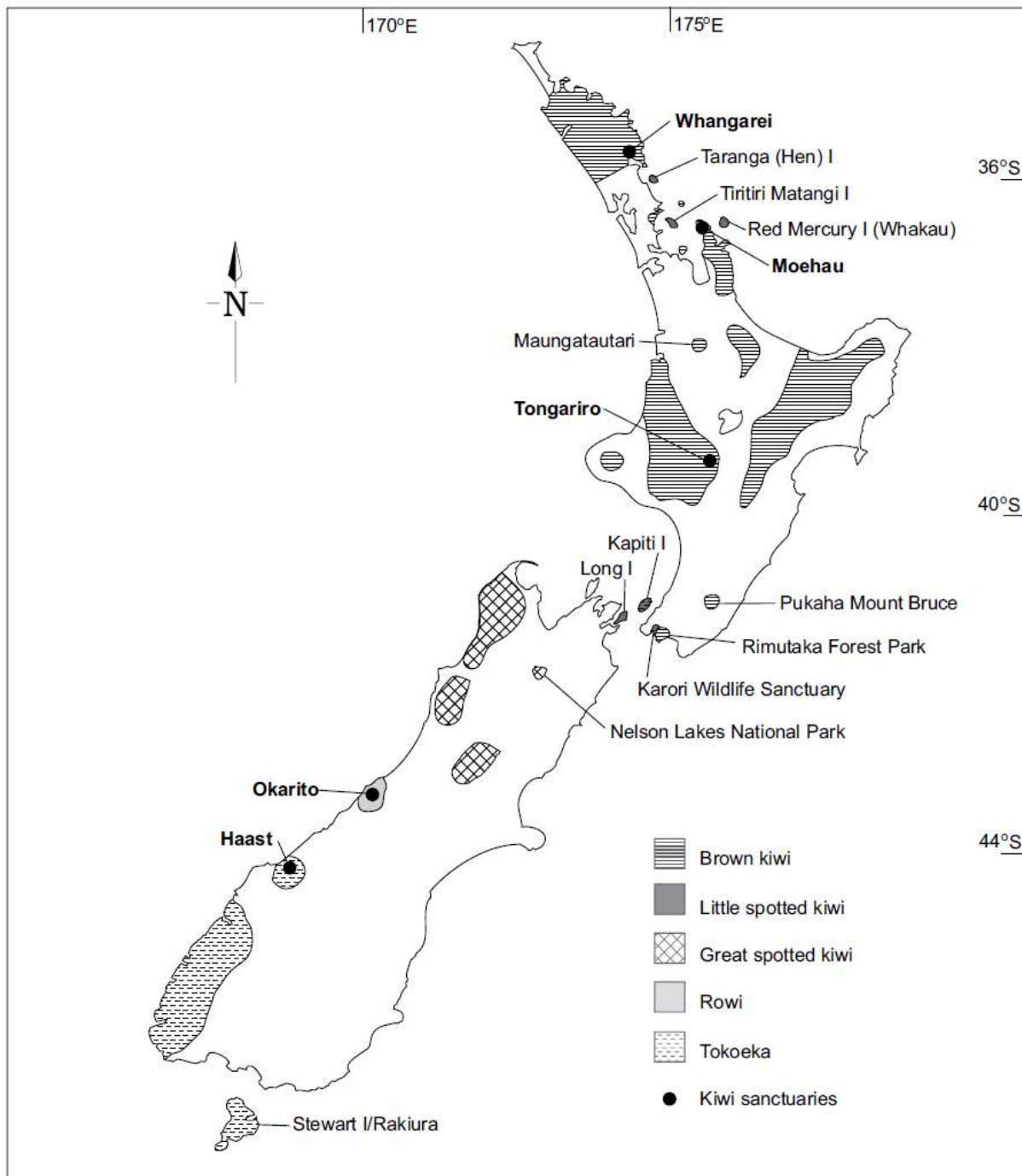
Figure 1. Present distribution of kiwi *(Apteryx spp.)* in New Zealand after Holzapfel et al. (2008)

The separation of these populations of GSK happened recently, because the different populations are still genetically similar (McLennan and McCann, 2002). The species of kiwi is different in their reproductive behaviour. Some species of kiwi share the effort of raising young between each sex, and some not (McLennan and McCann, 1991b). For GSK both sexes incubate the egg, but most of the time the male is the incubator (McLennan and McCann, 1991a, 1989).

This means that the male usually incubates the egg during the day to around midnight and then the female takes over for an average of 5.2 hours during the night (McLennan and McCann, 1991a). The incubation period of the egg is c.70 days and the egg has a weight equal to 12% of the female body weight (McLennan and McCann, 1991a). Normally GSK lay one single egg per year. The breeding success of the GSK is 0.5 chicks/pair/year (McLennan and McCann, 1991a).

At the age of 150 days GKS birds are not classified as chicks anymore but as subadults (until a age of 4.5 years or when they start breeding) (Robertson and Colbourn, 2003).

1.3   BNZ Operation Nest Egg™

The problem with the mammalian predator and low juvenile survival rate was one reason for the establishment of the Operation Nest Egg™ program (ONE) in 1994, under the patronage of the Bank of New Zealand Kiwi Recovery Group (Colbourne et al., 2005). The ONE program is now applied to all five kiwi species to increase their numbers. The description of ONE in this paper is based mainly on the paper of Colbourne et al. (2005). Basically, the idea is to artificially incubate and hatch the eggs of kiwi pairs living in the wild. These are then raised in captivity, until they are heavy and/or old enough to defend themselves against predators.

The collection of the eggs in the wild has to follow certain rules. For example in 1997, eggs of the Brown Kiwi were collected less than 30 days after the egg was laid. The knowledge of how old an egg is, is provided by the radio transmitter attached to the leg of a bird, called an "Egg Timer" (Wildtech New Zealand Ltd., 2007). This allows the monitoring of the bird and when the activity levels go below a certain level, it indicates the start of the incubation period. For Brown Kiwi the eggs are usually in a two-egg clutch with the oldest egg at 60 days and the second at 30 days old. The collection itself occurs mainly during the daytime and the collecting person has to be careful to prevent egg damage from a kicking adult bird. For the Okarito Rowi both adults share incubation of the egg, therefore the egg is never unattended. For this reason it is necessary to play kiwi calls on a tape to lure the adults away from the nest. Only then is it possible to collect the egg without danger of damage. (Colbourne et al., 2005)

The transportation of the egg to the next incubation facility is mostly done in a "chilly bin". To prevent damage of the egg during transport the chilly bin is filled with polystyrene bands or foamed material. To keep the egg warm, water bottles with warm water are also placed in the chilly bin. With these measures the egg should arrive safely at the incubation facility. In the incubator the egg is regularly turned by 90° and kept at 36.5°C. After hatching the chicks are fed for the first time after five days. (Colbourne et al., 2005)

In nature some kiwi chicks leave the burrow of the adults after 5-7days and fend for themselves, but normally the chicks regularly return to the burrow of the parents. For this reason the chicks within the ONE programme are transferred from brooders to outdoor pens or crèches at the age of 3-6 weeks.

Another possibility is to release the chicks into a so called "Mainland Island". An area on the mainland with no fence but with strong measures against predators (DOC, 2010b). There they sustain themselves until a weight of 800-1200g and then are released in the wild. (Colbourne et al., 2005)

Since the 2007/2008 breeding season GSK chicks were hatched and raised within the ONE programme (BNZ Save The Kiwi Trust, 2010). The release of the subadult GSK in this study is the second release ever (Wylie, pers. Comm.). This might be the reason why no information, about the success of subadult GSK released into the wild, prior to this study, was available.

Information regarding the release success of adult GSK comes from the study by Gasson (2005). This study showed that the birds stayed in the project "Mainland Island" area for 12-13.5 months after release (in 2004) and that the project was very successful in the first year. The five known wild hatched chicks showed that the success is ongoing today (DOC, 2010a). Another example of an successful translocation is the study by Colbourne and Robertson (1997). In this study mostly adult Little Spotted Kiwi *(Apteryx owenii)* were transferred to a predator free island and were able to establish a healthy population. Predator free islands are commonly used for translocation of kiwi to support the populations (Colbourne, 2005).

1.4   Objectives of the study

Because GSK are under pressure and their numbers are in decline the aims of this study are:

- Determine the success of the ONE-program in the Waimakariri area, because it is the first time that GSK subadults have been released into region of Canterbury, New Zealand and the second release ever (Wylie, pers. Comm.).

- Improve the knowledge about GSK juveniles/subadults. Knowledge about GSK in general is still small (McLennan and McCann, 1991a) and knowledge about chicks/subadults is nearly non-existent. The reason for this lack of information is that very few GSK chicks have been encountered by kiwi field workers (Gasson, 2005)

Therefore the research tries to answer following main research questions (RQ):

- **RQ-1** = What distance do the five released subadults travel away from the release point per night?
- **RQ-2** = How many hours per night are the five subadults active?
- **RQ-3** = Is the rate of activity for the adult birds, already present in this area, changing because of the presence of the released subadults?
- **RQ-4** = How fast are the released subadult birds able to establish their own "stable" home range and how far is it away from the point of release?
- **RQ-5** = Are the subadults establishing alone a home range or with a partner?
- **RQ-6** = Do the five subadults remain alone or together with other subadults after release?
- **RQ-7** = How is the weight of the subadults developing after release?
- **RQ-8** = Can the birds sustain themselves in the release area?

To reach the aims and to answer the research questions, the following hypotheses (Hi) are tested by parameters (P_i) in this study:

- **H_1** = The released subadult birds are able to establish own, solitary home range in the study area

    $P_{1.1}$ = Home range size
    $P_{1.2}$ = Overlap of home ranges between different birds

- **H_2** = The released subadult birds can sustain themselves in the study area

    $P_{2.1}$ = Activity per 24 hr
    $P_{2.2}$ = Weight development before and after release

- **H_3** = The adult birds already present in this area, are not changing the activity because of the presence of released subadult birds

    $P_{3.1}$ = Activity per 24 hr of adult birds
    $P_{3.2}$ = Activity per 24 hr of subadult birds

2   Study area and Methods

2.1   Study area

The study area is in Arthurs Pass National Park on the South Island of New Zealand. Arthurs Pass National Park is located in the centre of the South Island between Christchurch on the East Coast and Greymouth on the West Coast (see Figure 2).
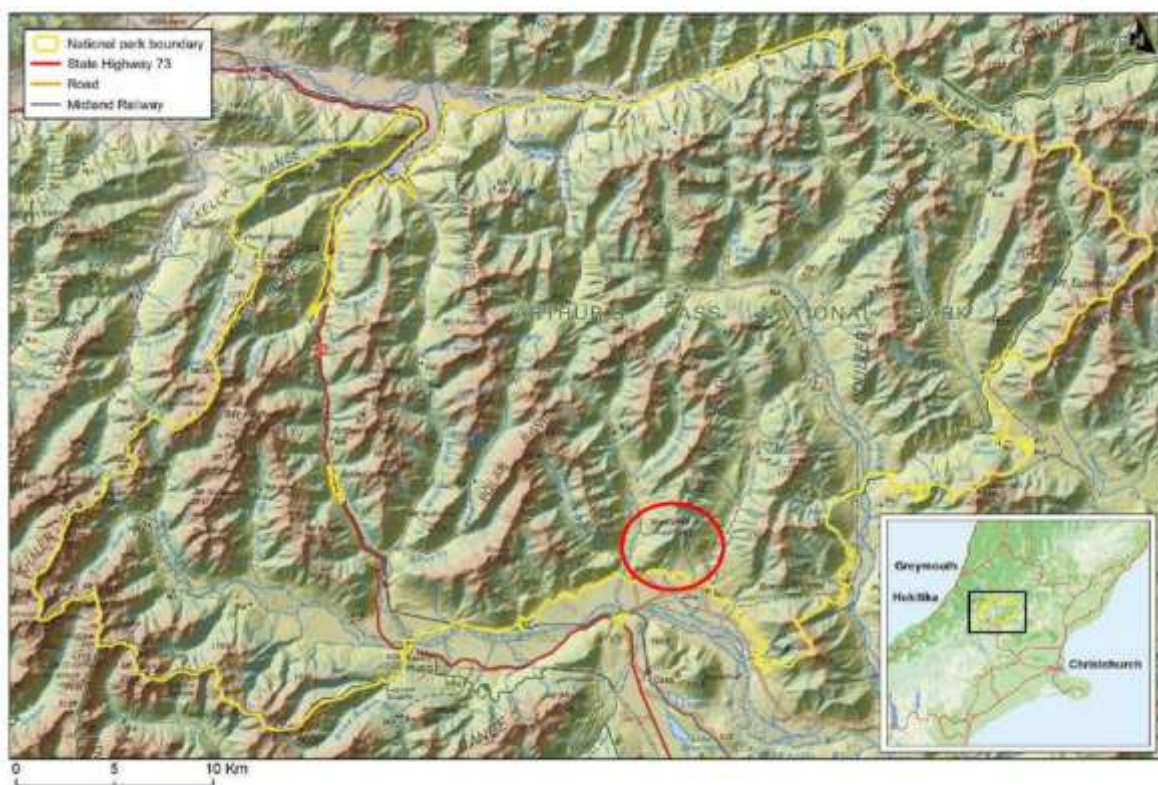
Figure 2. Map of Arthurs Pass National Park. Circle shows the study area. (modified from DOC 2007)

The area of Hawdon was chosen by the Department of Conservation as an ONE eggs collecting and release site for subadults GSK (Wylie et al., 2009). The reason for this was experts were concerned about collecting eggs from the Hurunui valley. This collection could influence the results of an mark-recapture project in this valley (Wylie et al., 2009).

The release area of the GSK chicks is located between the Hawdon valley and the Andrews valley on the true left hand side (facing downstream) of the Waimakariri River (see Figure 3). In the surrounding area are two campsites (Hawdon and Andrews) of the Department of Conservation and two private lodges (DOC, 2007).
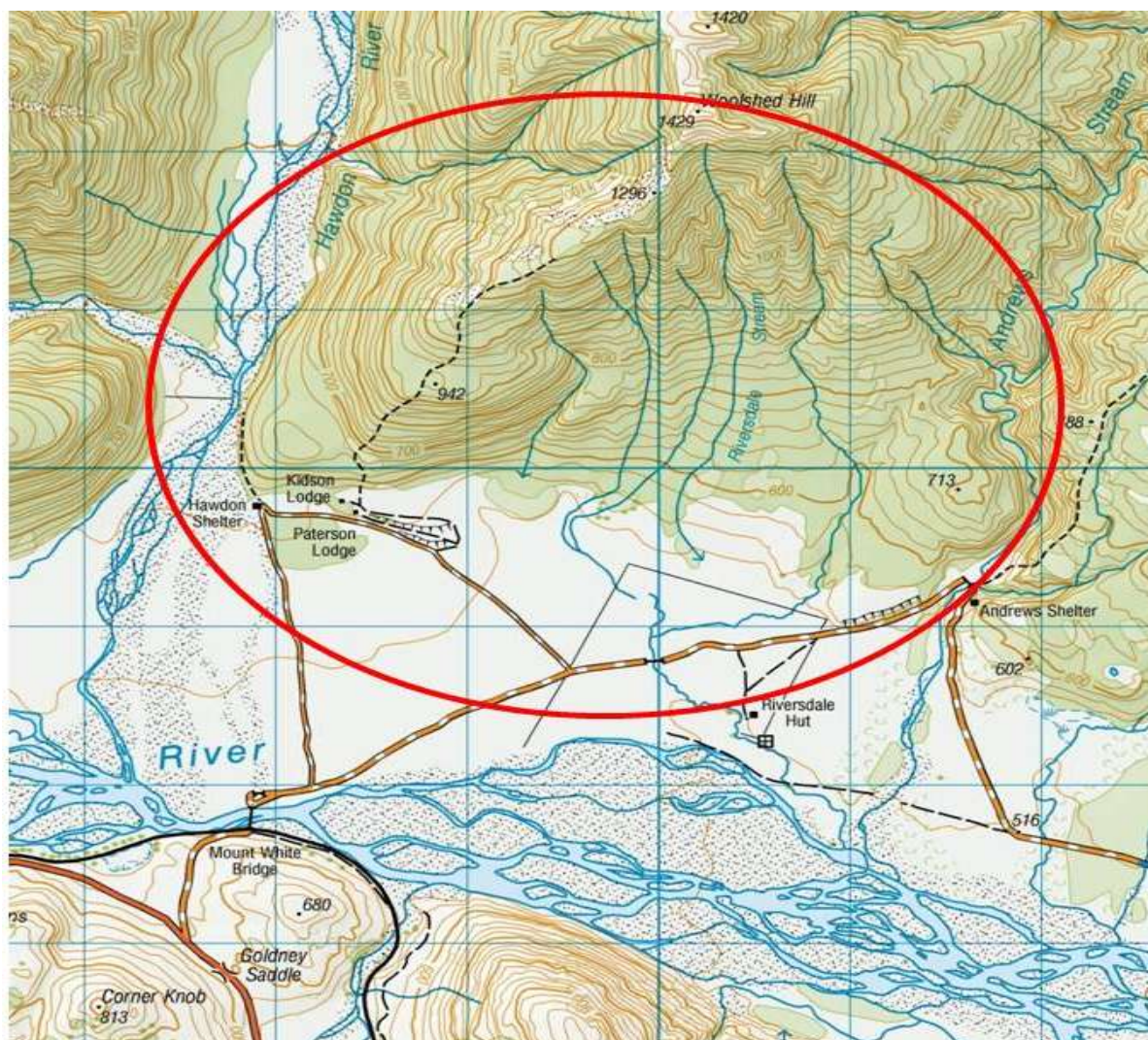
Figure 3. The circle shows the study area. Green is indigenous forest (mainly *Nothofagus spp.*) and white is extensive agricultural grassland (Landinformation New Zealand, 2009).

The study area is located between 540m and 1450m a.s.l. The average minimum temperature is -1.2°C and the average maximum temperature is 20.6°C. The annual average rainfall is 2016mm/year (Walker and Lee, 2002). The forest consists mainly of mixed beech *(Nothofagus spp.)* with a treeline of around 1200m a.s.l. The understory in the forest is generally open with patches of regenerating beech, Mountain toatoa (*Phyllocladus aspleniifolius var. alpinus*), Broadleaf *(Griselinia littoralis)* and various *Coprosma spp.* and *Pseudopanax spp.* (Lough, 2006).

Above the treeline (i.e. the sub-alpine vegetation) the scrublands are dominated by Inaka *(Dracophyllum spp.)* (Burrows, 1986, DOC, 2007). The valley floor between the Hawdon and Andrews shelters is either part of the Arthur National Park or other public Conservation Land (DOC, 2007fig. 3, p.82). The open grassland consists of *Festuca novae-zelandiae, Festuca matthewsii* grass and Matagouri *(Discaria toumatou)* (Walker and Lee, 2002, Lough, 2006) and is grazed by sheep.

2.2   History of the particular birds

In this study the five monitored subadult GSK are part of the ONE Program (see Table 1).

Table 1. Date and weight of the five Great Spotted Chicks transferred to Riccarton Bush

Name	Sex	Hatch date	Transfer to Ricarton Bush	Age (days)	Weight
Ringo	Male	30.01.2009	17.07.2009	168	1200g
Georgia	Female	14.02.2009	17.07.2009	153	1170g
Tahi	Male	23.11.2008	11.06.2009	200	1600g
Rua	Female	03.11.2008	11.06.2009	220	1420g
Willow	Female	03.01.2009	01.09.2009	242	920g

The subadults are two males and three females. The histories of these birds are mostly similar to each other with all birds being hatched at Willowbank Wildlife Reserve in Christchurch, New Zealand, on different dates. Willowbank is part of the ONE program and therefore a facility to incubate, hatch and raise kiwi. Beside GSK eggs, Willowbank gets eggs from the Okarito Brown Kiwi (Rowi) and Haast Tokoeka Kiwi (Willowbank Wildlife Reserve, 2010). After hatching and captive feeding in Willowbank, the five chicks were transferred to Riccarton Bush in Christchurch.

Riccarton Bush is a small (7.8ha) and last remnant of alluvial flood plain forest located in Christchurch City. It helps to distribute native plants back into Christchurch (Doody et al., 2000) and is protected by a predator-proof fence. This fence doesn't allow predators like stoats and rats to establish in this forest. For this reason Riccarton Bush is used for raising ONE kiwi chicks. The chicks there, learn to forage and nest in burrows in a predator-free environment (DOC, 2009).

During the time in Riccarton Bush all the birds gained weight, except Thai who stayed more or less on the same weight, and were able to sustain themselves (see Table 2). The chicks sometimes stayed together and shared burrows (Wylie, unpublished-b).

Table 2. Great Spotted Kiwis Chicks released into the wild and monitored in this study

Name	Sex	Release date	Release age (days)	Release weight	Channel
Ringo	Male	16.12.2009	320	1408g	40
Georgia	Female	16.12.2009	305	1530g	17
Tahi	Male	16.12.2009	388	1570g	31
Rua	Female	19.01.2010	442	1954g	19
Willow	Female	19.01.2010	382	1450g	5

The birds were fitted with radio transmitters from Wildtech New Zealand Ltd. (2007) to monitor the birds in Riccarton Bush (also after release into wild). This radio transmitter helped to check their health conditions regularly. Their health conditions varied during their time in Riccarton Bush. One of the birds for example got an infection and therefore, was it necessary to medically treat all the chicks (Wylie, unpublished-b). After the chicks had reached the minimum weight of 1400g they were released into the study area. Ringo, Georgia and Tahi were first and were followed by Rua and Willow about four weeks later (see Table 2).

2.3   Radio Telemetry

Wildlife telemetry or radio telemetry is the use of radio transmitters for tracking the movement of an animal. The term "telemetry" stands for acquiring data on the status of the animal from a distance (e.g. body temperature, activity,...) (Priede, 1992). Radio transmitters are also used for determination of location.

The VHF-band (wave length between 1m and 10m) is used for the "classical" radio tracking (Priede, 1992). VHF-radio transmitters can be used for animals that live or move in water, in the air and on the ground. A transmitter can have a weight of 350mg, which even allows the tracking of insects (Kenward, 2001). Weight is a crucial factor of the transmitter. A transmitter which is heavy can influence the behaviour of the animal. On the other hand, a lighter transmitter might have a too short battery life, which makes it necessary to change the transmitter over shorter periods and therefore causes more disruption to the animal. Transmitter design can be very different depending on the research questions and size of the animal. (Kenward, 2001)

After the correct transmitter is found, different methods are available for tracking. Tracking is possible by air, by satellite (GPS, Nimbus, Argos) and on the ground (homing, triangulation) (White and Garrott, 1990). These methods are applied on various animals e.g.: grassland earless dragon *(Tympanocryptis pinguicolla)* (Stevens et al., 2010), eagle owl *(Bubo bubo)* (Schaub et al., 2010), European wild rabbit *(Oryctolagus cuniculus)* (Rouco et al., 2010), African bats *(Scotophilus spp.)* (Monadjem et al., 2010), red deer *(Cervus elaphus)* (Bocci et al., 2010), Mediterranean Vipers *(Vipera aspis and Vipera latastei)* (Martinez-Freiria et al., 2010).

The determination of the animal's positions was in this study of crucial importance. All five birds were carrying a VHF-radio transmitter, which allowed for monitoring of the position of the birds following release. To establish locations of the birds, the study had mainly followed the recommendations of Kenward (2001) and White & Garrot (1990). The first step in the field was to verify our exact positions with the help of a hand held Global Positioning System (GPS) receiver. Every time the researchers changed their positions the GPS-location was verified again.

The radio signal of the VHF-radio transmitter "Egg Timer" (Wildtech New Zealand Ltd., 2007) was received with a handheld three-element-yagi antenna and a TR-4 receiver (Telonics, Inc.). With the antenna and the receiver was it possible to hear the impulses from the different radio transmitters. We used the "loudest/strongest signal method" to decide from which direction the signal was coming (Kenward, 2001, Springer, 1979).

After the direction of the signal was determined, it was measured by a hand held compass to get a bearing in degrees (see Figure 4). This was done by two people simultaneously, who were at a different angles to the estimated position of the bird. Even small time differences, between two recorded bearings could cause big location errors due to the movement of the bird (Kenward, 2001, Schmutz and White, 1990).
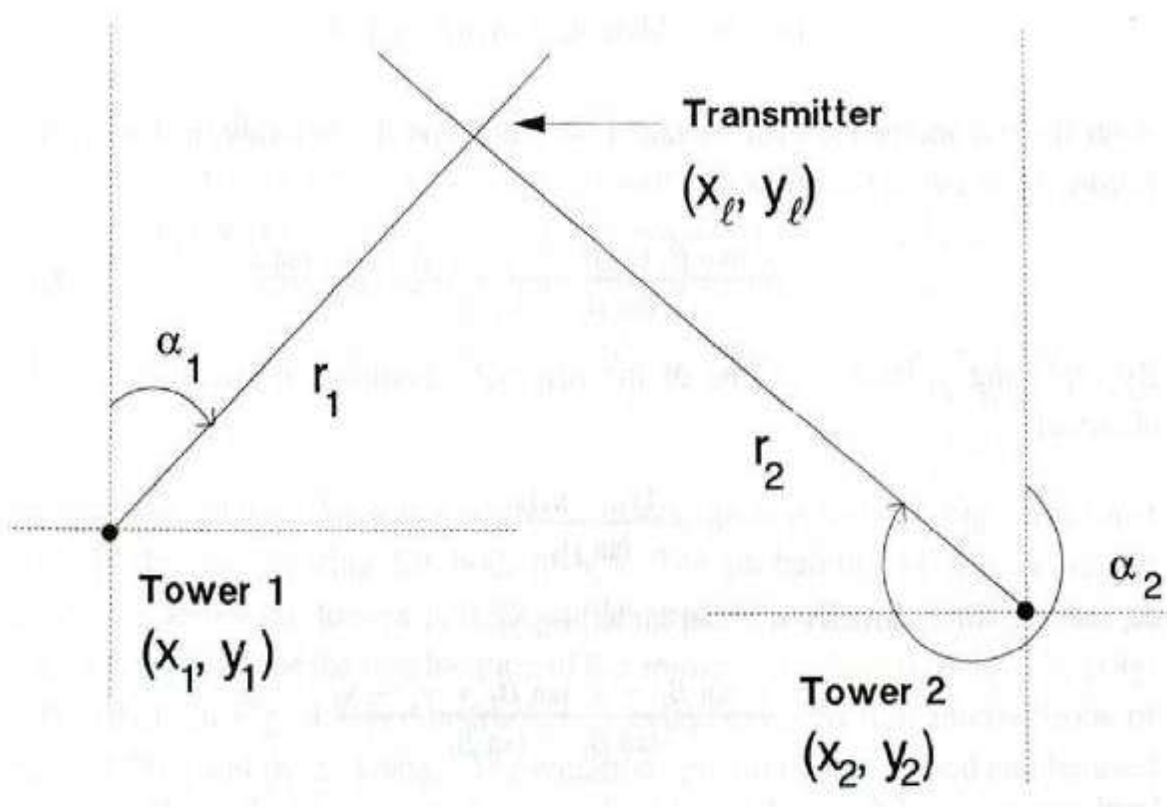
Figure 4. The triangulation process. The two solid lines represent the two bearings from the receiving points and intersect at the source of the signal. Towers represent by the researcher in this study with their coordinates. Symbol alpha stands for the bearing angle in degrees. r stands for the distance between the researcher and the transmitter. (modified from White and Garrott, 1990)

Because GSK and all other kiwi species are believed to be more or less nocturnal (Gasson, 2005, Marchant et al., 1990, Martin et al., 2007) the triangulation in the field was done during night. The design of the research in the field was based on the study of Keye (2008). This means we tried to collect a location for each bird every hour during the night, and additionally one location one hour before sunset and after sunrise. In theory this should give around 12 locations per night in the field.

After the work in the field, the next step was to perform the calculations, based on the data from the field and therefore the program Excel 2007 (Microsoft® Inc.) was used. For calculation of the animal locations was it necessary to convert the bearings, from degrees into radians. This happened with the equation of White and Garrot (1990) (see Figure 5).

$$\beta = (90 - \alpha) \times (\pi/180)$$

Figure 5. Equation for converting degrees into radians

Through the triangulation equation (see Figure 6) in White and Garrott (1990) it was then possible to calculate the coordinates of the intersection point of the two bearings and therefore the location of the animal (see Figure 4).

$$y_t = \frac{(x_2 - x_1)\tan \beta_1 \tan \beta_2 - y_2 \tan \beta_1 + y_1 \tan \beta_2}{\tan \beta_2 - \tan \beta_1}$$

$$x_t = \frac{x_1 \tan \beta_1 - x_2 \tan \beta_2 + y_2 - y_1}{\tan \beta_1 - \tan \beta_2}$$

Figure 6. Equation used in this study to determine the x-coordinate and y-coordinate of the transmitter location. β1 and β2 stand for the bearing in radians of tower 1 and 2. y1 and y2 are the y-coordinates of tower 1 or 2. The same for the variable x1 and x2. (White and Garrot 1990)

2.4   Homing

Beside the radio tracking of the birds during night, the so called "homing technique" was applied during the day (White and Garrott, 1990). This is only possible because GSK are nocturnal and therefore sheltering during the day. This allows for following the direction of the strongest signal. It was the same principal used as for the triangulation, but the difference to the triangulation was that the researchers didn't stay at the same place. On the way to the source of the signal the direction of the signal was freshly assessed at regular intervals. The closer to the source/shelter the stronger the signal. This made estimates of the distance to the source/shelter possible. The described method was continued until the signal was so strong that it even was possible to hear the signal at the next channel above or below the transmitted channel. At this signal strength it was assumed to be about 30m away of the shelter. This position was measured via GPS receiver. The reason for not determining the exact position of the shelter was so as not to disturb the birds.

The "homing technique" was applied when either: (i) it had not been done before, (ii) it was not possible to determine locations during the night, or (iii) it was necessary to find a new position in the field for triangulation during night.

2.5   Accuracy

The accuracy of this radio tracking is crucial for the correct interpretation of results. Determination of the animal positions is always a estimation with a certain error margin (Kenward, 2001, Springer, 1979, White and Garrott, 1990). To determine the location error there are methods available like the error polygon (Heezen and Tester, 1967), the beacon test (White and Garrott, 1990), and the maximum likelihood estimator of Lenth (Lenth, 1981). But the size of the location error depends on different factors such as: mapping error, signal bounce, vegetation density, animal movement, electromagnetic effects, distance and observer effects (Withey et al., 2001).

Signal bounce is caused when the signal has no clear line (line of sight) to the receiver. This line of sight depends on the topographic features of the landscape. For example if a hill is in the "line of sight" then it is possible that the signal is blocked and bounces or is reflected in another direction. When this signal is received then, it provides an incorrect bearing. The only solution for this is to find a better position in the field. Signal bounces can be caused by vegetation, wet snow and walls of canyons/gullies (Withey et al., 2001).

Rapid animal movement can cause errors in location, especially when the position of the animal is determined via triangulation. Therefore it is necessary to obtain the bearings simultaneously (Schmutz and White, 1990, White and Garrott, 1990). To prevent errors during animal movement it is necessary to have more than one person taking the bearings at the same time, or you take the bearing while the animal is resting. The reasons for the location error caused by the observer can be various. Observers can influence the movement of the animal by standing too close to it. This can cause a different behaviour and therefore, a different position of the animal. Also different observers can interpret different results. The number of observations can also be too low therefore, also influencing the results. The reasons for error can be numerous.

Because accuracy in radio telemetry is very important, it was necessary to test the accuracy of our own system in the field. For this reason a spare transmitter was hidden in flat grassland and in forest located on slopes. Those two landscapes being the dominant in the study area (see Chapter 2.1.). Beside the different landscapes different antennas were also tested, which were used in this study. The exact position of the hidden transmitter was known via the GPS receiver. During each test, only one of the researchers was aware of the transmitter's location and had noted it with GPS coordinates. This made it possible for the researcher, who didn't know where the transmitter was to take readings and do the triangulation or homing in an unbiased way.

Every researcher repeated five bearings with each antenna at one location. This procedure was repeated in total at four different locations. The locations were carried out at both close range and from a distance to the hidden transmitter. At the end of the tests each researcher had a total of 80 different bearings. All taken bearings have a certain variation to the true bearing.

The true bearing could be calculated, because of the known location of the hidden transmitter and the receiving location, by an equation of White and Garrot (1990) (see Figure 7).

$$\text{tan of angle} = \frac{\text{length of opposite side}}{\text{length of adjacent side}} = \frac{a}{b}$$
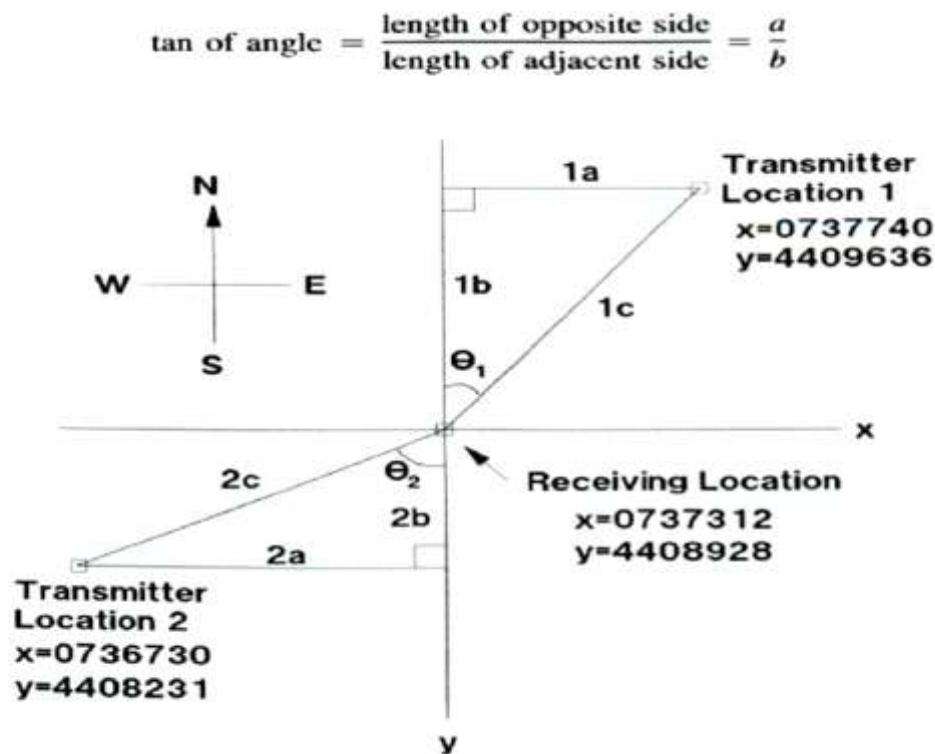
Figure 7. Example of the principal to calculate the true bearing. The result of equation is the bearing in radians which can be converted into degree. x/y coordinates are in this figure are examples (White and Garrott, 1990)

For a better comparison of the taken bearing and the true bearing, the result of this equation was converted from radians into degrees. To determine the bearing error of one single bearing the difference between the taken bearing and the true bearing was calculated. This was done for every bearing of both researchers.

The standard deviation (*s*) of all bearing errors in these tests (multiplied by 1.96) was then used to form the error polygon area (see Figure 8). The error polygon method was used in this study to determine the accuracy of the recorded bird locations during the night (Heezen and Tester, 1967). The error polygon area gives a probability of 95% that the real location of the bird is within this area. The aim in this study is to have small error polygon areas which show an accurate determination of the bird location. The reason for using the error polygon is that the Lenth estimator (Lenth, 1981) is better suited to three simultaneous bearings (White and Garrott, 1990), then for two bearings, as was used in this study.

After the confidence interval (± 1.96*s) (see Figure 8) was established, the x- and y-coordinates of the error polygon corners (A,B,C,D) could be calculated with the same equation (see Figure 6) as used in determining the bird locations. The variable β (bearing in radians) in this equation had to be adapted by ± 1.96*s. When the coordinates of the error polygon corners were calculated, then was it possible to calculate the area of the error polygon with the equation provided by White and Garrott (1990) (Figure 9).
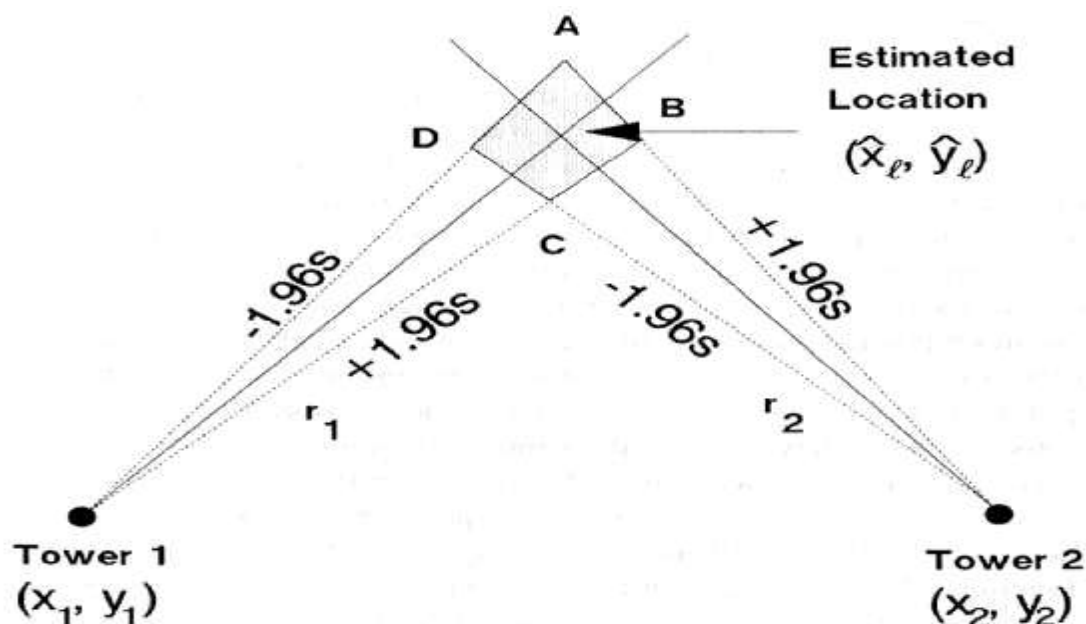
Figure 8. The principle of the Errorpolygon method. The solid line is the observed bearings, which have added 1.96s to it. Those dashed line form the four corners (A,B,C,D) of the Errorpolygon.

$$\text{area} = \frac{x_A(y_D - y_B) + x_B(y_A - y_C) + x_C(y_B - y_D) + x_D(y_C - y_A)}{2}$$

Figure 9. Equation for the area of the Errorpolygon. The x and y are standing for the x- and y-coordinates of the Errorpolygon corners A,B,C and D.

The negative results of this calculation had been converted into absolute results, because the recommended equation of White and Garrott (1990) gave the same results as the conversion into absolute numbers.

The results of the error polygon area calculation were ranked and the biggest areas were deleted and not used for the home range calculations. An example for this method can be found in the study of Tidemann et al. (1985). In this study the author deleted error polygon areas >20ha of locations for the Australian Ghost Bat (*Macroderma giga).* The reason for this was to ensure certain accuracy and to eliminate locations which made no sense or had a too big error polygon area.

Finally, when the locations of the animal and their accuracy are determined, then it is possible to use the locations and the four error polygon corners (only by MCP) to calculate a home range area.

2.6   Home Range Theory

Home Range movement is one aspect of animal movement. The first definition of home range was from Burt (1943) and he defined it as an: *"area traversed by the individual in its normal activities of food gathering, mating, and caring for young"*. Often some confusion occurs together with the term "territory". Some authors consider territory as another concept (Burt, 1943, Nice, 1941). Burt (1943) and Nice (1941) argue that home range is the total range, which the animal is using and territory is the smaller defended range within the home range where the nesting site is situated.

The home range definition of Burt (1943) was criticized and reviewed because of the term *"normal activities"*. Because these activities can change during a lifetime, the definition was changed to: "*the area traversed by an animal during a given time period"* (Hansteen et al., 1997, White and Garrott, 1990). To prevent confusion between the terms "territory" and "home range" this study uses only the term "home range" with the definition of Karnohan et al. (2001): *"...that home range be defined as the extent of area with a defined probability of occurrence of an animal during a specified time period"*.

For some research questions the size of the home range is not enough. In that case more information is needed about which parts of the home range or territory the animal is using more intensively. For this reason Hayne (1949) introduced the "center of activity" method. This method gives coordinates where the "center of activity" is within the home range. One problem with this method is that it allows for only one "center of activity" (Hodder et al., 1998). More recently the term of Hayne (1949) was replaced by the term "core area" (Hodder et al., 1998).

When the calculation of a home range size is the aim of the research, then is the question about "how many locations are necessary to calculate a robust home range"? This happens especially when time and money constraints are factors in the research project. For this reason, the incremental area analysis was adopted in this study. The incremental area analysis is done by plotting range size versus number of locations (Harris et al., 1990). The asymptote of the resulting graph is unique for every animal. Also is it possible that some animals never reach an asymptote. The meaning of an asymptote is the point where adding more locations would not increase the size of the home range. In other words the home range is then stable.

There are a high number of different methods for home range estimation. A few authors give an overview over the most common home range estimation methods (Millspaugh and Marzluff, 2001, Kenward, 2001, White and Garrott, 1990, Karnohan et al., 2001, Worton, 1987). Because of this high number it is important to choose the best home range estimator for answering the study question. (Horne and Garton, 2009). For this reason the study will give a brief overview about most common home range estimators and gives reasons for using or not using the methods in the study. For the calculation of the home ranges the software Ranges 8 from Anatrack Ltd. was used (Kenward et al., 2008).

2.6.1   Minimum Convex Polygon (MCP)

MCP is one of the simplest and earliest technique of home range estimation (Mohr, 1947). It is constructed by connecting the most outer locations with each other to form a polygon. The most outer locations gets determined when all internal angels do not exceeding 180° (Worton, 1987). The area of the home range gives the calculated area within the polygon. Ranges 8 (Kenward et al., 2008) finds the most southwest location first, as the first corner, then it seeks the least clockwise location. This continues until the most southwest location is reached again and the polygon is closed.

The major advantages of this method is: its simplicity, it is repeatable and therefore, possible to compare between studies; and the home range is easy to calculate with this method (Harris et al., 1990, White and Garrott, 1990). That is the reason why this method is used in this study.

One of the disadvantages of this method is that a high number of locations increase the probability of determining a bigger home range. The reason for this is that the home range estimation is a function of numbers of locations utilized to generate the estimate. One way to overcome this disadvantage is to eliminate "outliers", which are contributing the most to the total area. Accordingly, the home range is calculated with 95% of all locations (White and Garrott, 1990). This was done with the locations collected in the field. They were divided into 95%, 75% and 50% of the locations closest to the "peel" centre. Ranges exclude a proportion of locations furthest away from a chosen peel centre. In our study, the Harmonic Mean (Spencer and Barrett, 1984) peel centre was chosen, because it provides a more robust estimator than an arithmetic mean.

The original MCP method from Mohr (1947) doesn´t allow for the calculation of a "center of activity" or "core area" (Hayne, 1949, Hodder et al., 1998), because the method assumes a uniform distribution of the locations points (White and Garrott, 1990). But other methods like excluding proportions of locations in distance from the peel centre, are an index of the area most used by an animal (Kenward, 1987). Also is it possible to visually assess a core area through plotting the percent of locations against the percent of an area. This shows how many percent of the locations contribute to how much of the total area. This utilization distribution was also calculated for the locations in the study.

In the calculation of the home range size, the error polygon corners (A,B,C,D see Figure 8) were included (Springer, 1979). The reason for this is that the error polygon area has a probability of 90% to include the true location of the animal (White and Garrott, 1990) (see chapter 2.5).

Finally, one other negative feature of the MCP is that it can include areas which are not actually used by the animal. This can happen when the home range of a terrestrial animal is located for example around a lake. In this case the outer most border of the home range can reach over the lake. Including these unused areas can be prevented by certain rules regarding how a "border point" is defined. This happens within the Minimum Concave Polygon method.

2.6.2   Minimum Concave Polygon

This method is quite similar to the Minimum Convex Polygon method. But it can deal with unused areas, which are included in the home range estimation. It allows "border points" with an internal angle of greater than 30° (White and Garrott, 1990). A concave polygon is drawn when the distance to the next location point is under a certain distance (edge restriction).

This distance can be determined in different ways, but the basic method is the range span (i.e. the largest link distance in the range) between any locations (Kenward, 2001). The main difference to the Minimum Convex Polygon method is that it can calculate more than one home range centre (Kenward, 2001).

The edge restriction is the reason why this method was not used in this study. Every different edge restriction gives a different shape to the home range and therefore also a different size. There is no objective way to decide which value of the edge restriction comes closest to reality. For this reason this method was not used in this study.

2.6.3   Ellipse

This method is the simplest probabilistic density technique. It produces bivariate normal probability distribution ellipses (Jennrich and Turner, 1969). The centre of the calculated Ellipse can be the mean location (mean *x* and mean *y* location). The assumptions in this model are that the animals are moving randomly about their home range and their locations points are independently distributed (White and Garrott, 1990). These assumptions can be problematic, because the distribution of animals is in reality often not regularly around the arithmetic centre and therefore this ellipse estimation can include areas never visited or used by the animal (Kenward, 2001). Trials with Ranges (Kenward et al., 2008) showed that the Ellipse method had the most area included in the home range which the birds never visited. This was the reason for not using this method in this study

An advantage of the ellipse technique is that it is not just a function of sample size. The home range ellipse size of 100 data points is expected to be the same, as the ellipse size of 500 data points (White and Garrott, 1990). Another feature of the ellipse estimator is that an outlier, which is not big enough to influence the placing of the arithmetic mean range centre, can influence greatly the shape and the area of the ellipse. To overcome this problem Kenward (2001) recommends the use of a weighted ellipse estimator like the one used by Samuel and Garton (1985).

2.6.4   Harmonic Mean

This home range estimator was established by Dixon and Chapman (1980) and describes the home range size and the internal structure (Harris et al., 1990). It is based on the harmonic mean of the areal distribution. The "centre of activity" is located in the areas of greatest activity. The area of the home range is developed from a grid of points. The harmonic mean of the distances between the grid node and the location points then allows calculating the area of the home range. Generally, a higher harmonic mean, gives a lower probability of occurrence of the animal. (White and Garrott, 1990, Dixon and Chapman, 1980)

An advantage of this method is that it allows more than one "centre of activity". This makes it possible distinguish between different spatial uses of the animal. This feature was what was required in this study. One of the problems of this estimator occurs when the grid nod and the location point are located in the same place. A solution for this problem would be to shift the grid nod to an small extend, so that all distances are positive (White and Garrott, 1990).

Kenward (2001) has a different solution to this problem. This author recommends that the distances between grid nod and location point, should be not smaller than the tracking resolution (accuracy). A second problem of this estimator is that the result is unique for the grid and the number of grid nods. Different grids produce different results (see below).

A Ranges 8 calculates in tracking resolution units, which have to be defined beforehand. The adjustments of Ranges 8 for Harmonic Mean calculations were all set to default. This means:

- Contours were based on the mean and the variance for the distribution of density indices. They were including 95% (default is in Ranges 99%) of all locations. This approach is most stable to estimate home ranges (Kenward et al., 2008). Also were the 75% and 50% of the locations drawn to estimate the core area and to eliminate outliers.
- The interval between matrix intersections, matrix was set to 150x150 cells and is no more than the minimum distance (tracking resolution) between locations. In Ranges 8 this option is called "Unmodified Locations Centering" This is the more robust treatment of locations (Kenward, 2001).
- The matrix is set on rescaling. This means that contours tend to extend beyond the outermost location and therefore outside the matrix. To prevent this Ranges 8 sets the locations in the central 70% of the matrix. If still the locations are outside the matrix, Ranges will rescale the matrix in 5% steps until it fits again.

Another reason for using Harmonic Mean instead of Kernel techniques (see below), was that the Harmonic Mean gives greater precision than kernels with nominal (fixed) smoothing (Robertson et al., 1998). Also, there is big variation between the different types of Kernels (Powell, 2000) and this makes it difficult to objectively assess which home range is the closest to reality.

2.6.5   Kernel Estimate

This home range estimator is similar but more complex than the harmonic mean estimator and appears to represent the internal structure of the home range (Harris et al., 1990). The kernel home range estimator was introduced by Worton (1989). The kernel method creates contours of intensity of utilization (utilization distribution) by calculating the mean influence of the animal's location at grid points. Mainly there are two types of the Kernel estimator available: fixed kernel (with a fixed smoothing parameter *h*) and adaptive kernel (smoothing parameter *h* is variable) (Worton, 1989). This smoothing parameter *h,* also called "band-width" or "window-width" (Powell, 2000), strongly influences the estimated home range area (Harris et al., 1990, Kenward, 2001). On the other hand it is not really influenced by the grid size, compared to the harmonic mean method, which is strongly affected by grid size (Kenward, 2001).

2.7   Bird movement

After all homing data and triangulation data were collected the calculation of the bird movement was done. For this purpose was it necessary to sort all remaining locations by date and time. Date and time were always additionally recorded with the locations.

The calculation of the movement was done with help of Microsoft Excel 2007 software. This software allows you to sort the data and to calculate the movement based on the equation of White and Garrot (1990) (see Figure 10).

$$d_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

Figure 10. Equation for movement calculation. Coordinates *x* and *y* are the locations. *d* stands for distance (White and Garrot, 1990)

Beside the distance between two consecutive locations, also included were - for each bird - the total distances travelled, travel distance per whole night, the total distance divided by the days of the study period and the mean distance of all calculated distances determined.

2.8   Bird Activity

The transmitter which the birds had attached to their legs are called "Egg Timer" from Wildtech Ltd. (Wildtech New Zealand Ltd., 2007). Those "Egg Timer" transmitters are designed to signal the start and end of the incubating period. The weight of an adult transmitter is about 23 grams (Keye, 2008).

The "Egg Timer" transmitter also has an output of 15 different sets of information. This includes the activity data which were collected in this study. The transmitter can store the activity data for up to one week ready for collection. The data is transmitted by a beep sequence of about 10mins duration and once every 15 minutes. This beep sequence is divided into 15 different output blocks (see Table 3).

The monitoring of the activity done for the subadult and adult birds was the only parameter which was also monitored for the adults. This was done by the author or by the Department of Conservation field staff. The adult GSK were known to be present close to the study area:

- Tom = Male, Channel 45
- Kat = Female, Partner of Tom, Channel 35
- Neil = Male, Channel 25
- Paddy = Male, Channel 11

Table 3. Output information of the "Egg Timer" transmitter (Wildtech New Zealand Ltd., 2007)

Beep sequence output blocks		Standard pulsing (pulses per minute)
1. Days since change of state	9. Activity 6 days ago	30 ppm = not incubating
2. Activity yesterday	10. Activity 7 days ago	48 ppm = incubating
3. Mean activity	11. Fidget sum yesterday	80 ppm = mortality
4. Twitch counter	12. Fidget sum 2 days ago	
5. Activity 2 days ago	13. Fidget count yesterday	
6. Activity 3 days ago	14. Twitch counter	
7. Activity 4 days ago	15. Pulse counter	
8. Activity 5 days ago		

Beside this beep sequence the transmitter has three different standard pulsing rates. The mortality mode (80ppm) is only active when the transmitter is not moving for 24hr. When this happens either the transmitter is damaged, fallen off or the bird is dead.

The whole beep sequence is structured like:

Standard pulsing (30, 48 or 80ppm)...3sec gap...output block 1 part 1 (e.g. 6 pulses)...3sec gap... output block 1 part 2 (e.g. 9 pulses)...3sec gap...five standard pulses before next output block ...3sec gap...next output block part 1...etc.

The end of the beep sequences can look like this:

Standard pulsing...|6,9|8,2|6,4|2,4|8,9|8,9|7,4|8,4|6,4|6,4|5,11|6,7|6,6|2,4|2,2|...

...Standard pulsing

Each output block is separated in two parts for example in 6 pulses and 9 pulses. To be able to read the information it is necessary to reduce each number (6 and 9 pulses) by two. This gives in this output block 4 and 7. Put the two letters together then it gives the number 47 and the result of this output block. In the output blocks 2, 3, 5-10 it is needed to multiply the number by 10 (47*10 = 470min), this gives the activity in minutes. In the other output blocks multiplying by 10 is not necessary.

2.9   Weight development of the birds

Finally, the weight data is based on unpublished data from M.Wylie (unpublished-c). The workers of Willowbank Wildlife Center weighed the five birds from hatching to release into Riccarton Bush. After that the workers of the DOC weighed the subadults in the Riccarton Bush and in the wild.

In the first month of their life the birds get weighed nearly every day. After this time they were weighed between once and twice a month.

To handle these birds people were needed who could follow certain guidelines. Those guidelines were developed by Robertson and Colbourne (2003) and give advice regarding how to handle and measure a kiwi.

3 Results

3.1 Accuracy

The determination of the bird locations was unfortunately not always possible at the planned time due to a weak or no signal. Therefore the interval between two locations was not always one hour as planned in the study design. But in total it was possible to collect locations with triangulation between the 16.12.2009 and 6.2.2010. The number of locations had a range from 33-50 locations for each bird (see Table 5).

To assess the accuracy of the locations, the transmitter test and therefore calculation of the error polygon area could be done with Excel 2007[TM] software from Microsoft (see chapter 2.5). In the transmitter test (see Table 4) the difference between the two antennas (0.54°) and persons (0.62°) is small when calculated in degrees but bigger when expressed in meters. That is the same between the two people. The biggest effect shows the distance to the transmitter. Less distance to the transmitter gives you more variance and a greater error margin.

Table 4. Results of the Transmitter test. Also were the different persons, landscapes and antennas tested.

	X (m)	Y (m)	Degree
General Mean	147.77 (n=51)	174.81 (n=51)	6.01 (n=106)
Mean Antenna 1	194.37 (n=20)	270.26 (n=20)	4.25 (n=40)
Mean Antenna 2	147.93 (n=20)	107.07 (n=20)	4.79 (n=40)
Mean Person 1	103.70 (n=20)	111.62 (n=20)	4.21 (n=40)
Mean Person 2	238.60 (n=20)	265.72 (n=20)	4.83 (n=40)
Mean Forest	54.13 (n=6)	39.55 (n=6)	11.71 (n=12)
Mean Grass land	73.06 (n=5)	226.24 (n=5)	10.22 (n=10)
Mean Transmitter far	8.78 (n=20)	28.17 (n=20)	4.03 (n=40)
Mean Transmitter close	333.54 (n=20)	349.16 (n=20)	5.01 (n=40)
Standard deviation all	245.57 (n=51)	282.52 (n=51)	4.73 (n=106)

The standard deviation of all degrees (s=4.73) was used to calculate the error polygon area (bearing ±1.96*s). The distribution of this error polygon area for each location error is shown in Figure 11.
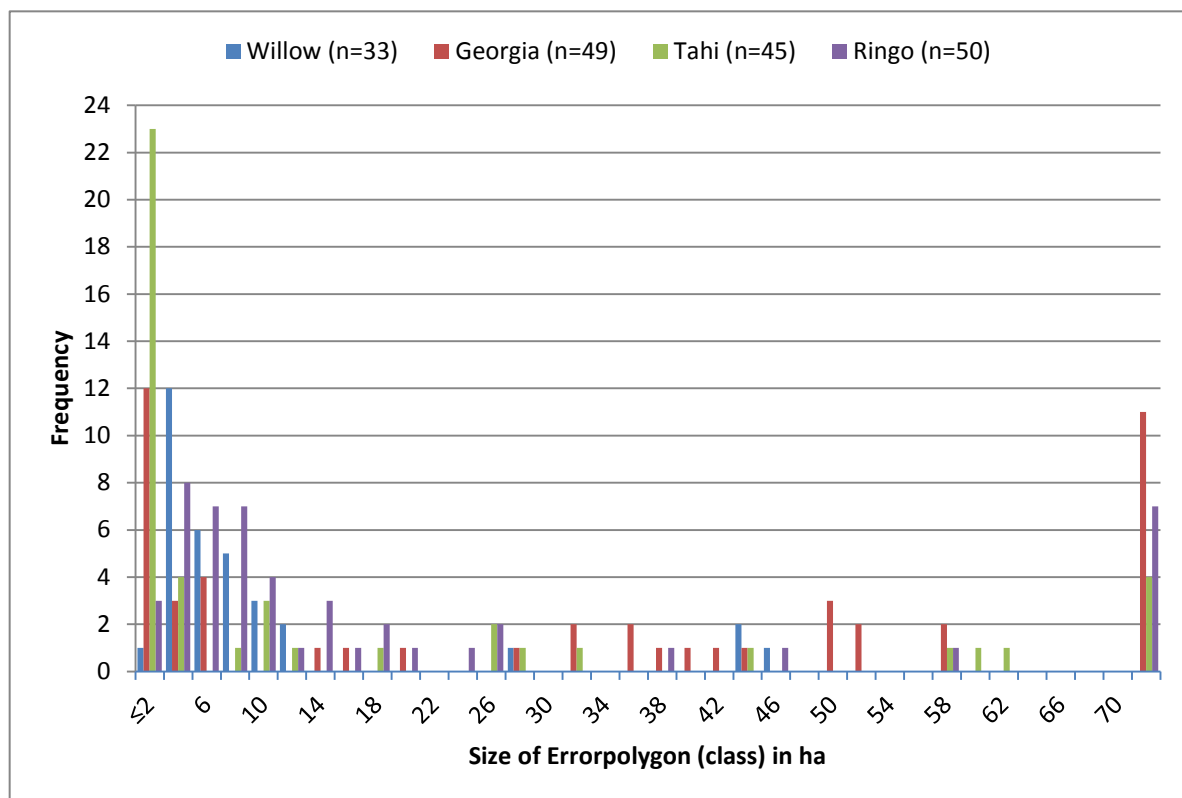
Figure 11. Frequency of the error polygon size

The histogram classes were set to 2ha because that gives a finer distribution. Figure 11 shows that the majority of the error polygons are under 10ha of size. Because of this reason 10ha was chosen as threshold size for the error polygon. The error polygons over this threshold were excluded from further use in this study. This method should help to attain more accurate positions of the birds. In the end between 58-81% of location fixes were used for home range calculation (see Table 5).

Table 5. Duration of the collection and number of locations, collected by triangulation in the field. The number of locations used for home range calculation, is after the correction with errorpolygon method. The low number of Rua can be explained by the death of the bird.

Name	Study period	Number of locations collected in the field	Number of locations used for home range calcualtion
Ringo	17.12.2009 - 3.2.2010	50	29 (58%)
Georgia	17.12.2009 - 29.1.2010	49	19 (39%)
Tahi	17.12.2009 - 28.1.2010	45	31 (69%)
Rua	19.1.2010 - 29.1.2010	2	-
Willow	19.1.2010 - 6.2.2010	33	27 (81%)

3.1   Homing

In addition to the location fixes determined by triangulation, positions of the bird's day shelter were used for home range calculation. The following data was collected by the author and also includes unpublished data from M. Wylie (Wylie, unpublished-b).
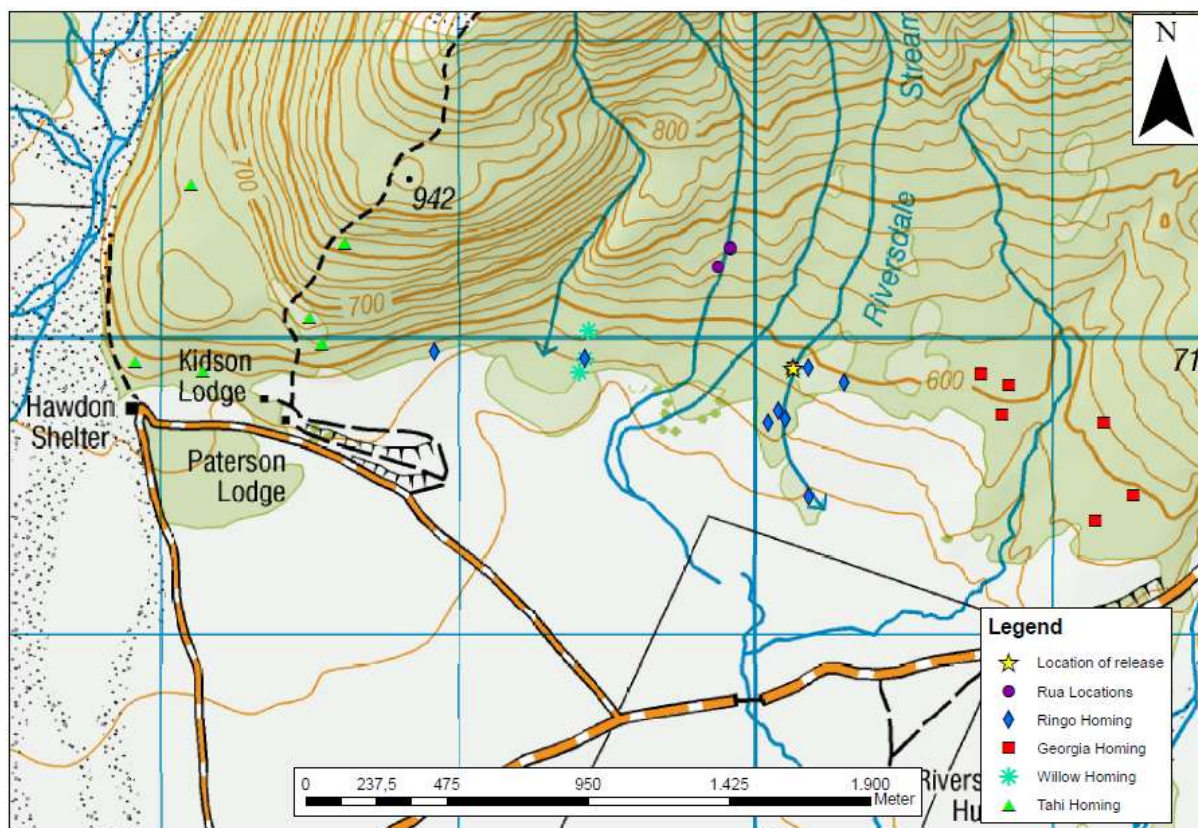
Figure 12. Locations of the day shelter of all birds.

Figure 12 gives an overview of all day shelter locations of the birds in the study area. Mostly the different day shelter locations were close to the forest edge and therefore close to the open grassland. Only Rua and Thai had a day shelter at an altitude between 650m and 800m a.s.l. The reason for Rua's low number of shelters is due to her death 7 days after release. One location of Rua in this map is also the position of death.

Ringo
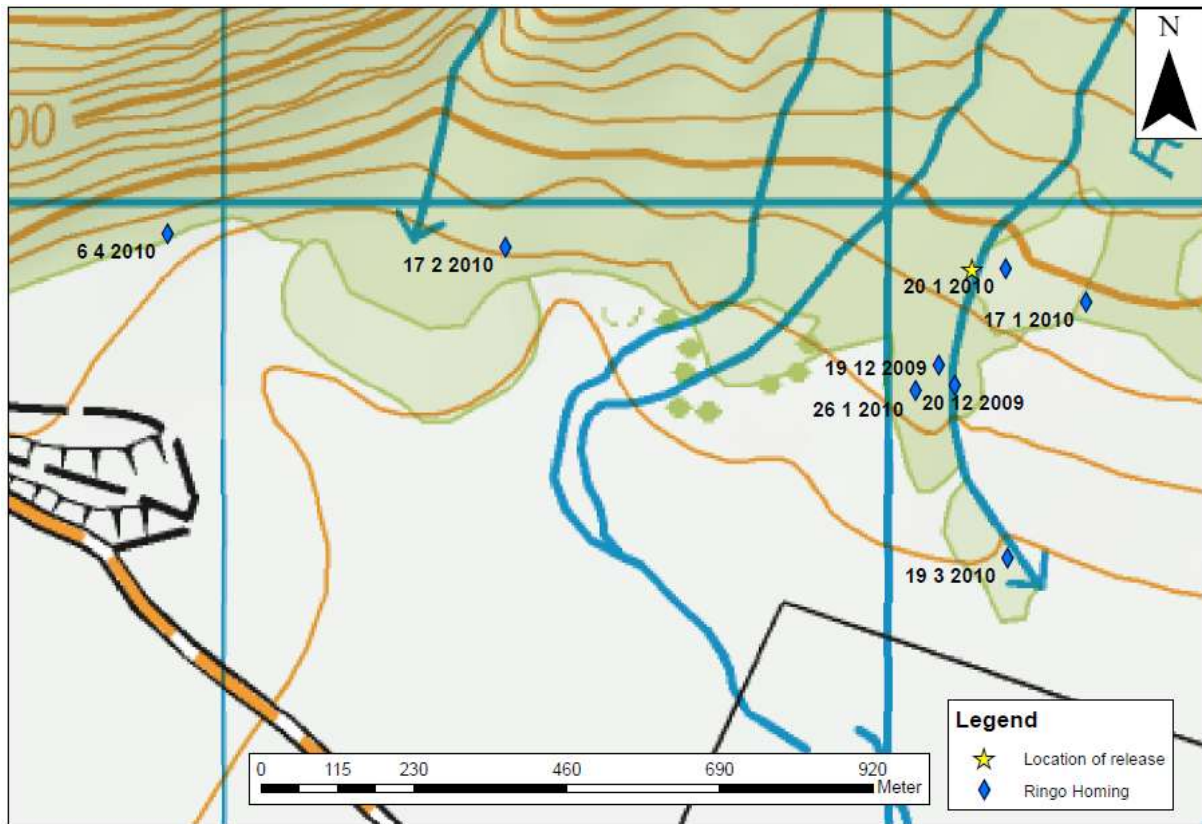
Figure 13. Locations of Ringo day shelters.

The homing data of Ringo shows that he stayed close to the release area. All day shelters are close to the forest edge and under an altitude of 600m but, all were located in the forest. On the 17th of February, 2010 Ringo shared the same day shelter with Willow. The last homing location on the 6th of April, 2010 was the most distant location compared to the rest of the locations (see Figure 13).

Tahi
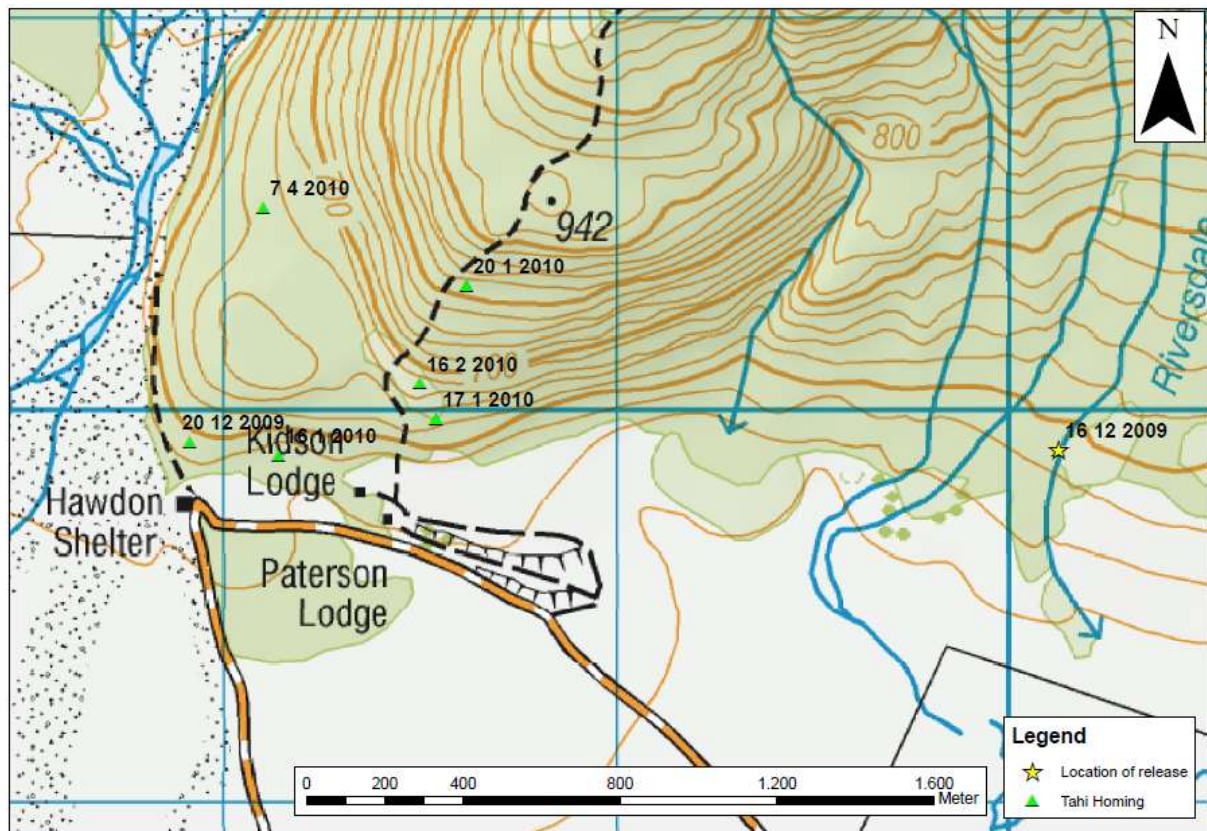
Figure 14. Locations of Tahi day shelters.

The day shelters of Tahi were located in the area of the Hawdon Shelter and Campsite of the Department of Conservation. Three day shelters were close to the track, which leads to the Woolshed Hill. Two other day shelters were close to the Hawdon Shelter. Also, here all day shelters were located in the forest.

Willow
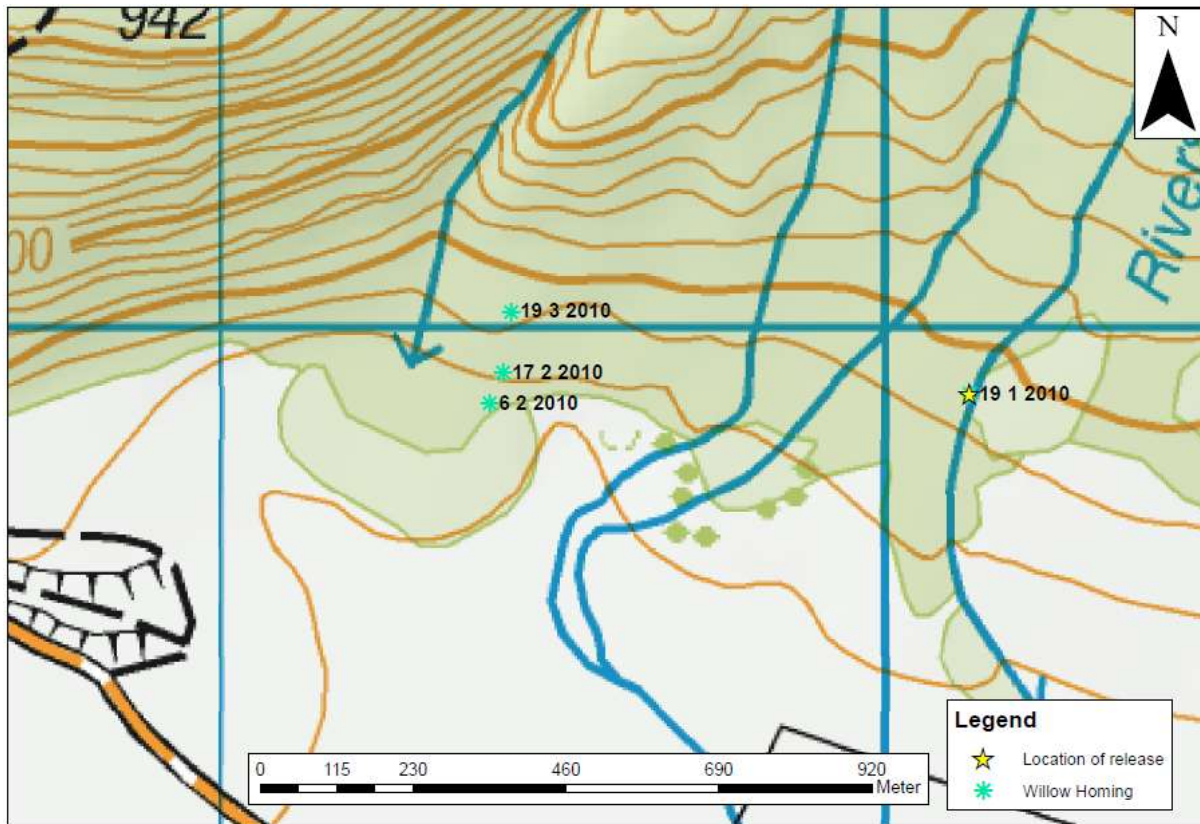
Figure 15. Locations of Willow day shelters.

The day shelters of Willow were between those of Tahi and Ringo. Also, close to the forest edge. Willow shared the burrow with Ringo on the 17th of February, 2010. All locations of Willow were close to each other, when compared to those of Ringo or Tahi.

Georgia
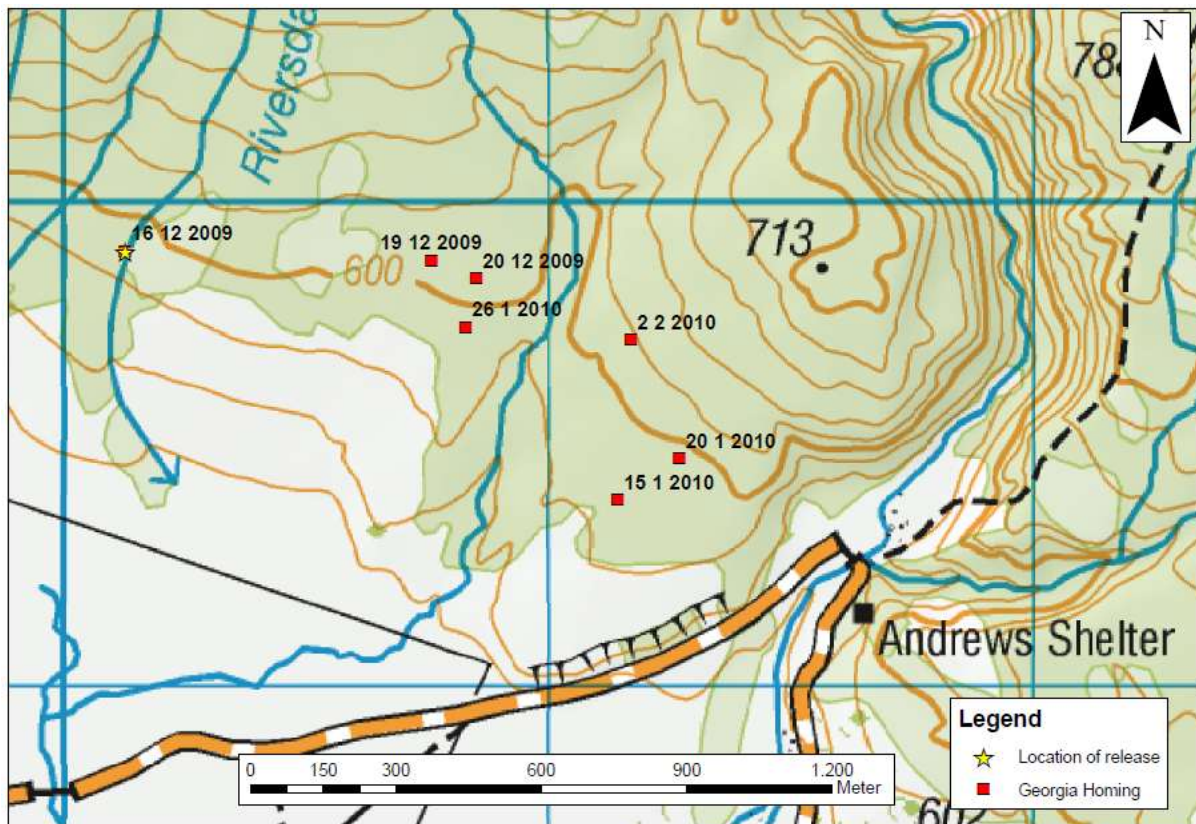
Figure 16. Locations of Georgia day shelters.

The day shelters of Georgia were located east of the release point. The shelters were closer to the Andrews Shelter and campsite of the Department of Conservation than to the Hawdon Shelter, but far enough to probably not be disturbed by the presence of humans.

3.2   Home Range

The calculation of the home range was possible for MCP and Harmonic Mean. Both methods were calculated with 95%, 75% and 50% of all locations. The locations include the homing locations with inaccurate fixes indentified by the error polygon method and removed.

Table 6. Size of the home ranges and the number of locations used for it. The number of locations for MCP home range consists out of the locations corrected by the error polygon method, the error polygon corners of the corrected locations and the homing locations. The location numbers for the harmonic mean home range consist out of the locations corrected by the error polygon method and the homing locations.

Name	Study period	Number of locations for MCP	Number of locations for Harmonic Mean	Size (ha) of MCP homerange			Size (ha) of Harmonic Mean homerange		
				95%	75%	50%	95%	75%	50%
Ringo	17.12.09-3.2.10	154	38	68.96	17.85	5.74	122.49	43.70	19.69
Georgia	17.12.09-29.1.10	96	25	77.15	68.30	11.33	60.01	31.87	13.29
Tahi	17.12.09-28.1.10	145	33	61.33	8.08	2.84	84.82	32.14	14.29
Rua	19.1.10-29.1.10	-	-	-	-	-	-	-	-
Willow	19.1.10-6.2.10	140	31	22.91	8.11	3.71	63.76	23.70	11.07

3.2.1   Minimum Convex Polygon
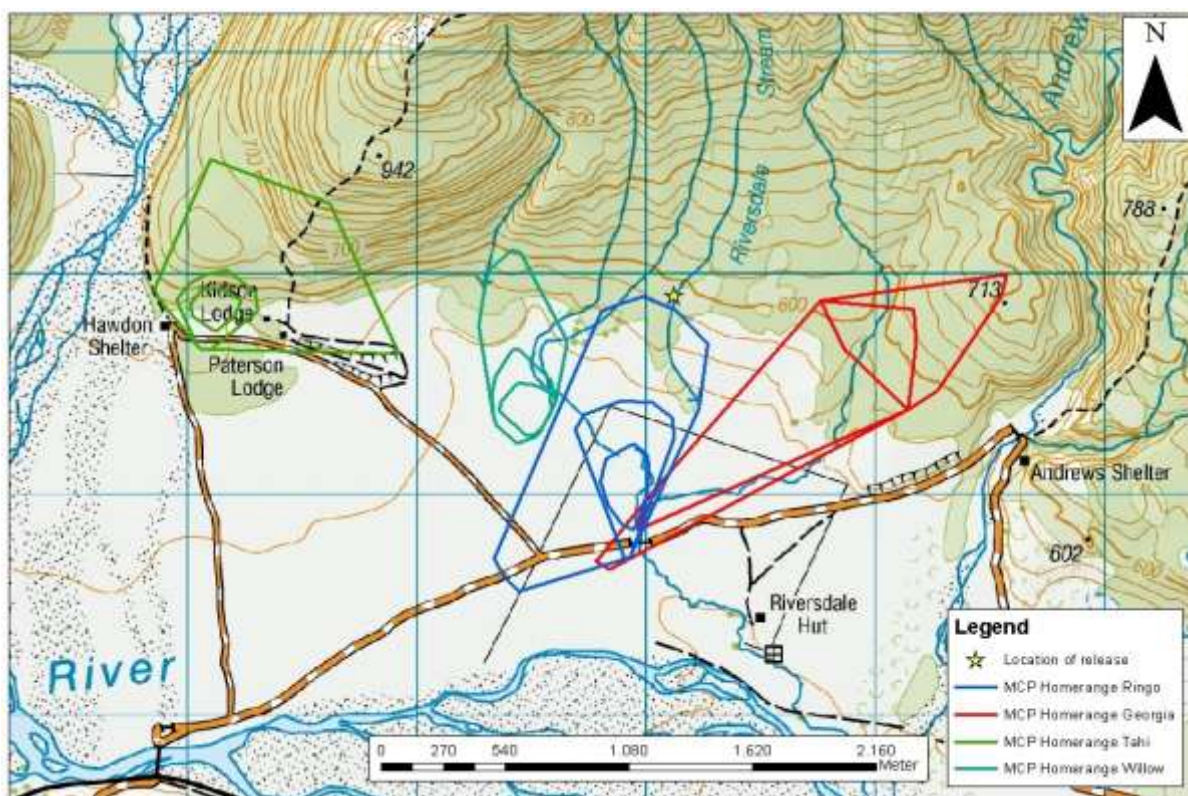
Figure 17. All MCP 95%, 75% and 50% (from the outside 95% to 50% at the inside) home ranges of the birds.

Figure 17 shows the distribution of the MCP home ranges of all birds. The home ranges of Ringo, Willow and Georgia are partly over open grassland. The home range of Tahi is mainly in the forest. The area where the home ranges are located is the same as the area of the day shelters. This shows that Ringo stayed close to the release area, Georgia east of it, Tahi west of it and Willow between Tahi and Ringo. The sizes of the home ranges range between 77ha and 22ha. The largest home range is from Georgia. The smallest is from Willow. The home ranges of Georgia and Ringo overlap by 11%.

The incremental analysis of the MCP locations shows that the numbers of locations are sufficient for building a statistical stable home range for all the birds (see Figure 18). The home range of Georgia reaches their asymptote at 100% with 78 locations, Willow with 33 locations, Tahi with 119 locations and Ringo with 125 locations. All home ranges have more locations than necessary for stability.
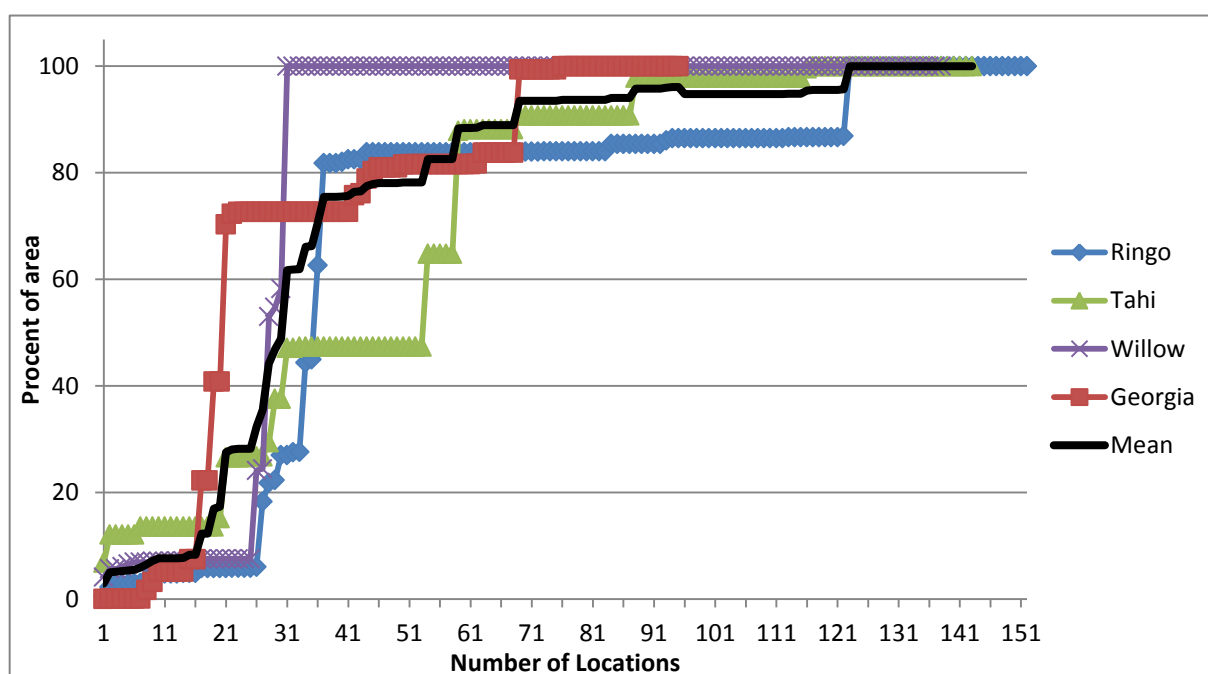
Figure 18. Incremental analysis of all birds. Minimum convex polygon with Errorpolygon points (100% MCP, Kernel peel center)

The utilization analysis shows that by Ringo, Tahi and Willow 95% of the locations are between 22% and 37% of the total area. This indicates the building of a core in those home ranges. Also this makes it possible to exclude the most outlying locations. In comparison Georgia has 70% of the locations in 80% of the area. The more uniform distribution of the locations can be an explanation for this difference in the utilization of Georgia.
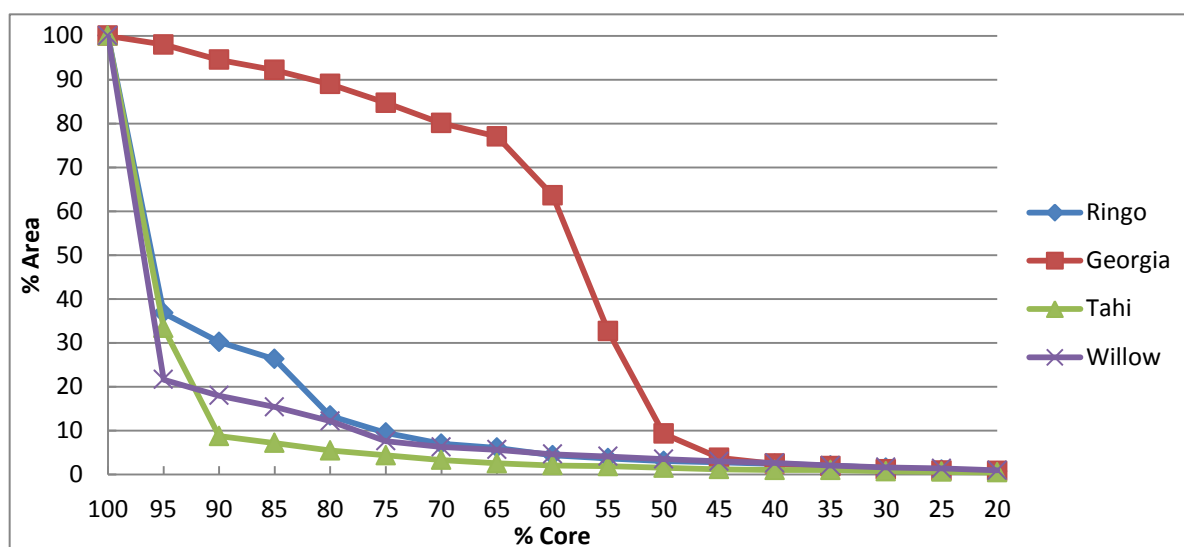
Figure 19. Utilisation distribution of all birds. MCP including error polygon points (100% MCP, Kernel peel center)

Ringo
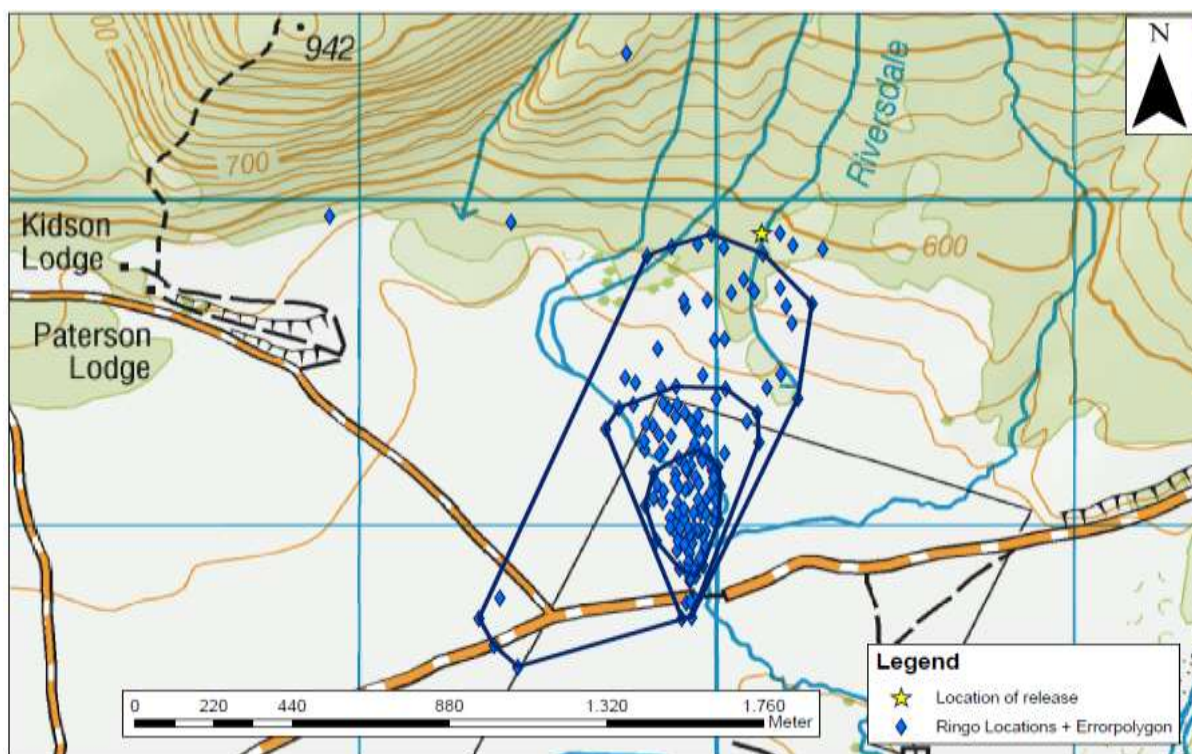
Figure 20. 95%, 75% and 50% MCP home range of Ringo with locations and errorpolygon corners

Ringo´s home range is mainly in open grassland. It is close to the release area. The most locations are in the 75% isopleths of the home range estimation. There is also the highest density of the locations. The home range of Ringo is divided into three different isopleths (95% of all locations the outermost line and 50% the innermost line).

Tahi
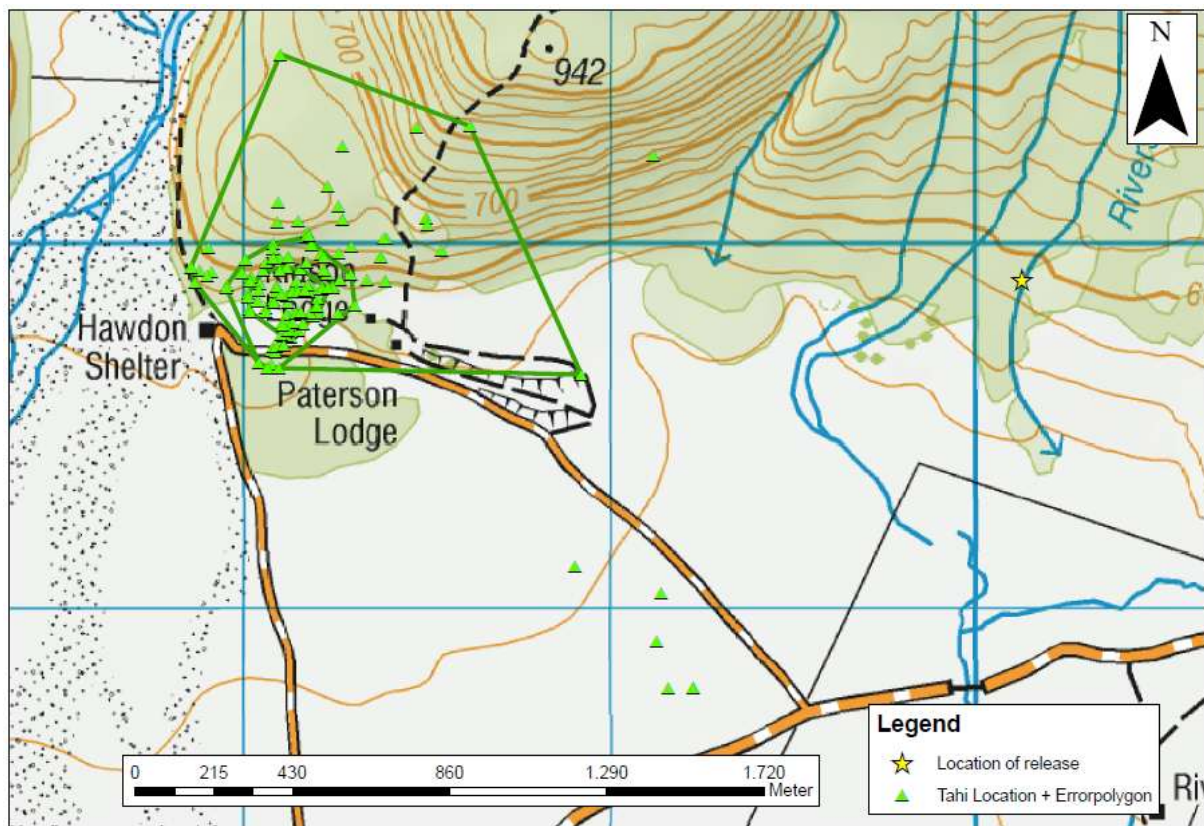
Figure 21. MCP home range of Tahi with locations and errorpolygon corners

The MCP home range of Tahi is close to the Hawdon Shelter and therefore near to the Hawdon River. Locations have the highest density within the 75% isopleths and in a distance to the shelter of approximately 400m. Compared to the locations of Ringo the locations of Tahi are mainly in the forest and in an altitude range between 600m and 800m.

Willow
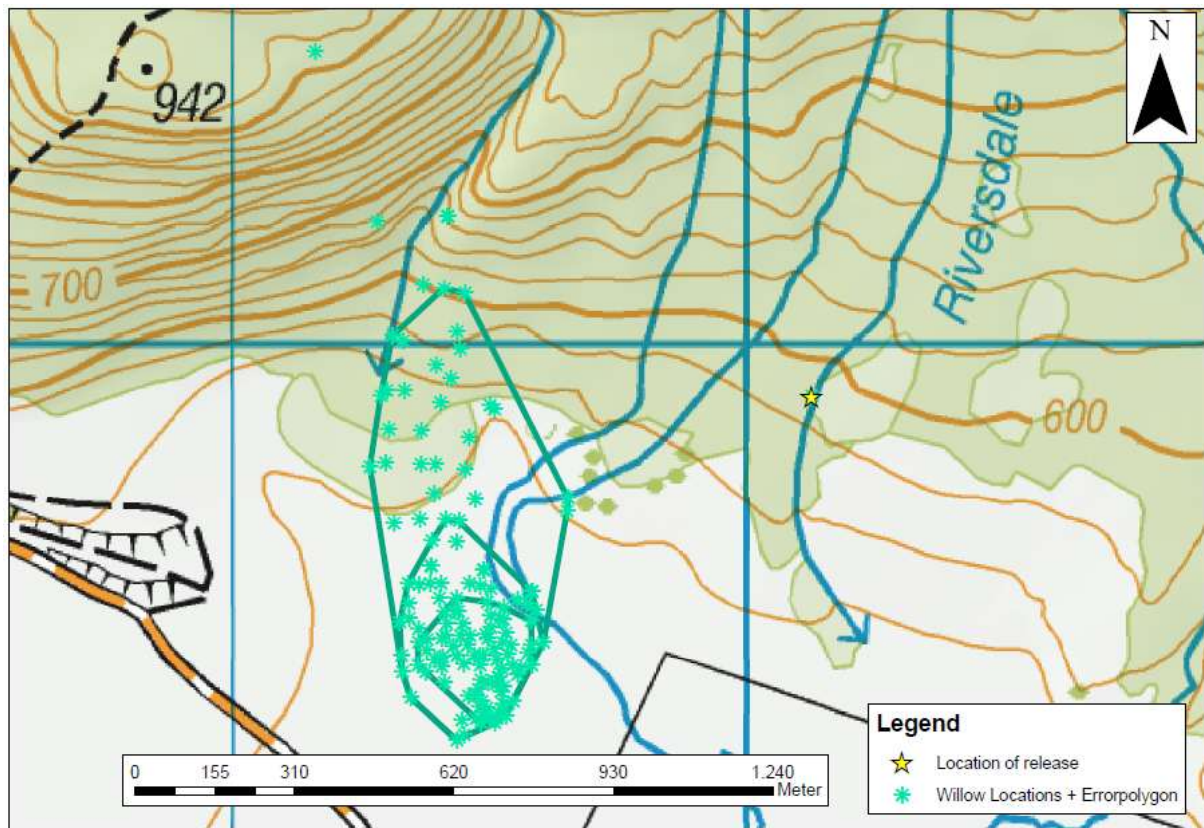
Figure 22. MCP home range of Willow with locations and errorpolygon corners

The home range of Willow is the smallest of all the birds (22.91ha). This is supported by the fact that the locations are densely distributed. The majority of the locations are in the open grassland. The home range is located between the home range of Tahi and Ringo.

Georgia
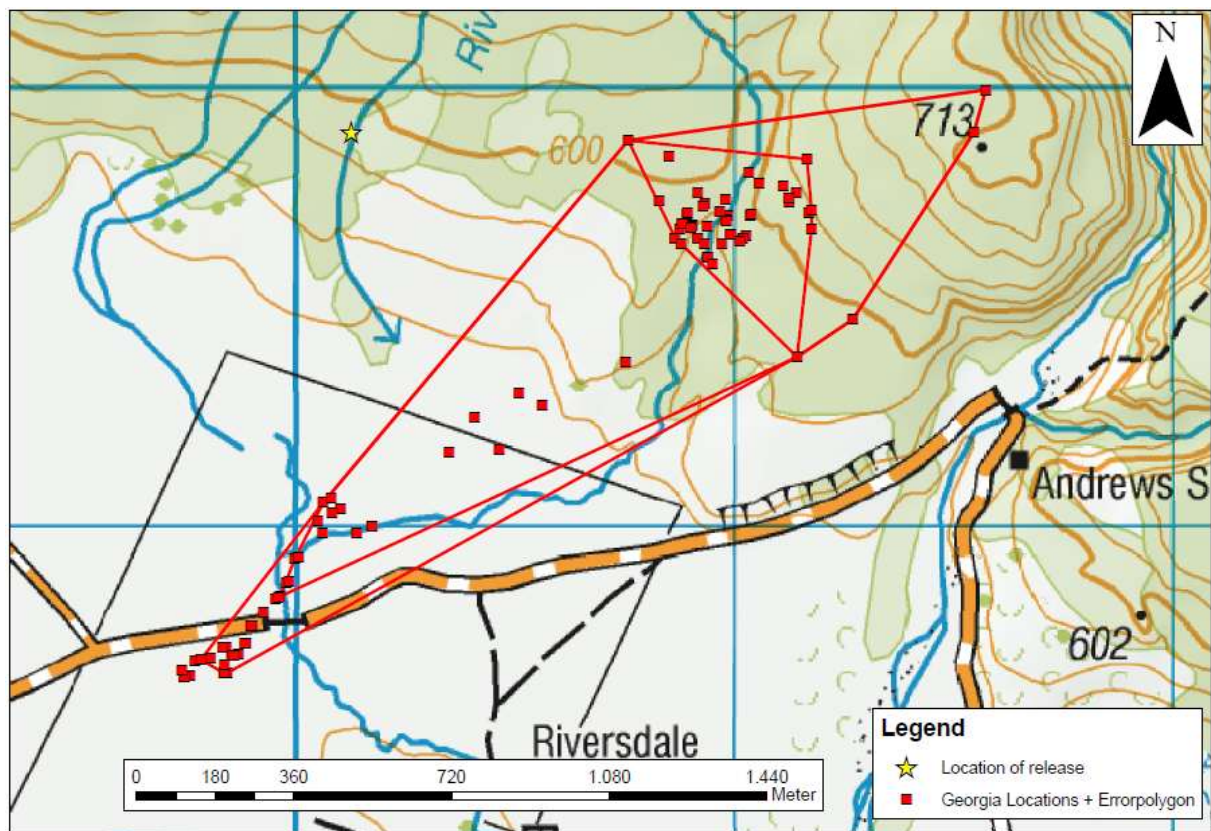
Figure 23. MCP home range of Georgia with locations and errorpolygon corners

The home range of Georgia is the largest of all the other birds and close to the Andrews Shelter. All locations are widely distributed and concentrated in two different areas. The home range is located in the forest and in the open grassland. The difference in size between the 95% and 75% isopleths is around 9ha.

3.2.2   Harmonic Mean
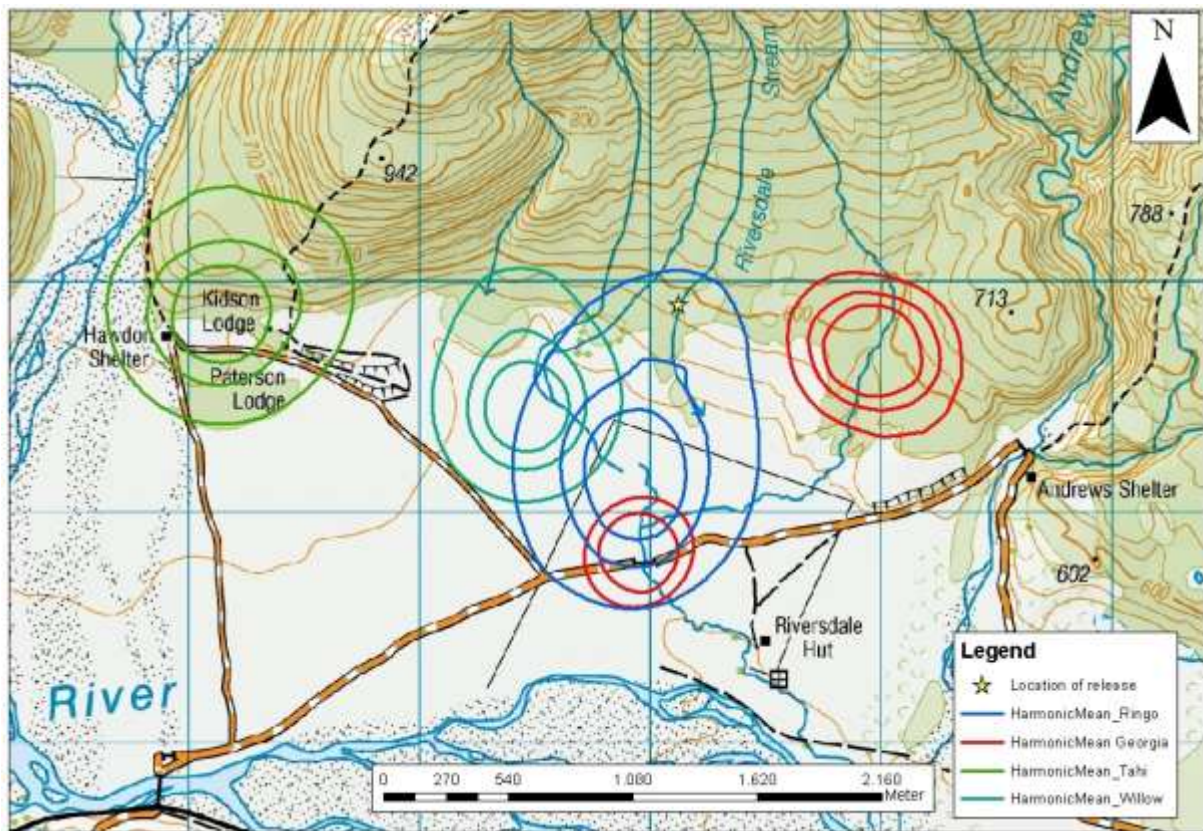
Figure 24. Overview about Harmonic Mean home ranges of all birds.

With the Harmonic Mean method was it also possible to calculate the home ranges of all the birds. The sizes of the home ranges of Ringo, Willow and Tahi are bigger than with the MCP determined home ranges. Only the home range of Georgia is smaller with the Harmonic Mean method.

Ringo has the largest home range and Georgia the smallest. The home ranges of Ringo and Willow overlap by 53%. The position of the home ranges is similar to the MCP home ranges. Georgia has two different cores compared to the others who only have one core. The utilization analysis shows uniform distribution of the locations. All birds show similar distribution.
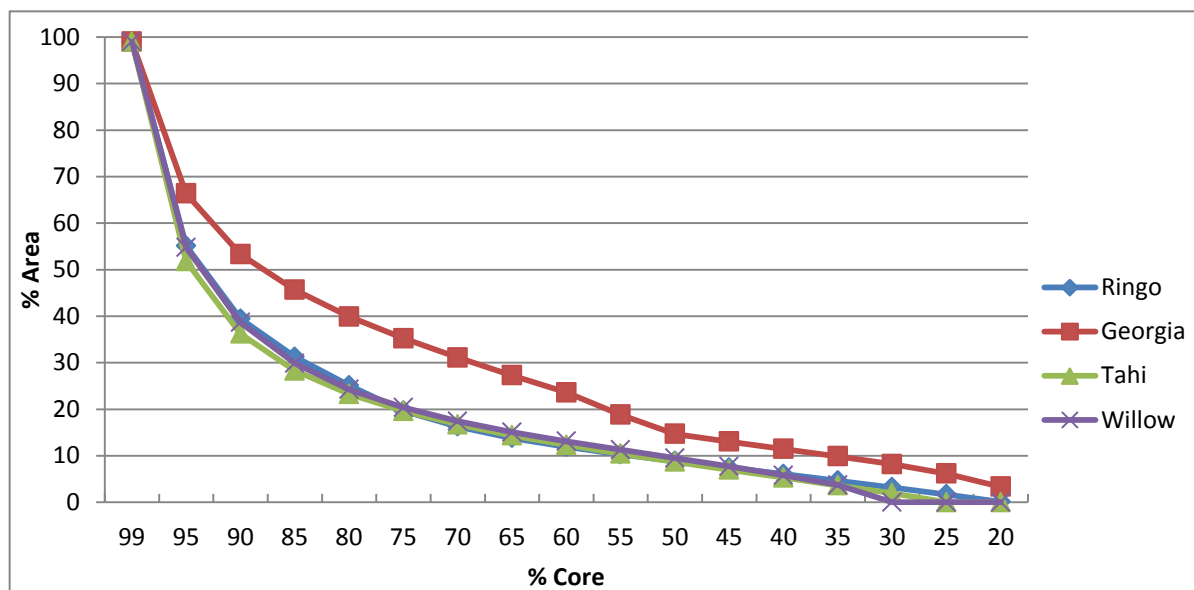
Figure 25. Harmonic Mean Utilization distribution

Ringo
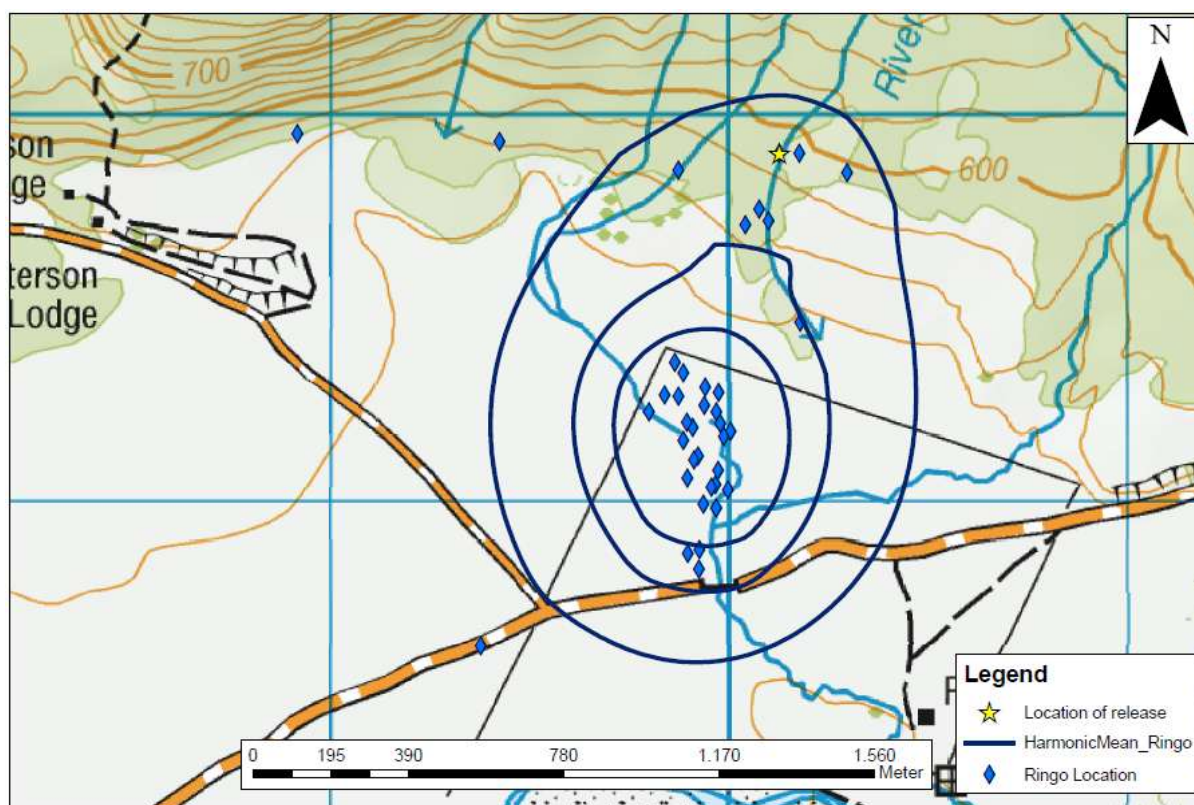
Figure 26. Harmonic Mean home range of Ringo.

The Harmonic Mean home range of Ringo is located at the release point and mainly in open grassland. The most locations are within the 50% isopleths. This indicates the core of the home range.

Tahi
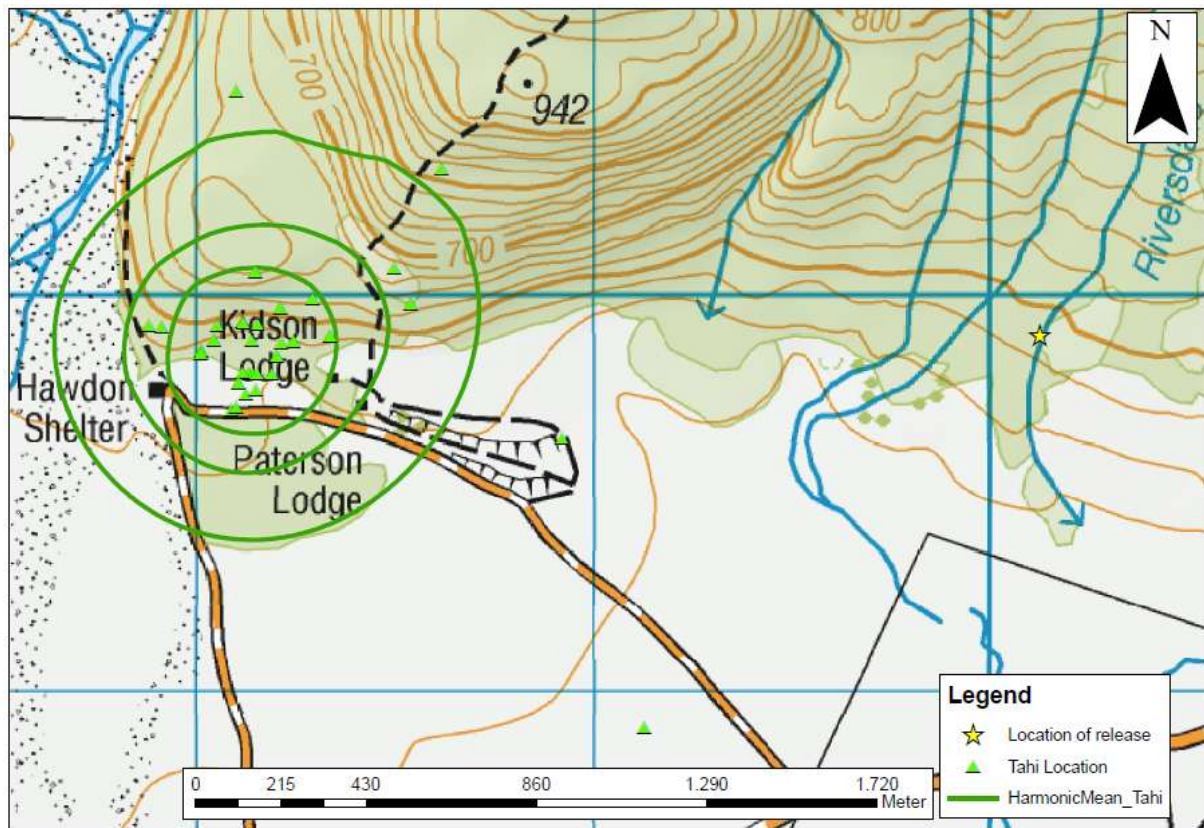
Figure 27. Harmonic Mean home range of Tahi.

The Harmonic Mean home range of Tahi is running partly over the Hawdon Riverbed. Most of the locations are also at Tahi's home range within the 50% isopleths. The shape of this home range is circular.

Willow
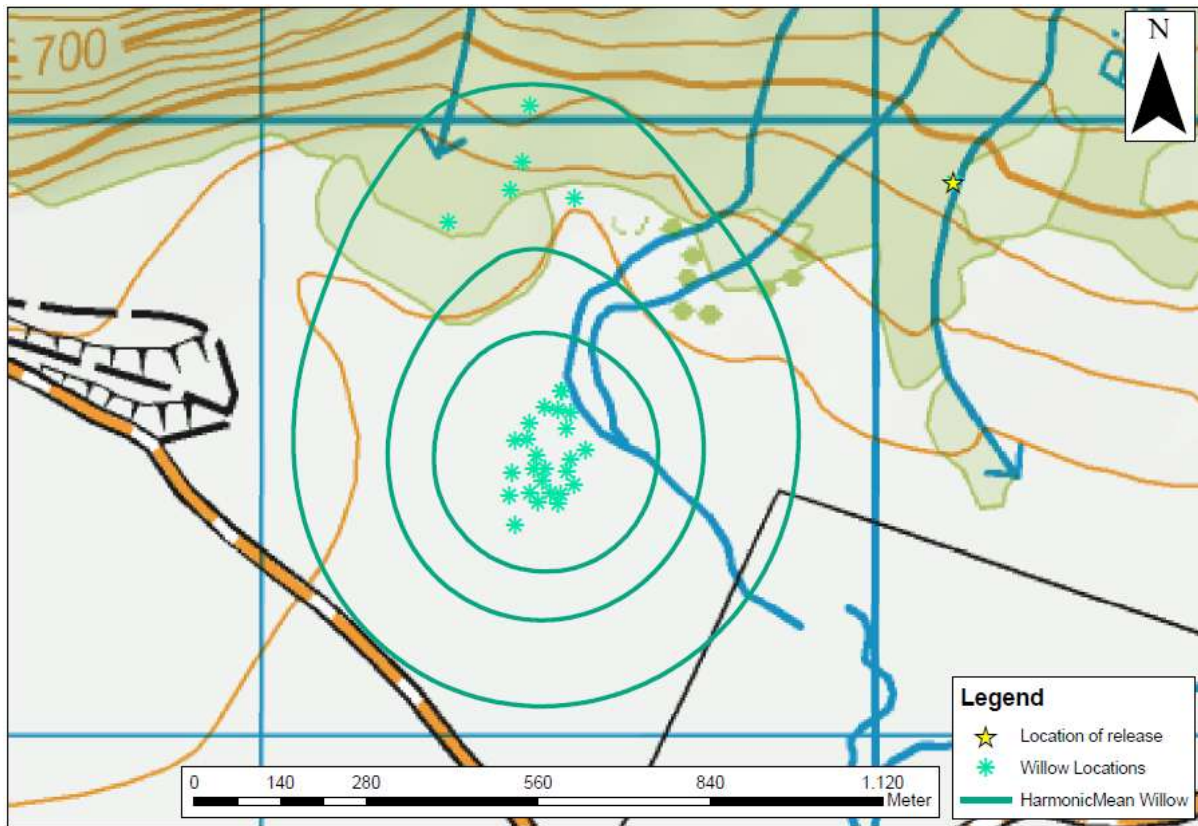
Figure 28. Harmonic Mean home range of Willow.

The Harmonic Mean home range of Willow is mainly located in open grassland. Again most locations are also within the 50% isopleths. The difference in size between the MCP and the Harmonic Mean home range is c. 40ha.

Georgia
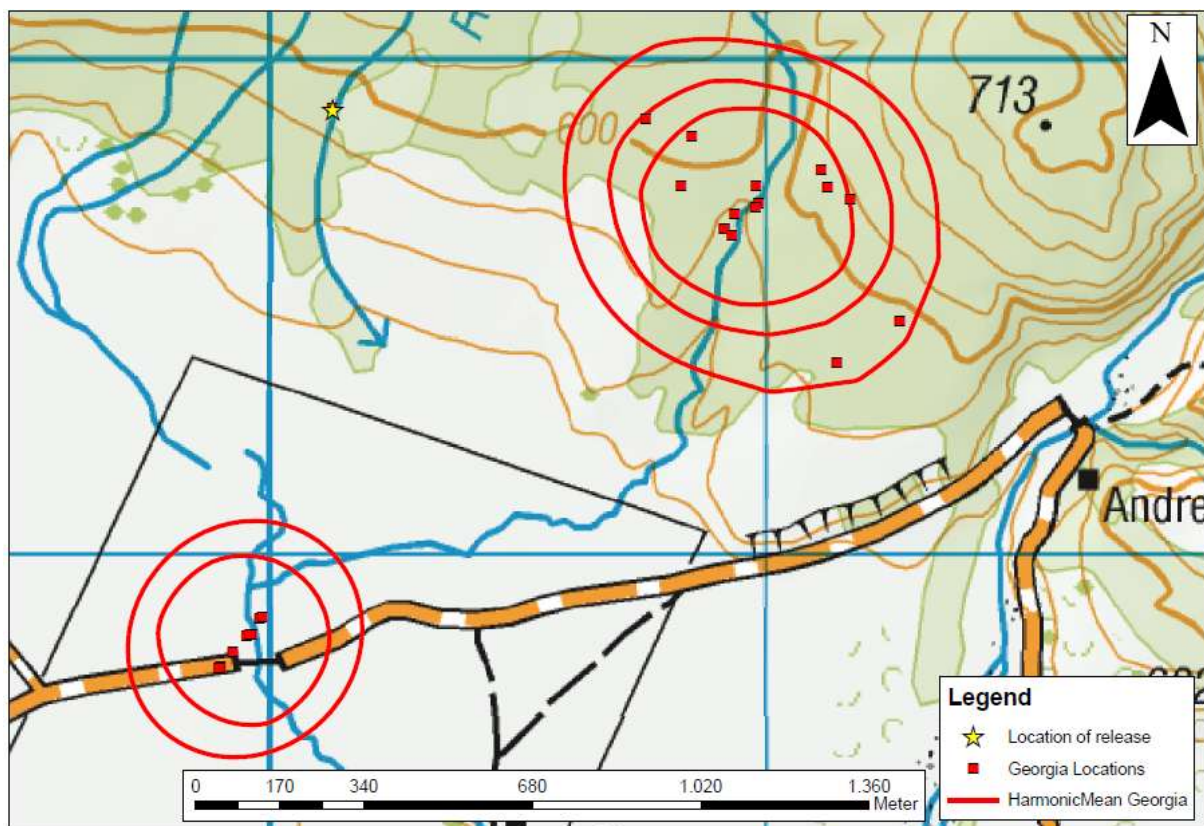
Figure 29. Harmonic Mean home range of Georgia.

Georgia's Harmonic Mean is the only one which shows two cores. One core is located in forest and the other is located in open grassland. Both cores have separate home range estimates with no connection to each other.

3.3   Activity
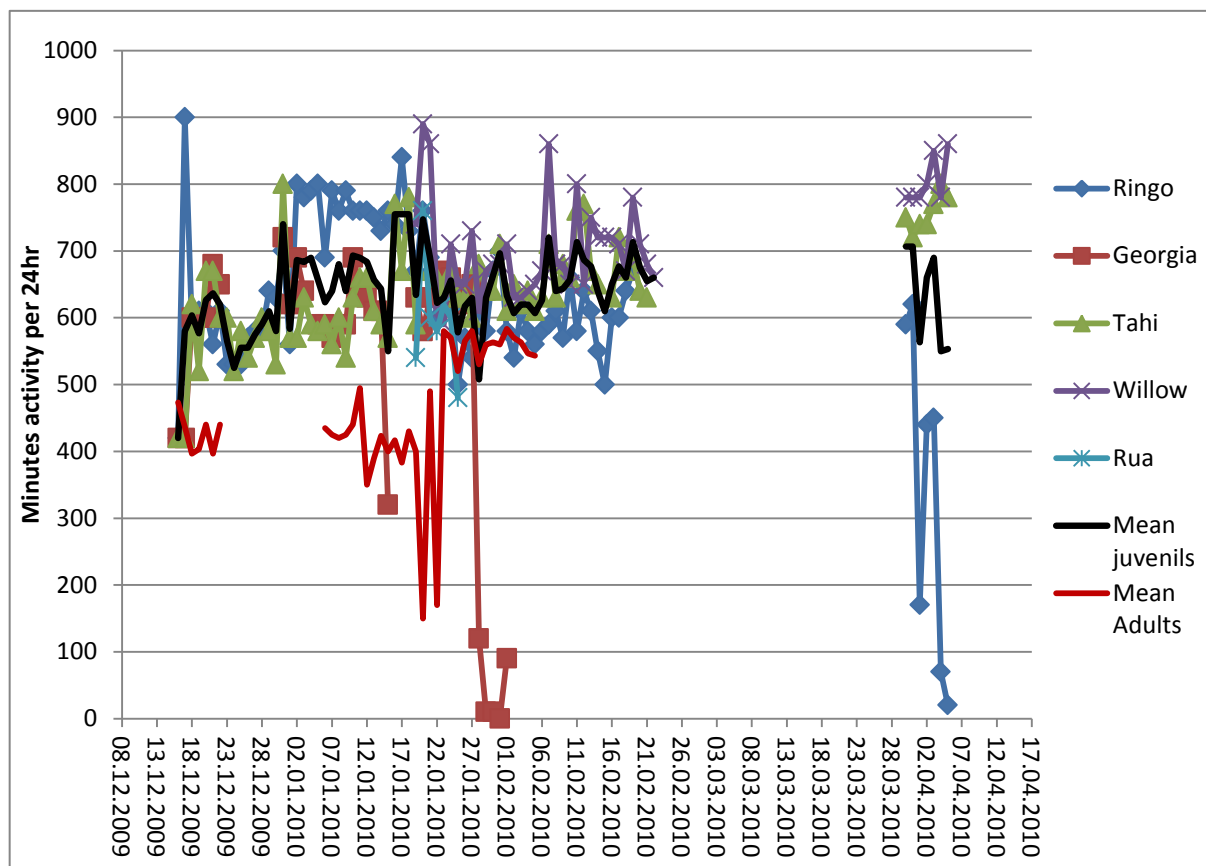
Figure 30. Activity of all subadult and adult GSK since release into the wild. The mean of the adults is lower between the 16.12.2009 and 22.1.2010.

Figure 30 shows the rate of activity of all juvenile and adult birds monitored in the area. The data was collected by the author and by M. Wylie (unpublished-a). The data for the adults have gaps, because it was not always possible to get a signal and therefore was it not possible to complete the activity data. But the existing data indicates that between the 16.12.2009 and the 22.1.2010 a lower mean activity than those of the juveniles. The mean of all the juveniles ranges between 500min/24hr and 750min/24hr.

The decrease in activity by Ringo and Georgia can be explained by the death of both birds. The small increase in activity of Georgia after dropping nearly to zero, can be explained by movement of the body after its death. The decrease in activity before the death of the birds is not included in the calculation of the mean activity.

Table 7. Summary of subadult and adult birds (25, 35, 45) activity

Bird	Mean activity (min/24hr) of all recorded days	Number of recorded days (24hr) activity	Max activity (min/24hr)	Min activity (min/24hr)
Ringo	616.16	73	900	20
Georgia	542.65	34	720	10
Tahi	640.27	73	800	420
Rua	597.14	7	760	480
Willow	715.95	42	890	590
25	596.18	34	720	520
35	428.75	32	620	150
45	349.63	27	570	40

Table 7 gives an overview of the activity of the birds. The variation between the different days is high. Tahi for example had an activity range of 420-800min/24hr. The mean of the subadult birds is between 542 and 715min/24hr. But the mean also depends on the number of recorded days of activity.

Ringo
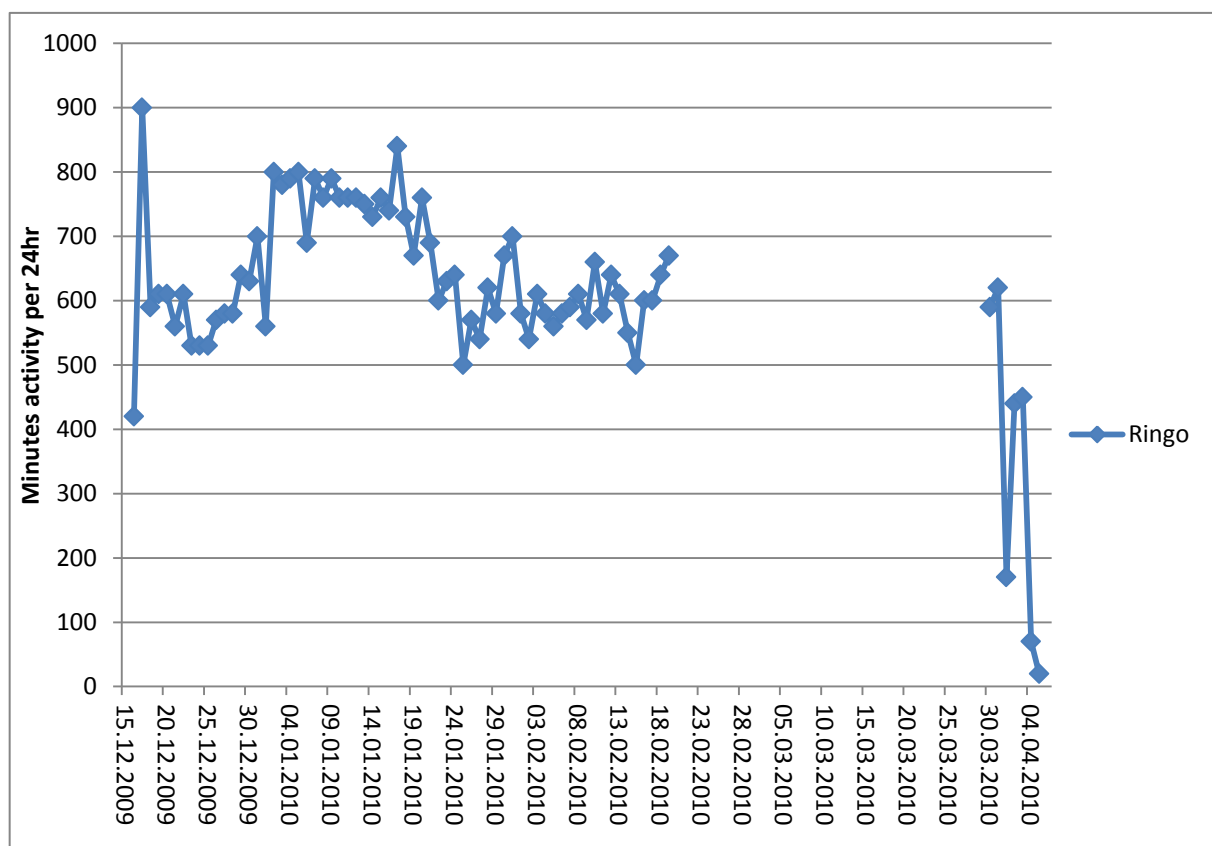
Figure 31. Activity of Ringo (min/24hr)

Ringo's activity shows a strong increase on the second night after the release. It changed from 7h (420min) activity to 15h (900min) activity the following night. This change can be supported by observations made in the field. On the first night after the release the signal of the birds were clear and came from the same direction the whole night. On the second night the signals were much weaker and the quality was not satisfactory. This circumstance for this can be explained by the high activity on this night and therefore, a weak signal caused by the rapid movement of the birds.

After the strong increase in activity the rate of activity decreased to a level between 500min/24hr and 700min/24hr until the 1.1.2010. After this the level of activity increased to a range between 680min/24hr and 840min/24hr until 20.1.2010. On the 21.1.2010 the level was back between 500min/24hr and 700min/24hr. Shortly before the death of Ringo the level of activity stayed at the same level.

Georgia
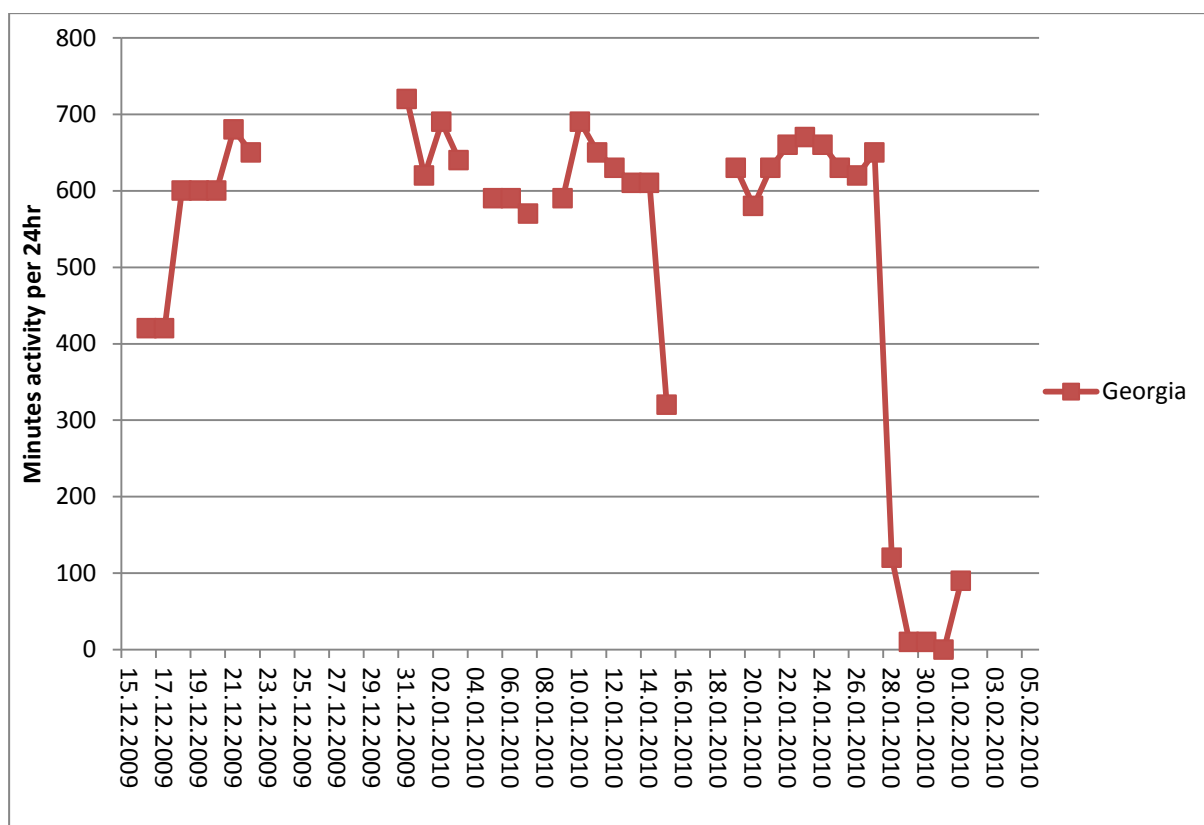
Figure 32. Activity of Georgia (min/24hr)

Georgia's activity also increased on the second night after her release from 420min/24hr to 600min/24hr. The data has some gaps, but it gives some indications that the level of activity stays between 590min/24hr and 720min/24hr. On the 15.1.2010 the activity decreased to 320min/24hr. Because of missing data, it is not possible to see for how long the bird stayed on this low level of activity. After four days the activity was back at 630min/24hr and in the same range as before.

Tahi
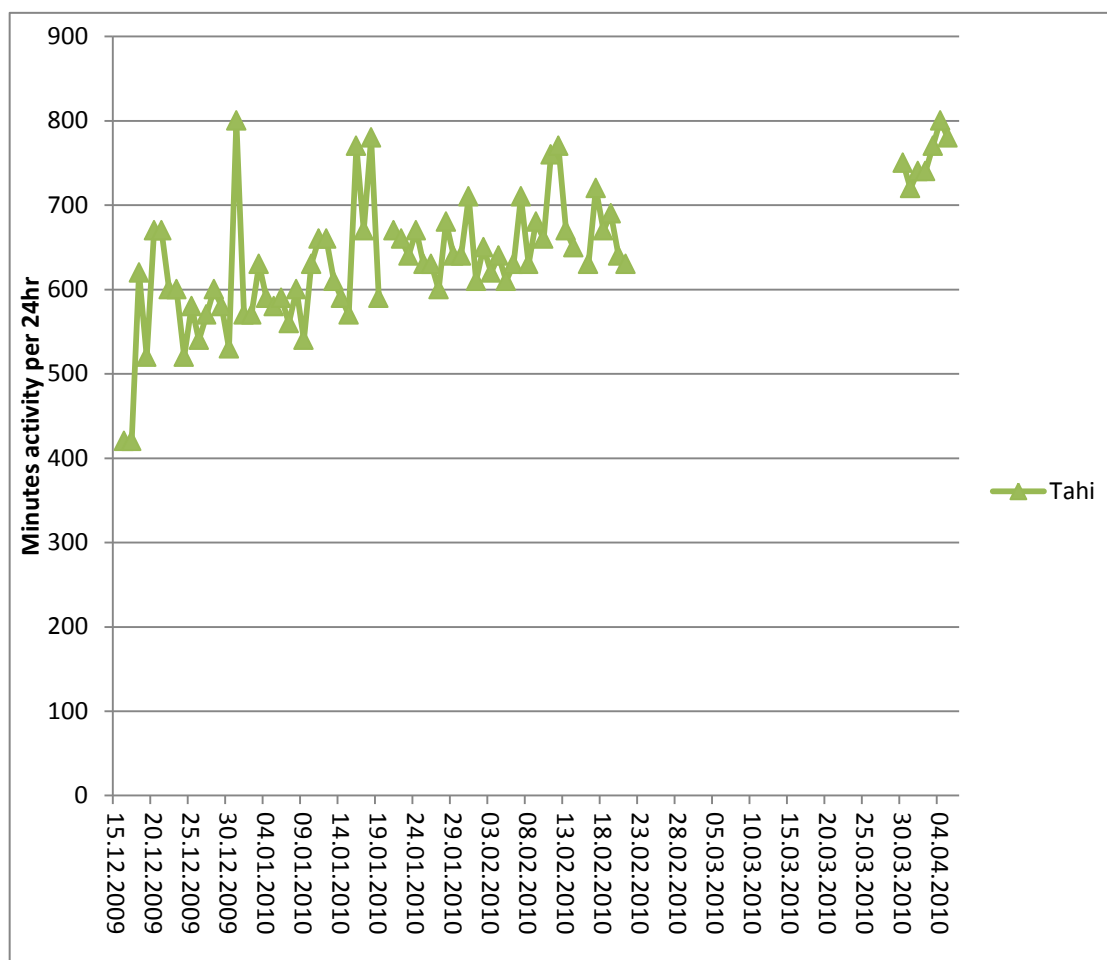
Figure 33. Activity of Tahi (min/24hr).

Ringo and Georgia showed the same behaviour as Thai. On the second night after release the activity of Tahi increased from 420min/24hr to 620min/24hr. The rest of the month saw the activity range between 520min/24hr and 680min/24hr. The biggest increase from 530min/24hr to 800min/24hr happened from the 30.12.2009 to the 31.12.2009. The next big increase was from the 17.1.2010 to the 19.1.2010 from 670min/24hr to 780min/24hr and then back to 590min/24hr. The general trend of the activity of Tahi seems to increase over time.

Willow
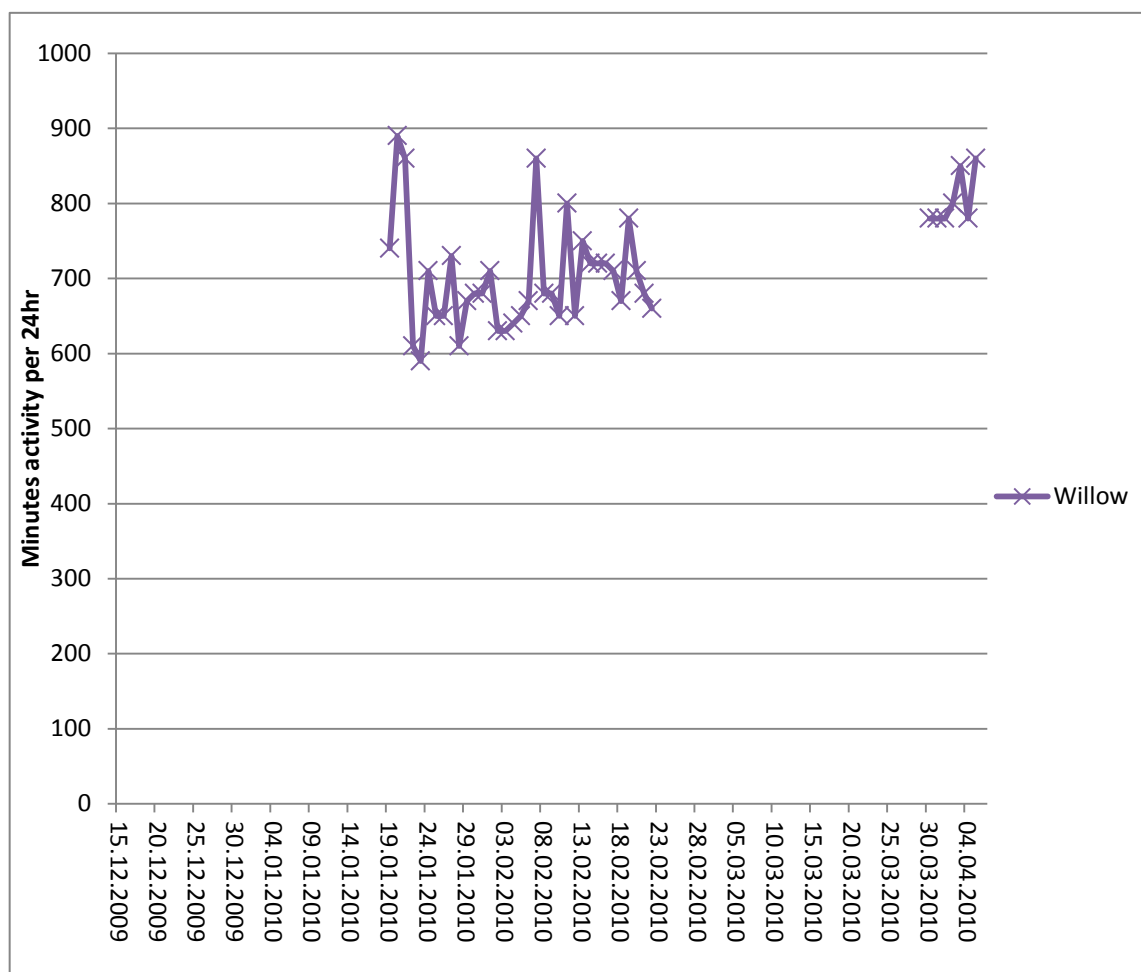
Figure 34. Activity of Willow (min/24hr)

Again Willow showed an increase in activity on the second night after release. She was increasing from 740min/24hr to 890min/hr and after two nights decreasing back to 610min/24hr. After that the range of the level of activity was high, between 590min/24hr and 860min/24hr. The peak activity is higher than the other birds.

3.4 Weight development of the birds
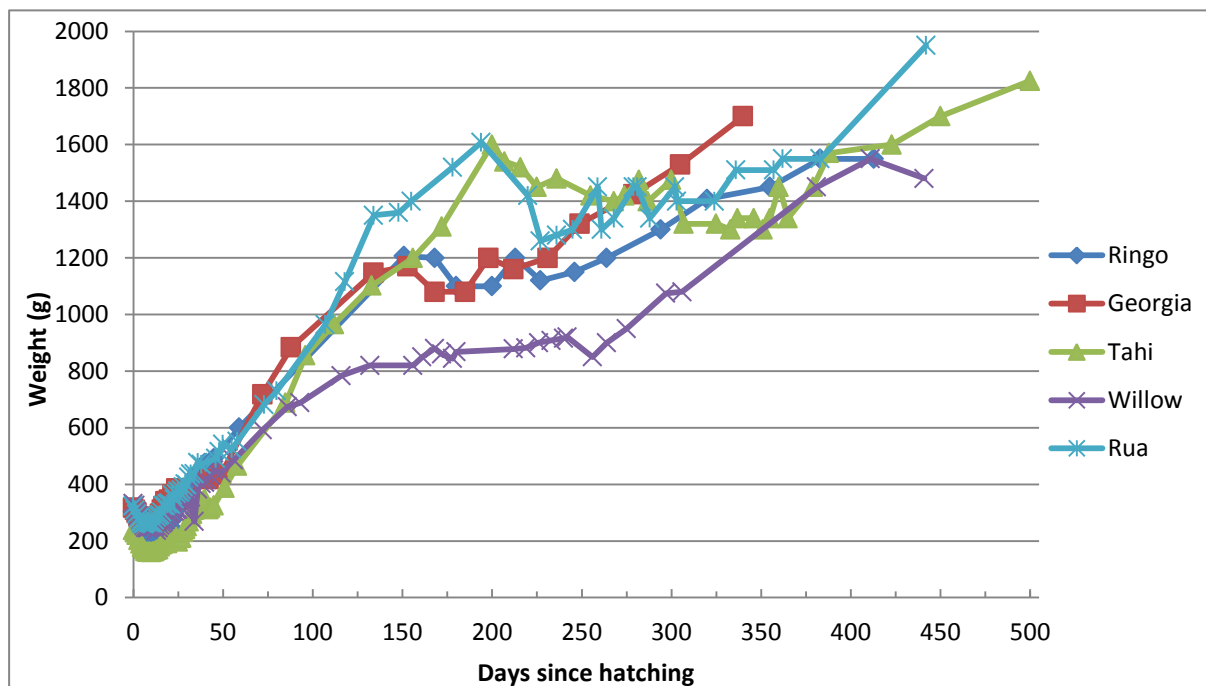
Figure 35. Weight development of all birds in days since hatching and including time in the wild. Release time into Riccarton Bush and into the wild are indicated in the following figures

The data for the weight development is based on unpublished data from M. Wylie (unpublished-c). It shows the development since the first day of hatching. All birds decrease in weight after hatching until an age of around 7days. After this age all birds increased their weight.
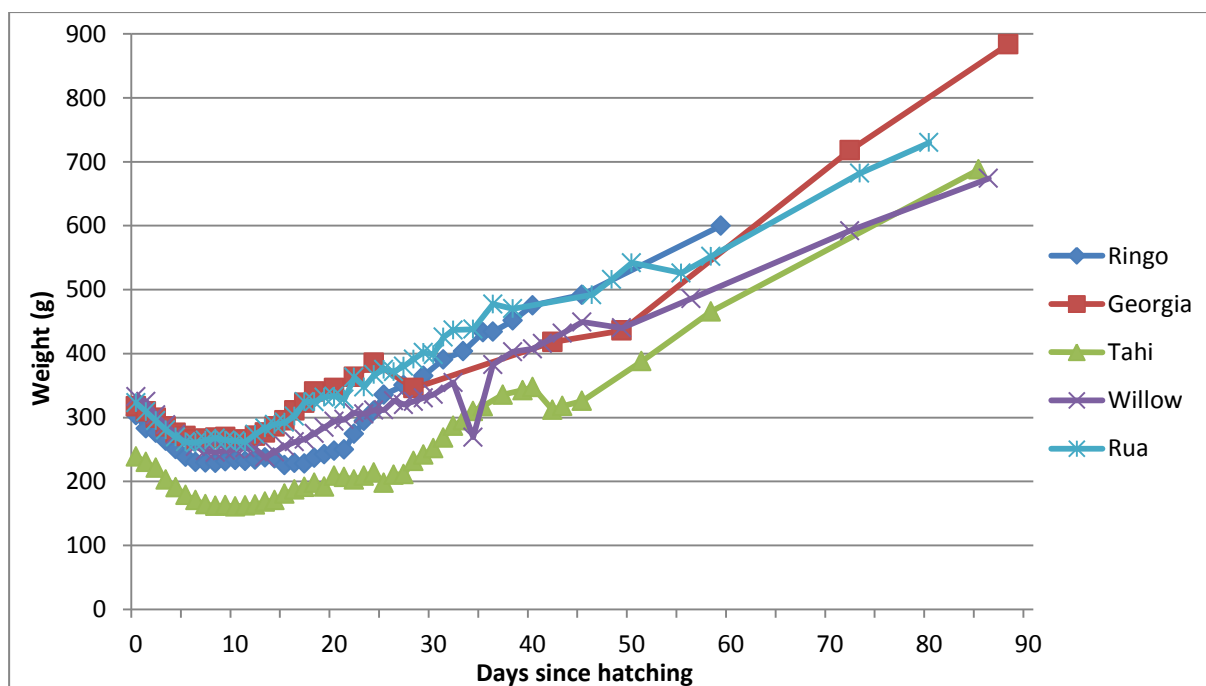
Figure 36. Weight development of all birds in the first three months.

The development of the birds in the first three months was similar. Thai had the same development as the other birds, but on average around 100g less (see Figure 36). The improvement of Willow after the age of 100 days was not as fast as the other birds. But by the age of 325 days Willow had reached a weight similar to that of the other birds.

Ringo
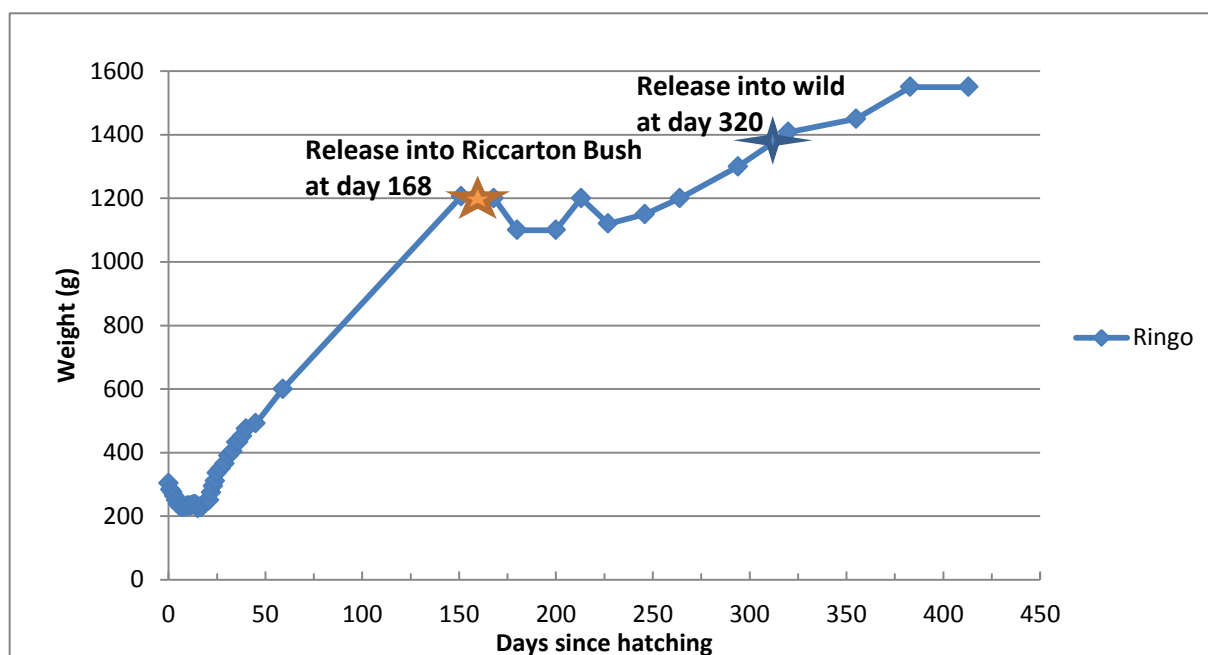
Figure 37. Weight development of Ringo

Ringo steadily increased in weight up to an age of 168 days. At this age Ringo was released into Riccarton Bush. After this age Ringo varied between a weight of 1100g and 1200g. At the age of 283 days Ringo's weight started to increase again. The release into the wild had no impact on the weight development.

Georgia
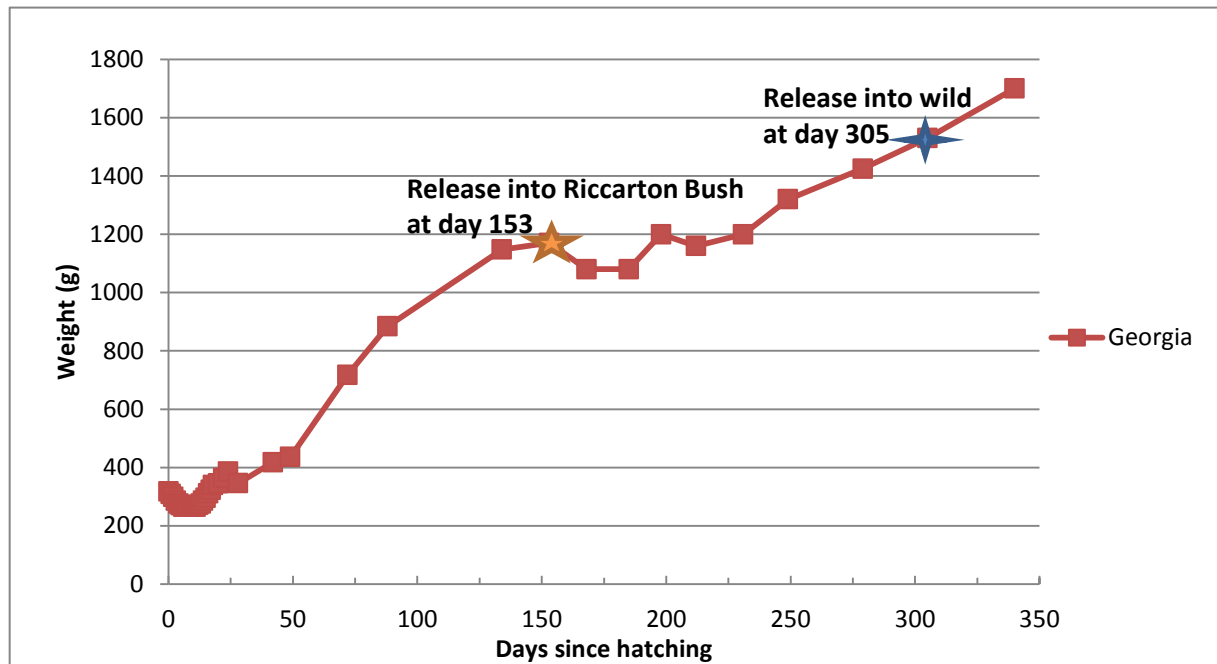
Figure 38. Weight development of Georgia

Georgia had a similar weight development to Ringo. Until the release into Riccarton Bush Georgia's weight steadily increased. At the age of 153 days the weight improvement stopped and the weight decreased. After the age of 283 days her weight reached 1200g again and continued to rise even after her release into the wild.

Tahi
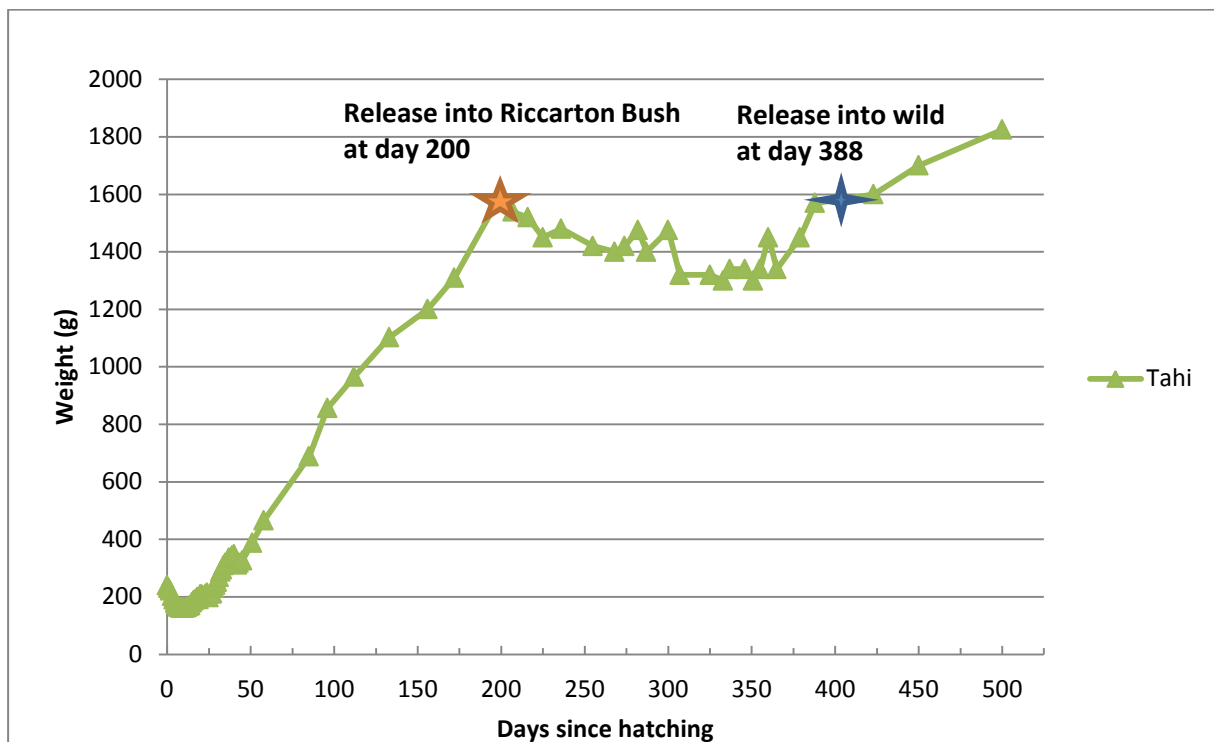
Figure 39. Weight development of Tahi

Also Thai's weight development was similar to the others. The weight constantly increased until the age of 200 days then dropped following release into Riccarton Bush. It then took until the age of 388 days to reach the same weight as before. Compared to the other birds, the decrease in weight, of around 300g, was larger than the weight decrease of the other birds. The release into the wild seemed to have had no impact on his weight development.

Willow
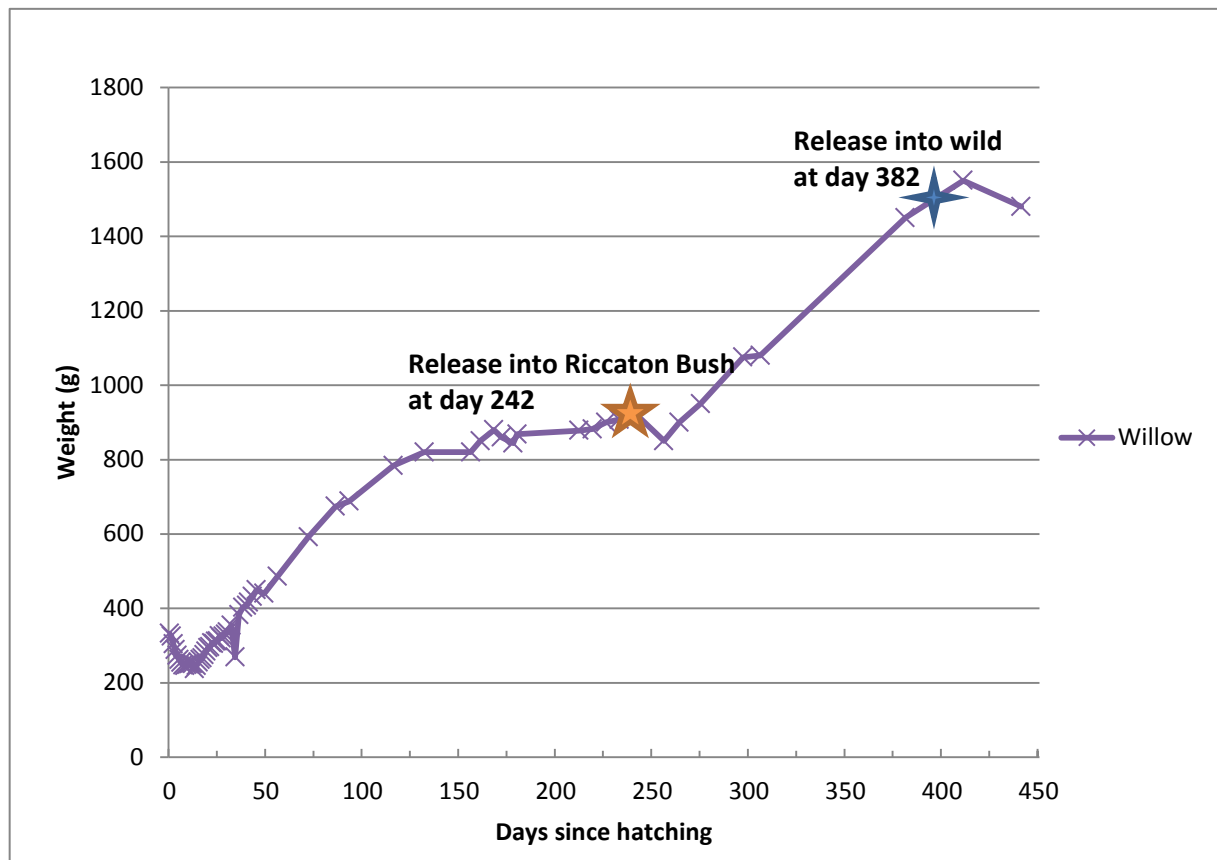
Figure 40. Weight development of Willow

Willow's weight increased until her release into Riccarton Bush. Compared to the other birds, the decrease in weight after Riccarton Bush was not as great. The other difference was that after her release into the wild her weight increase was not as pronounced as the other birds.

Rua
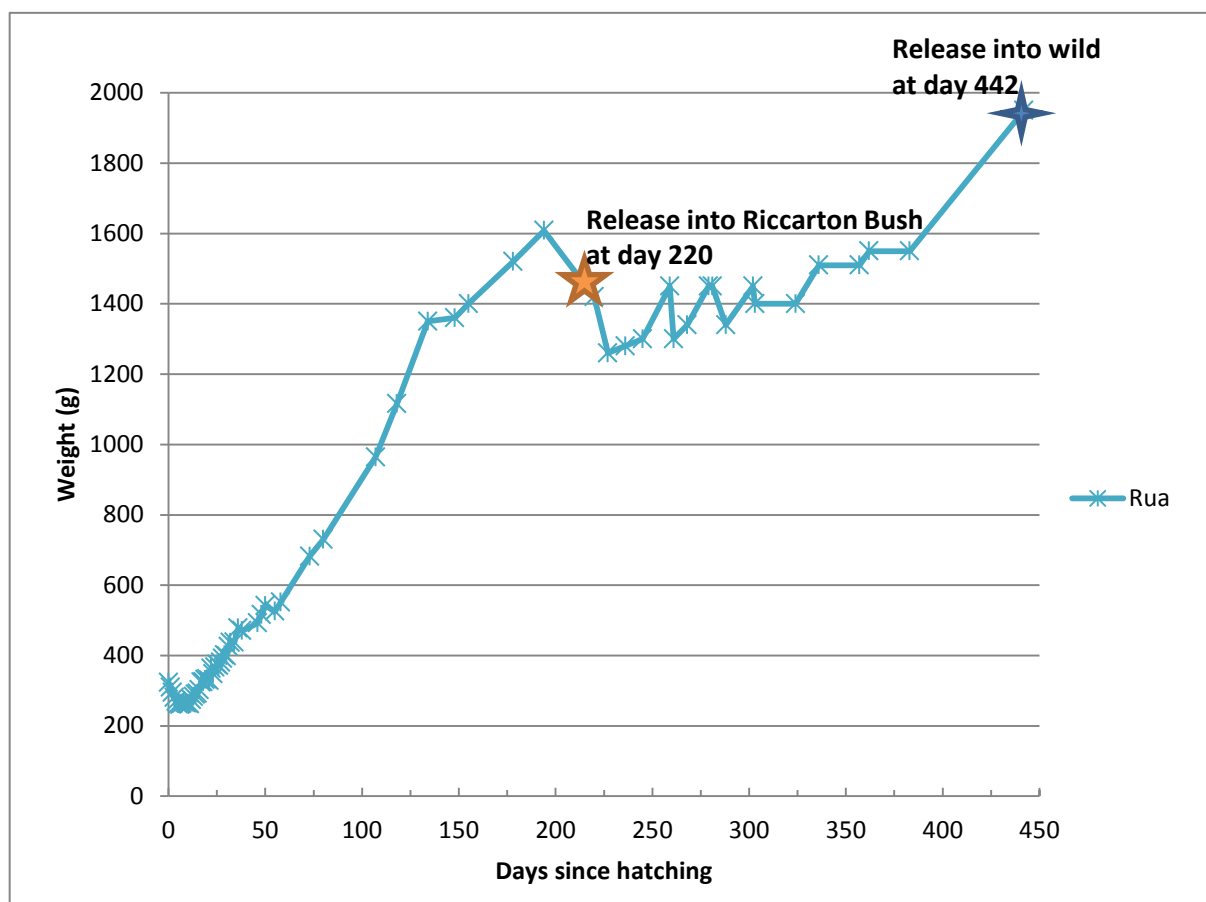
Figure 41. Weight development of Rua

Rua reached a weight of 1608g by the age of 194 days. After this age the weight began to decrease. The release into Riccarton Bush was not the reason, as with the other birds. The decrease of around 300g was the same as with Tahi. It took Rua until the age of 362 days to reach a weight of 1550g. After that her weight increased until her death 3 days after her release into the wild.

3.5   Bird movement

Table 8. Summary of the movement of all subadult birds. Mean and total distance is based on all recorded fixes over the study period. Distances and time of movement at night refer to total travel distances from a whole recorded night. The last column is the total distance travelled divided through the days of the study period with the result of meters per day.

Name	Total distance and time of movement in whole night (number of fixes in particular night)	Mean distances of all recorded fixes (number of fixes)	Total Distance travelled (number of fixes)	Total distance travelled / Days of study period
Georgia	28.-29.1.10; 10h 732.22m (n=9)	16.12.09 - 12.2.10 330.81m (n=26)	16.12.09 - 12.2.10 8270.36m (n=26)	142.60m per day (58 days)
Tahi	13.-14.1.10; 10h 891.52m (n=10)	16.12.09 - 7.4.10 299.25m (n=38)	16.12.09 - 7.4.10 11072.36m (n=38)	98.86m per day (112 days)
Willow	4.-5.2.10; 12h15min 753.45m (n=10) 5.-6.2.10; 8h05min 734.85m (n=9)	19.1.10 - 19.3.10 219.21m (n=34)	19.1.10 - 19.3.10 7233.93m (n=34)	122.61m per day (59 days)
Ringo	11.-12.1.10; 9h35min 752.66m (n=8) 14.-15.1.10; 9h50min 1087.70m (n=8)	16.12.09 - 6.4.10 346.85m (n=39)	16.12.09 - 6.4.10 13180.44m (n=39)	118.74m per day (111 days)

Table 8 gives an overview of the movement of the birds. All calculations are based on the homing and triangulation data collected in the field. The distances travelled in one night were unfortunately not possible to calculate for every night. The reason for this was that the data often had time gaps. For Ringo and Willow was it possible to calculate the travel distance for only two whole nights, for the other birds was only possible for one whole night. Ringo travelled the greatest distance for one night.

The fact that the data has gaps is shown in the last column. The total distance was divided by the number of days of the study period. Georgia has the highest travel distance per day with the lowest number of days. Ringo travelled around 2000m (total distance) more than Tahi, who has one day more. Ringo also has the highest total travel distance.

Figure 42 shows how the distances of the birds are distributed. It also gives an overview of how far the birds travel per time interval. With 1600m, Tahi has the greatest travel distance of all the birds. The ten first time intervals have higher distances than the time intervals later. The last time intervals also have increasing distances. Except for Rua, all bird data could be collected. It was also possible to collect data for Ringo and Georgia, before their deaths.
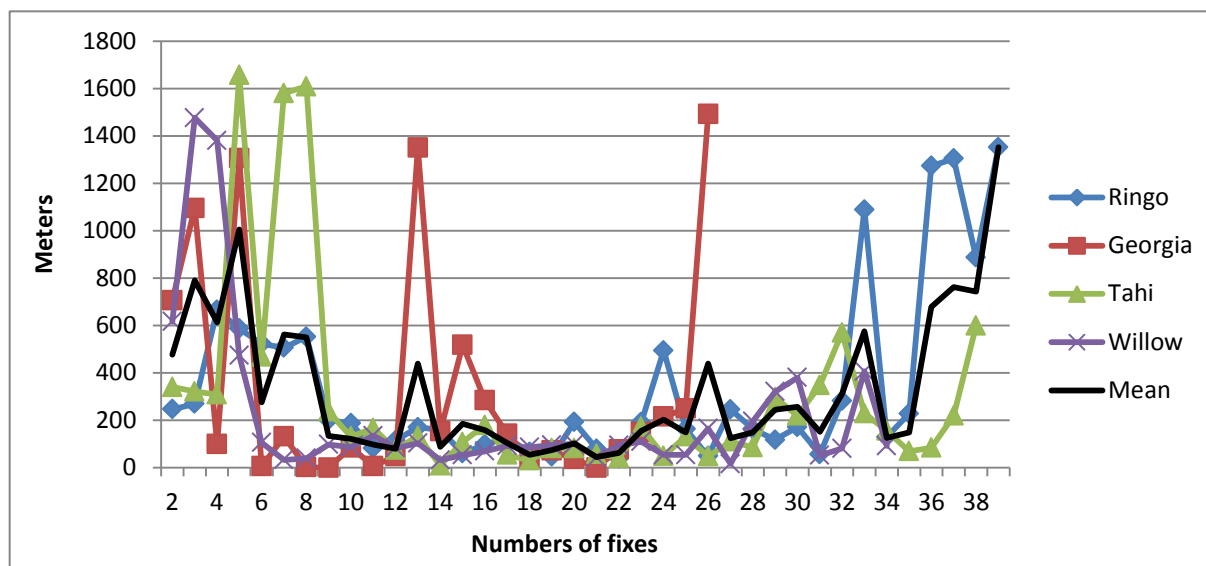
Figure 42. Travel distances of all birds over the study period. Distances are calculated between different fixes which are sorted in time.

Tahi
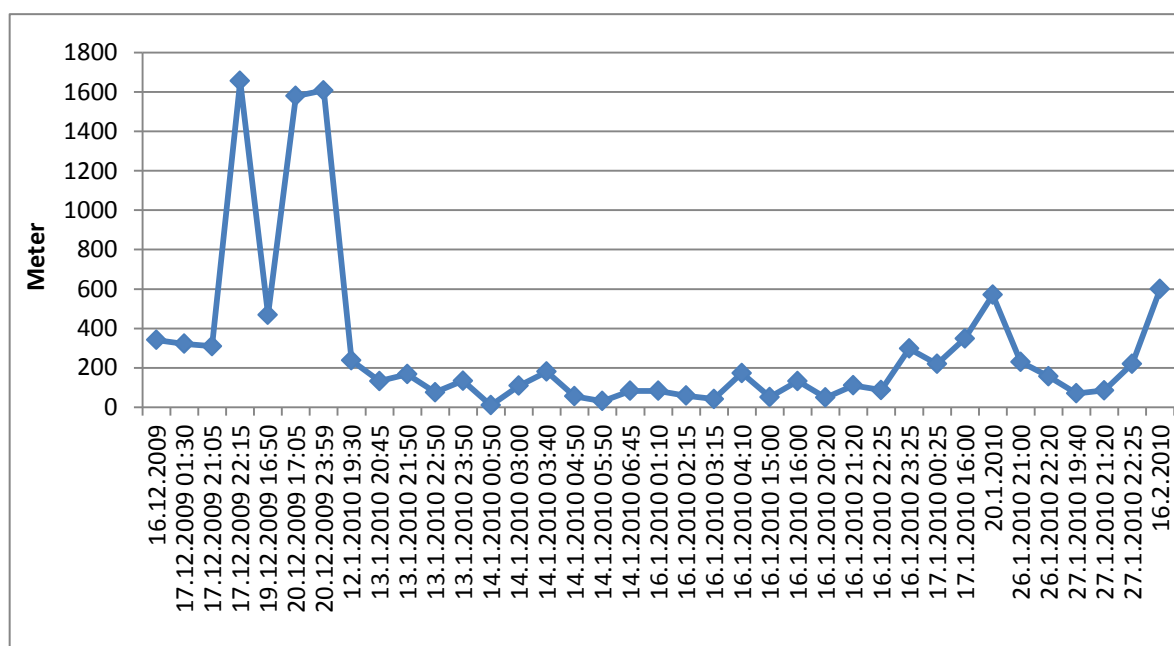
Figure 43. Travel distance of Tahi after release

Tahi has low travel distances until the night of 17.12.09, then the distances increase until the 12.1.2010 when it dropped to a level under 200m per time interval. From the 12.1.2010 the travel distance never exceeded 600m, even when the time intervals were quite large. The highest distance at the begin was never reached again.

Ringo
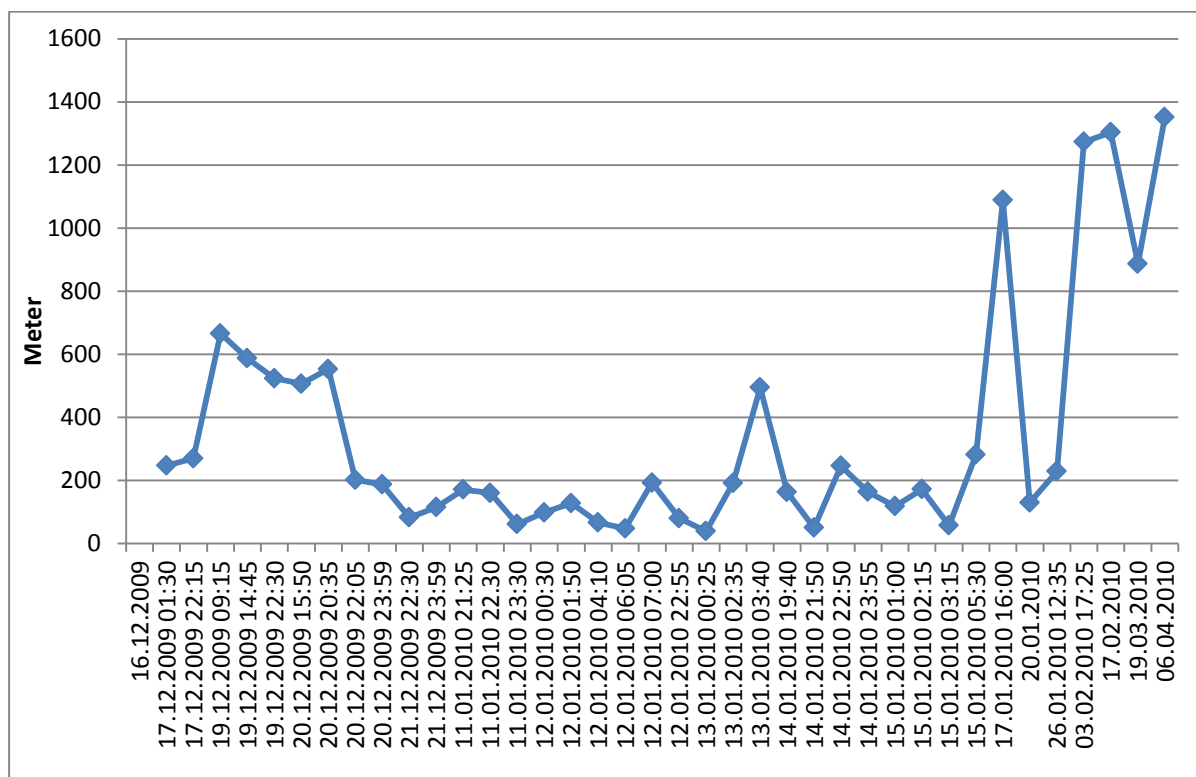
Figure 44. Travel distance of Ringo after release

After the release, Ringo started travelling on the second night. Until the 20.12.2009 he travelled around 600m per time interval. Between the 20.12.2009 and 12.1.2010 he travelled less than 200m per time interval. On nights from the 13.1.2010 to 14.1.2010 Ringo travelled up to 500m. During the last time intervals, (17.1.10 to 6.4.10) his travel distances were higher, but this can be explained by the larger time intervals.

Willow
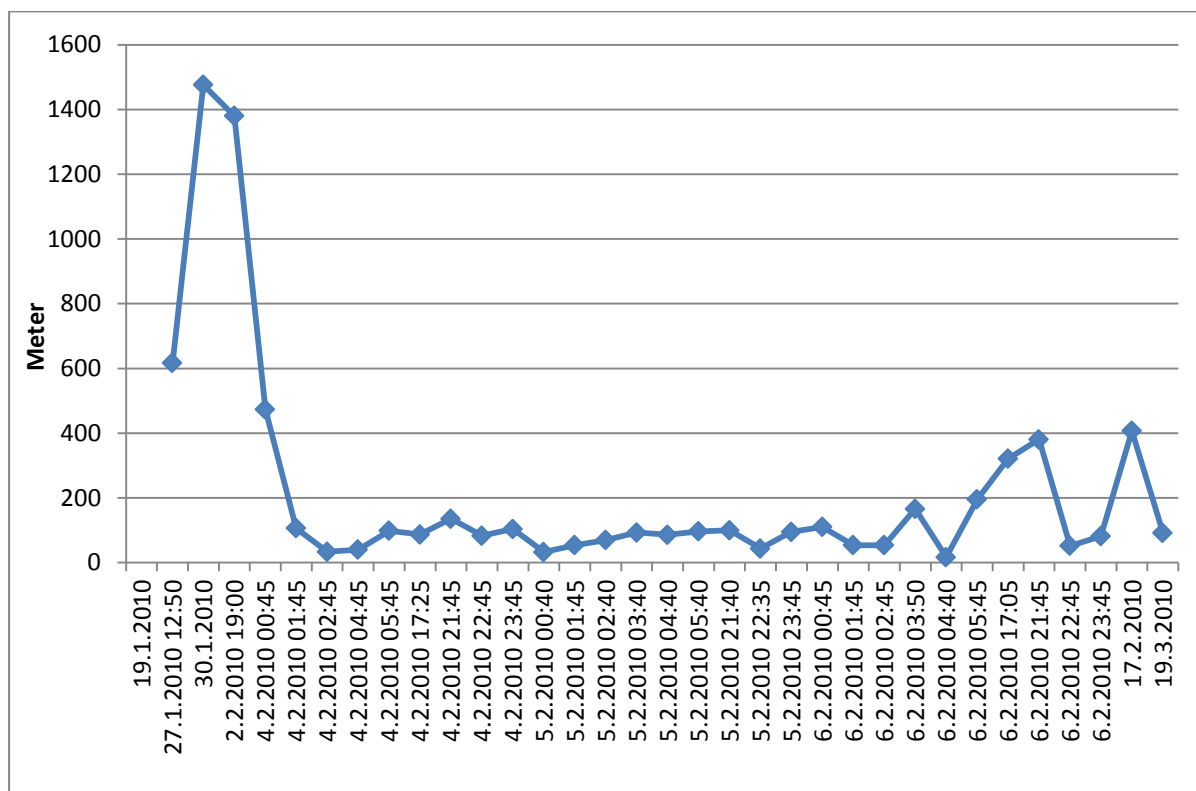
Figure 45. Travel distance of Willow after release

Willow's travel distance was the highest after release until 4.2.2010 and reaching around 1500m. After this time the distance stayed below 200m per time interval. At the end of the studied period the distance stayed below 400m, even when the time interval was 10 days or one month.

Georgia
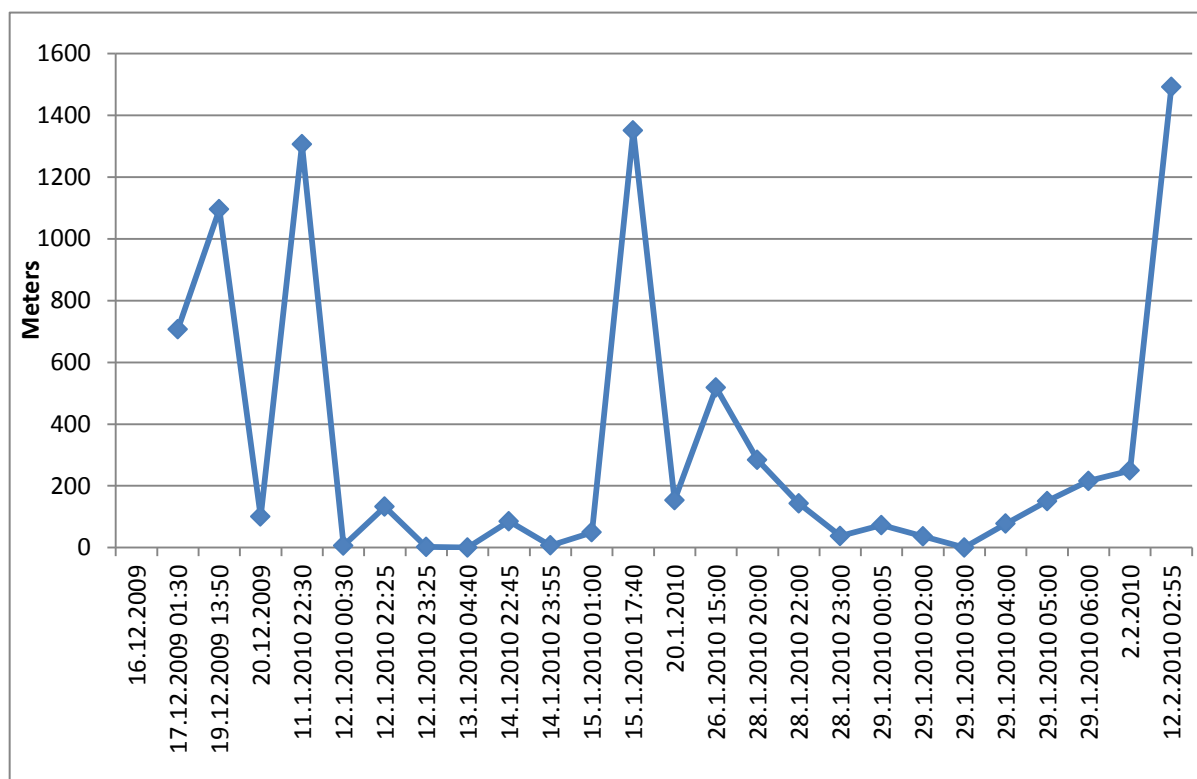
Figure 46. Travel distance of Georgia after release

After her release Georgia's travel distances varied. From the 20.12.2009 to 11.1.2010, Georgia travelled 1300m. After this time this distance could be toped at the 15.1.2010 from 1:40am to 5:40pm with 1350m. The highest travel distance is on the last recorded time interval of 1500m.

4   Discussion

In this study eight research questions and three hypotheses were made (see chapter 1.3). The following chapters try to answer those research questions and try to prove the hypotheses.

4.1   Movement

It was partly possible to answer the research question "What distance do the five released subadults travel away from the release point per night?"

The results support the general impression of the field that the birds were resting on the first night after release. The following nights, the birds became more active and travelled to the areas where the home ranges now are located. Until the end of the research the birds stayed in these areas. Ringo stayed close to the release area, Willow and Georgia c.1000m and Tahi c.2000m away from the release point. These distances can answer only how far the birds were travelling away from the release point and not how much per night. How much they travel per night could be not answered because of time gaps of the data.

These time gaps occurred because it was not always possible to gain locations of a bird during a whole night. For this reason it was only possible over one and two whole nights to collect data. The time gaps were probably caused by for example: bird movement, signal bounce, weak signal, etc.

On top of that, the results of the movement analysis are only estimates. The distances between the different points are linear lines. It doesn´t show the exact movement of the birds. But is still gives an idea about how much the bird was moving. It shows that the peak distances of the birds were similar as those in the study of Keye (Keye, 2008). Regarding the movement during the whole night and within the home range the results are not satisfactory. It would have been more appropriate using a GPS telemetry technique. This technique is already available, GPS transmitters can reach a weight around 30g (Lewis and Flint, 2008). This would allow for the bird to be tracked in a more exact way.

But on the other hand, no study was done to ascertain whether GPS transmitter would be useful for kiwis or not. One important point of such a study would be the reception of this GPS transmitter in mountainous terrain. However this GPS tracking has potential for use with the kiwi but is still not clear if it could be used or not. Due to this reason further research is necessary.

4.2   Activity

This chapter answers the question: "How many hours per night are the five subadults active?". Tahi, for example, has an activity range of 420-800min/24hr and is different every day. The number of minutes active per 24hr varies between birds and nights. This same large variation has been noted in the study of Keye (2008) with the adults and subadults in the Hurunui North Branch area. The activity data from this study is from April 2007 to April 2008. The highest activity is around 880min and the mean activity between 515min and 673min (Keye, 2008). This high variation in different days is similar in all subadult and adult birds.

The next question was: "Is the rate of activity for the adult birds, already present in this area, changing because of the presence of the released subadults?". The result show that the activity of the adult birds is not clearly different compared to the subadults. Also, no effect was observed by the released subadults. This fact supports our hypothesis (H_3) that the adult birds show no change in activity because of the release of the subadults.

Also the activity data from Wylie et al. (2009) shows the same activity range for non-incubating adults between 2008 and 2009 as founded in our study.

The result of the adult GSK in the other studies indicates that the subadults have the same range of activities. It is clear that the data from the other studies are from different years, but it indicates that the range of activity is the same as 2009/2010. One difference between our study and the others is that the data have different time frames. However, all studies covered the month December, January and February. In the end, it can be assumed that the ranges of the subadults are similar to those of the adults.

The same range of adults and subadults indicates that the released birds may have the same success in finding food as the adults. If the subadults were less successful in finding food, they would probably need more time to get a sufficient amount for survival. But on the other hand, it is not known how much of the time adults and subadults use for feeding or for other activities. Therefore more research is necessary to confirm or disconfirm this assumption.

4.3   Home ranges

In this section we will look at the question: "How fast a subadult is able to establish their own 'stable' home range and how far it is away from the point of release?". This question can be answered. The subadult birds spent the first night after release close to the release point. The following nights they travelled in the area were the home range is located and stayed there until the end of the research.

The next question was: "Are the subadults establishing a home range alone or with a partner?" All the birds except of Ringo and Willow established a solitary home range. The home range of Ringo (male) and Willow (female) are overlapping when calculated with Harmonic Mean. Another indication that the two birds were sharing their home range was that they once were observed sharing the same burrow. It could be possible that both birds would have paired together and started to breed in the future. Unfortunately, due to the death of Ringo this prevented the relationship from evolving.

This result also partly answers the next question: "Do the five subadults remain alone or together with other subadults after release?". Ringo and Willow show some indication, that they stayed together, but for the other birds there was no indication there that they stayed together. It could have been different because the birds stayed together in Riccarton Bush. For this reason, it could have been that they also stay together in the wild. An explanation as to why this could not be the case could be that the birds have much more space in the wild and therefore, tried to avoid each other.

The results of the two research questions before, supports partly the hypothesis (H_1) that the subadults established their own, solitary home range. All the birds were able to establish a own home range but only Tahi and Georgia remained solitary. The sizes of the home range varying from bird to bird.

The home ranges of the birds had different sizes when determined by MCP or Harmonic Mean. It shows that different methods give different results. But then the question rises, which home range size is closer to reality? This question is difficult to answer. Home range calculations are always estimates and not an exact reality (Kenward, 2001, Springer, 1979, White and Garrott, 1990).

The home ranges of the Harmonic Mean method are bigger than those of the MCP method. One exception is Georgia. Her home range is bigger when calculated with MCP. The home range sizes of the subadult birds are bigger than those in the study of Keye (2008). This study determined the home range sizes of adult GSK pairs in the Hurunui North Branch area. The home ranges varied in size between 19.59 ha and 35.41ha (Keye, 2008). In the Gouland Downs GSK home ranges were around 12-26ha (Marchant et al., 1990), in the Saxon area 10-42ha and at Kahurangi Point 8-25ha (McLennan and McCann, 1991a). The size of the home range of Brown Kiwi in one study varied between 19.1 to 42.3ha (McLennan et al., 1987). In a study of Miles et al. (1997), for Brown Kiwi in the Tongariro National Park, the MCP home range varied from 30.8 to 91.8ha and the adaptive kernel estimate ranged from 28.2 to 74.8ha. The GSK home ranges are in other studies smaller. What are the reasons for that?

One explanation is that home range sizes are different and depending probably on region, food supply and intruder pressure (McLennan et al., 1987). Food supply could be an explanation as to why home range sizes in our study are bigger than in other studies, because the birds need this size to find a sufficient amount of food in order to sustain themselves. Maybe, the habitat in this area is not so good than those in the other studies. The number of adult birds already present in the Hawdon area shows that the habitat must be appropriate to sustain GSK in this area (Wylie et al., 2009).

An additional explanation for the larger home range size, is when the population density in areas are low, then the home ranges are large (McLennan and McCann, 1991a). This can be true for the Hawdon area, because there are less than 5birds/km² (Keye, 2008) or 3-4birds/km² (McLennan and McCann, 1991a). The density between all subadults birds were around 2 birds/km² (mean home range size divided by number of birds).

One other reason for larger home ranges could be the fact that the birds in this study are subadults and for that reason not yet settled. Maybe, they are still "looking around". Probably at one stage the remaining birds will move in another area together with a partner. At the moment, this home range is enough for them to find enough food. The home range calculated in this study during the research period was stable. Maybe, this home range is not the home range in the long term.

In the end, more research is necessary to determine the home range size of the adults and remaining subadults in the Hawdon area. This would allow a comparison to be made between the home range size of the subadults and the adults. This could explain if the home ranges are in general bigger in the Hawdon area or not. Assessment of the development of the subadult home ranges would also be of benefit for any additional research.

The location of Thai's home range, so close to the Hawdon Shelter, was quite a surprise in this study. It wasn't expected that one of the birds stayed so close to human infrastructure. It is hard to assess the degree of human disturbance via the campsite. During the main tourist season in New Zealand (December and January) were not many people at the campsite. But there were still enough to possible disturb the bird Tahi. So far Thai wasn't influenced too much by the human presence. If it had been the case it is assumed that she would had move away. Hopefully there will be no problems with that in future.

4.4   Weight development

In this section the questions: "How is the weight of the chicks developing after release? Can the birds sustain themselves in the release area?" is discussed. The development of the weight from the release into the wild was not influenced. This might be explained by the time spent in Riccarton Bush. When the birds were released into Riccarton Bush their weight decreased until the birds were used to finding food and therefore able to gain weight again. This experience in Riccarton Bush teaches the birds how to find food and this knowledge was probably the reason for not losing weight after release into the wild.

This fact supports the hypothesis (H_2) that the birds were able to sustain themselves in the wild. Also the activity data shows that the birds were not significantly more active compare to the adult "experience" birds. But on the other hand, the activity data does not show if the birds were searching for food or not during their time active. However, the birds are able to sustain themselves in this area and able to gain weight.

4.5   Locations

The most important results in this study are the locations collected in the field. But there are some rising questions. One of those questions is: "Is it possible that Ringo and Georgia have their locations so close to the street?"

Firstly, it is important to see that this street is a gravel road to a farm and it is also the connection between the Hawdon Shelter/Campsite and the Andrews Shelter/Campsite. During this time when the research was done, there were not many cars driving on the road. More to the point during night when the birds were active, there were very few cars driving on this road. Due to this reason, it could be possible that the birds (Ringo and Georgia), were not or rarely influenced by cars, passing so close on the street.

Also, is it unlikely that the researchers were influencing the birds with their presence, because the researchers were often standing on the street to collect the bearings of the birds. This spot on the street was often a good place to collect the bearings, because of the reception from multiple birds. The signal strength of the birds was strong enough at this location, so that the researchers didn't need to change their position in order not to disturb the birds. If they would have been disturbed they would probably have been not so close to the street. The study of Gasson (2005) supported this assumption because they reported two sightings of a GSK beside the Buller Gorge road in August 2002.

Also they considered: ..."*there was also a chance that kiwi would favour habitats beside the road (e.g. road verges and Black Valley Swamp) for feeding.*" (Gasson, 2005). This shows that some GSK are not influenced by roads.

One other possible reason why some locations of Ringo and Georgia are so close to the street, could be errors by the researcher in taking bearings. Mistakes could have occurred when reading the bearings and estimating the direction of the strongest signal. Wrong reading of the bearing could happen through the movement of the antenna, while taking a bearing. The deviation in the study was determined by the transmitter test and results in a mean deviation of the bearing of ±6.01°. This ±6.01° could have caused some points of Ringo and Georgia to appear closer to the street than in actual fact. Also is it possible that the signal was bouncing or was reflected from the slope, north of the street (see Figure 3).

Beside that fact that Ringo and Georgia have locations close to the street, there are many other locations where Ringo, Georgia and Willow are in open grass land. The locations of Willow are reasonably correct because the researcher had good positions and reception in the field. Other indices for GSK feeding in open grassland are based on the experience of the DOC staff, which is monitoring the GSK for a time in the Hurunui valley and in the same area as the study area. They had some findings which could explain that GSK feed and/or stay in the open.

They found Ringo outside the forest, hiding in some Matagouri and bush cover (M. Wylie, DOC Waimakariri Area Office, pers. comm., 4th April 2010). Another finding of the DOC staff was that once, one GSK was hit by a train, close to Arthurs Pass, in a place which was a few hundred meters away from the forest (M. Wylie, DOC Waimakariri Area Office, pers. comm., 13th May 2010). Also was it possible for DOC staff, during monitoring work at night, to hear some calls of adults, which were out in the grassy flats (M. Wylie, DOC Waimakariri Area Office, pers. comm., 13th May 2010).

These findings support the assumption and give some evidence to the fact that GSK are feeding or even sheltering in the open. That adult GSK are sheltering in the subalpine region, above the treeline is already known (Wylie et al., 2009). Within the ONE program were once an egg collected from Tom and Katie, this is a GSK pair lives on the top of the Woolsheld Hill (see Figure 3). Tom and the egg were in a burrow which was in an area of *Dracophyllum* scrub and around 40 metres from the bush edge (Wylie et al., 2009). This GSK pair lives on the same hill, as the released birds and this could have forced the released birds to feed in the open grassland. Shelters in the open grassland were not found in this study.

That GSK are using a different types of habitat are known (BirdLife International, 2010, Gasson, 2005, Marchant et al., 1990). But the definition of the type of habitat is different. Gasson (2005) talks about different grassland habitats, which are an habitat for GSK. In comparison Marchant (1990) is talking about tussock grassland as an habitat for GSK. But both authors confirm that GSK are using grassland as a habitat.

4.6   Causes of death

Unfortunately, only two of the five birds are still alive. Ringo, Georgia and Rua died from different causes.

4.6.1   Ringo

Ringo was found dead on the 6.4.2010 beneath partial shelter of Crown fern and Coprosma out on grassy flats. The bird's body was in poor condition but showed no sign of predation (Wylie, unpublished-b). A post-mortem examination was done on the body, the result of that was that Ringo had died from Avian Malaria (M. Wylie, DOC Waimakariri Area Office, pers. comm., 1th September 2010).

Avian Malaria is a disease which is not native to New Zealand. It is caused by the *Plasmodium spp.* parasite. The vector of this is Hawaii mosquitoes. Which vectors are responsible in the New Zealand case is not exactly know but experts are assuming that is the same mosquito as in Hawaii (Derraik, 2006). Beside that exotic birds in New Zealand could be the hosts for the parasite. This widespread species such as the Sparrow *(Passer domesticus)*, Song Thrush *(Turdus philomelos*) and Blackbird *(Turdus merula)* can carry the parasite for a life time and pass the parasite on to other native birds (Derraik, 2006). This contributes strongly to the distribution of this disease.

It is hard to tell exactly how Ringo was infected by this disease. He could have been infected in Riccarton bush or after release, but this remains unknown. This disease can be a problem for the translocations of different native species (Alley et al., 2010, Derraik et al., 2008). Hopefully, this single case remains the only one and this disease will not be a problem for future release of relocations projects.

4.6.2   Georgia

Georgia died from predation either a ferret or stoat (M. Wylie, DOC Waimakariri Area Office, pers. comm., 1th September 2010). The body was found on a beech regeneration area and was covered in wasps (Wylie, unpublished-b). No data was found about the success of the rodent trapping done in the Andrews valley and the area around the valley entrance, where Georgia was. For this reason it is not possible to assess if those measurements taken are appropriate or not.

4.6.3   Rua

The cause of Rua's death on the 28.1.2010 was fungal pneumonia (M. Wylie, DOC Waimakariri Area Office, pers. comm., 6th December 2010). Rua was found lying in a little stream. The body had no external injuries (Wylie, unpublished-b).

Fungal pneumonia is an infection of the lung caused by different fungus (Olias et al., 2010b). This fungus occurs predominantly in immune-compromised individuals (Olias et al., 2010a). Immune suppression can be caused by antibiotics (Panigrahy et al., 1979). This might have happened with Rua. Before release she was treated with antibiotics (Wylie, unpublished-b) and that could have suppressed her immune system. In the wild she might ingested a fungus which caused a fungal pneumonia and as a result of it, her death. The other birds were also treated with antibiotics (Wylie, unpublished-b), but they either didn't ingested a fungus in the wild or their immune system was not as susceptible as Rua's.

Rua death may have been possible to prevent through a anti-fungal treatment before release, especially in case of treatment of antibiotics (Morgan, 2008). Antibiotics have to be used carefully because it can cause problems in wildlife populations through accumulation (Lemus et al., 2008).

4.7   Operation Nest Egg™ Release project

The release of five GSK subadults into the Hawdon area was partly a success. Unfortunately, three of the five subadults died after release. Ringo died of avian malaria, Georgia of predation and Rua of fungal pneumonia. The development of all birds after release was very promising. The only exception was Rua. She died a few days after release. All four remaining birds were able to sustain themselves in the release area. This means that the captive reared birds were learning how to find food on their own.

This learn-process was achieved during the time they spent in Riccarton Bush. During this time the bird weren't fed by the humans. That fact can be seen in the weight development of the birds. All the birds had a decrease in weight at the start of the time in Riccarton Bush. But after a time they were able to increase their weight constantly again. This increase in weight was not halted after their release into the wild. The ONE program is able to prepare GSK to sustain them self in the wild and to establish their own home ranges.

This program gives young kiwi a good start in life. But it cannot prevent losses. Therefore, it is necessary for this project to improve their measurements so that more birds survive. The release in this study is a so called "soft release". A "soft release" allows the animal to acclimated to a novel site before release, compared to a "hard release" which doesn't allows the animal to acclimate before release (Bright and Morris, 1994). This fact raises the question if in the ONE program a "hard release" would be possible. This type of release would make the stays of the juvenile birds in crèches like Riccarton Bush not necessary anymore. It would mean that the birds were release as chicks and not as subadults.

"Hard release" and release as chick, within the ONE program would only be useful when the release area has a low number or even no mammalian predators. Then the chances of survival for the birds would be higher. This was done with three GSK chicks in the Nelson Lakes National Park (DOC, 2010b). They were released in a managed area where mammalian predators have been eradicated. The future and more research will show if that could be a possibility for the ONE program.

Another variation of a "hard release" could be to keep the birds until they reach a predator-safe weight in the hatching facility. This approach would increase the costs because the birds have to be fed by humans for a longer time. Also the bird could get used to humans and their food which makes the bird unable to sustain itself in the wild. For this reason this variation of the "hard release" is not option for the ONE program.

Mammalian predation is one of the major reasons for the decline of the kiwi populations. For this reason predator control is widely applied in New Zealand. This measures supports native birds, also the kiwis, more than introduced exotic bird species (Starling-Windhof et al., 2010). Together with the reintroduction of kiwi, the ONE program is promising to support the kiwi population and in hopefully prevent the extinction of New Zealand's national icon.

4.8   Recommendations for the future

In the case of future releases of kiwi the ONE program should focus more on the medicinal state of the birds planned to be release. The aim should be that all birds which are going to be release are really healthy. In this study the medical treatment of the birds was done, but more research is necessary to find the reasons why Ringo contracted avian malaria and Rua fungal pneumonia. Medicinal issues are always possible but this knowledge can help to prevent these failures in future and increase the success of the ONE even more.

The combination of predator control and the ONE program increases the survival of kiwi and supports their population. This combination should be maintained.

More research is necessary to find out if the home range sizes of the subadults in this study are "normal" for this area or not and which types of habitats in this area these birds are using. This would help to estimated how many kiwis this area can support.

Checking if GPS tracking systems are appropriate for kiwis in mountainous terrain also needs to be looked into. This technique could greatly improve the quality of data in scientific studies and therefore improve the knowledge about the kiwi.

The future of the two remaining subadults of this study looks promising Tahi is now regularly seen with a wild mate (M. Wylie, DOC Waimakariri Area Office, pers. comm., 6th December 2010). This gives hope for the future.

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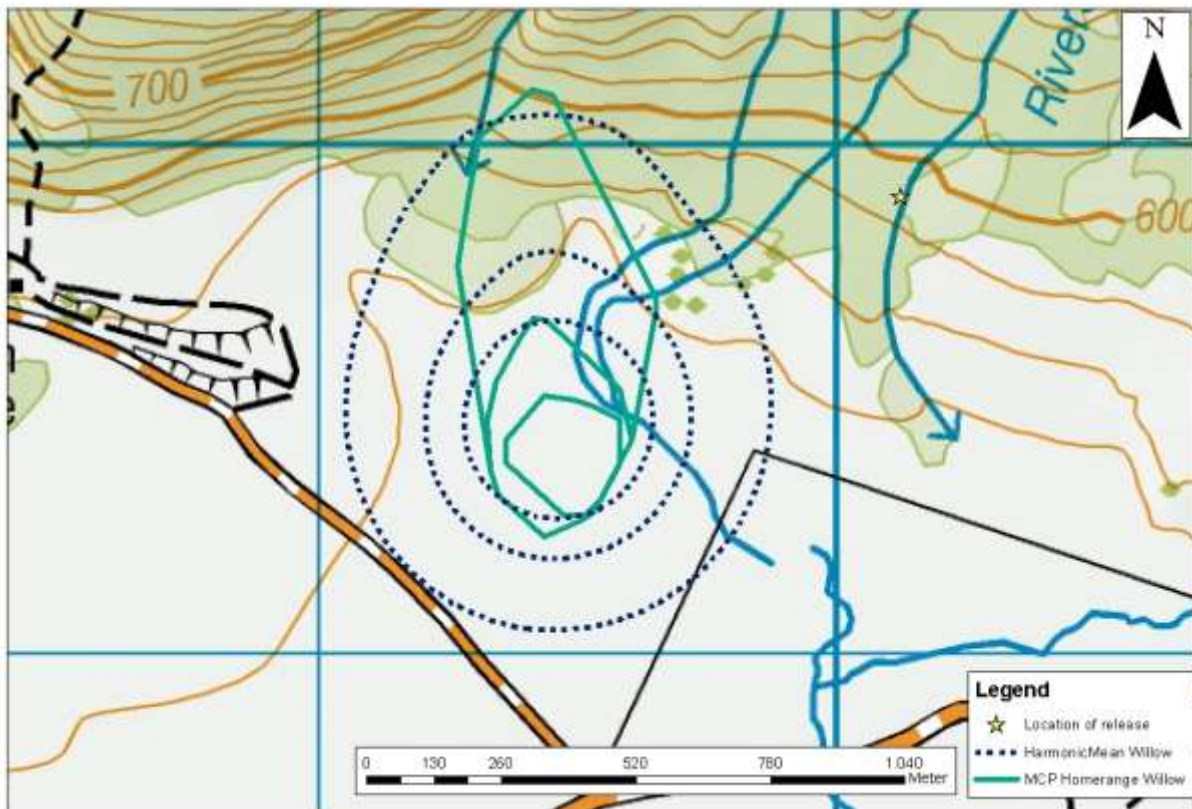
Appendix

Ringo MCP and Harmonic Mean
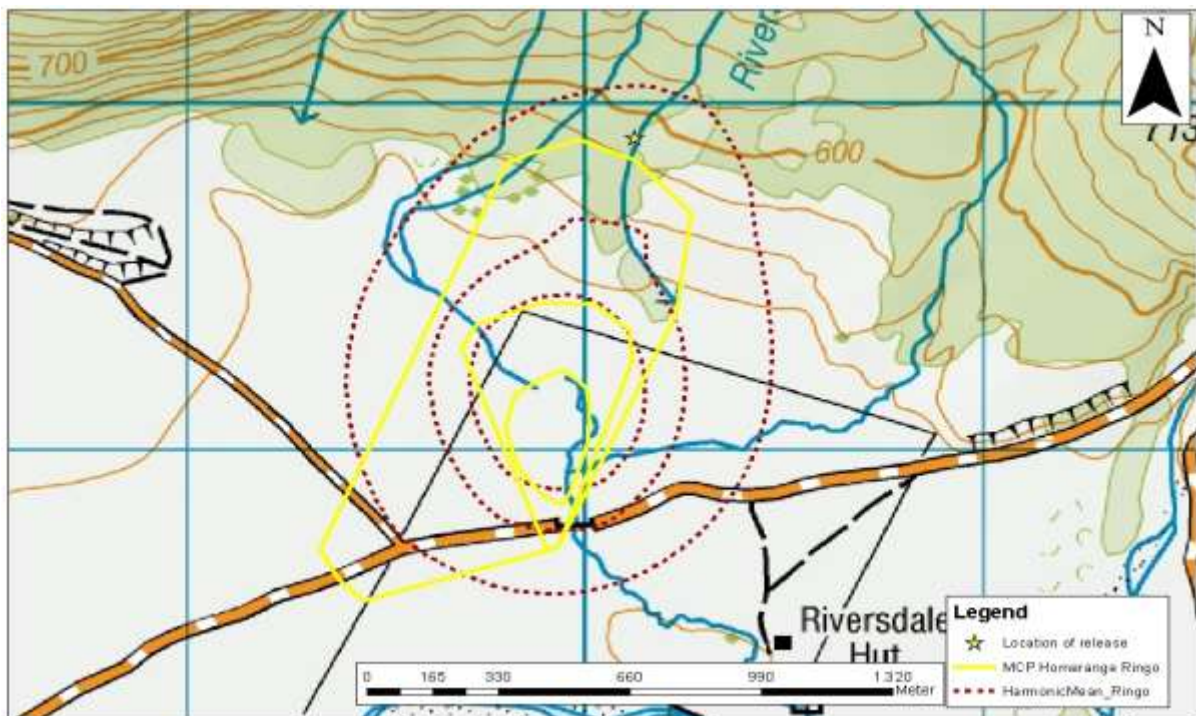
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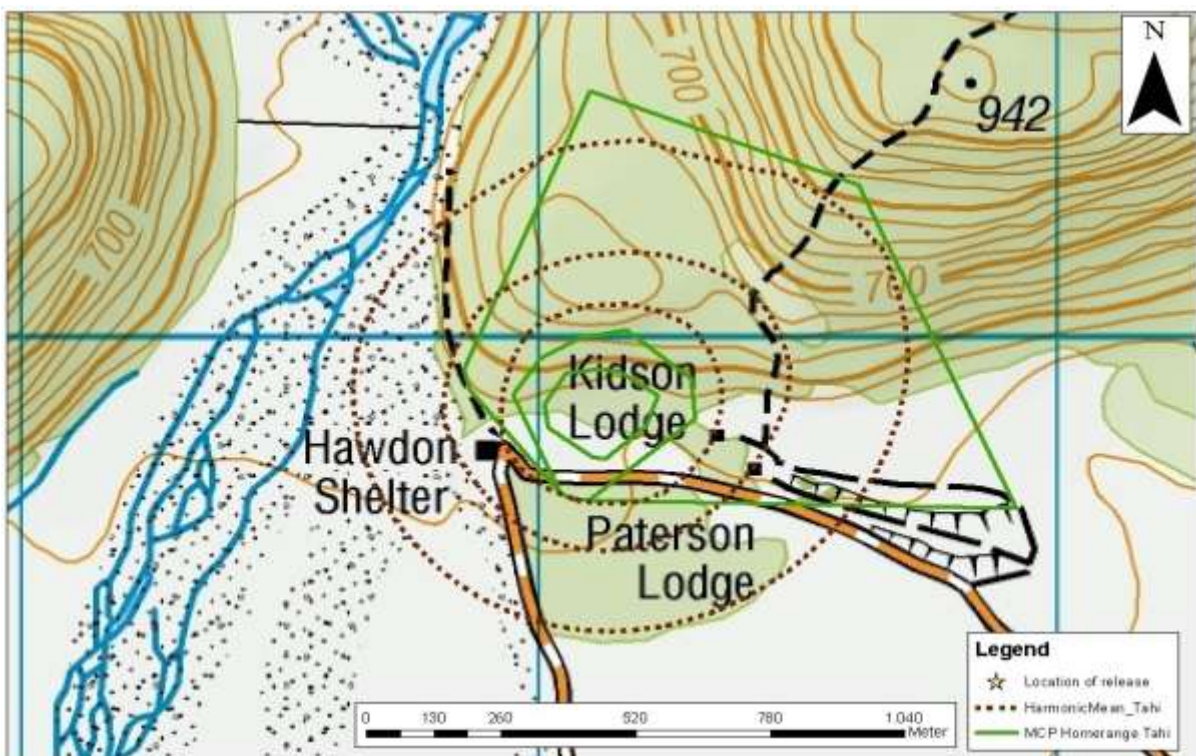
Willow MCP and Harmonic Mean

Georgia MCP and Harmonic Mean