Local movements of Karoro/Southern blackbacked gull (*Larus dominicanus*) on the lower Hakatere/Ashburton River



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Table of Contents

| EXECUTIV | VE SUMMARY | |
|------------|--|----------|
| INTROD | UCTION | 4 |
| BACKGE | ROUND | |
| OBJECT | IVES | |
| Метно | DDS | |
| RESULT | S | |
| Discus | SION | |
| CONCLU | JDING THOUGHTS AND LEARNINGS | 5 |
| OVERVIE | w | 6 |
| BACKGE | ROUND | 6 |
| CONTRO | DL | 7 |
| TRANS | MITTERS | |
| DNA S | EXING | 9 |
| OBJECTI | /ES | 9 |
| METHOD | 9S | 9 |
| STUDY | Area | 9 |
| TRANSM | AITTERS | |
| ANALYS | SIS | |
| DNA S | EXING | |
| RESULTS | | |
| CAPTUR | RED BIRDS | |
| DNA se | EXING | |
| TRANS | AITTER ANALYSIS | |
| <i>A</i>) | The distances that they travel | |
| B) | Movements at the landscape level | |
| <i>C)</i> | Preferred habitat at the foraging sites | |
| D) E) | Colony Jiight Jrequency and speed | |
| E) E) | Travel to other colonies | |
| | | |
| DISCUSSI | | |
| | RED BIRDS | |
| | EXING | |
| I RANSN | The distances that they travel | |
| אן ם | Movements at the landscane level | 39 ۸۸ |
| <i>с</i>) | Preferred habitat at the forgaing sites | 40 |
| כי ומ | Colony flight frequency and speed | 41 |
| E) | Similarities and variation between individuals | |
| _, F) | Travel to other colonies | |
| CONCLUI | DING THOUGHTS AND LEARNINGS | |
| REFEREN | CES | |
| | | |

Executive Summary

Introduction

The purpose of this research was to pilot methods of bird capture and to deploy 10 transmitter units on nesting karoro on the lower Hakatere/Ashburton River. These transmitters would collect spatial data to assess how karoro use and move through the landscape.

Background

Karoro/Southern black-backed gull (*Larus dominicanus*) are a large native gull in Aotearoa New Zealand. Karoro have significantly increased over the past decades and have become considered a pest in some areas due to nest predation and harassment of other braided river birds that are considered 'at risk' or 'threatened'. Little is known about the daily movements of karoro, with only one other study in Aotearoa New Zealand in 2018 that was conducted at Wellington Airport, where they assessed the movements of five karoro (Avisure, 2019).

Objectives

The objectives of this research were to:

- 1. Determine methods of bird capture and GPS transmitter deployment.
- 2. Determine the movements of karoro by observing;
 - a) the distances that they travel,
 - b) movements at the landscape level,
 - c) preferred habitat at the forage sites,
 - d) colony flight frequency and speeds,
 - e) similarities and variations between individuals,
 - f) travel to other colonies.

Methods

Breeding karoro were captured on the lower Hakatere/Ashburton River from 8-17 November 2022 using drop-traps at nests with 2-3 eggs. Birds were weighed and banded. Birds assessed as suitable for a transmitter were fitted with a Druid Lego E 2G or 3G unit. Movement data was collected from November 2022 to April 2023. Additionally, 2-5 breast feathers were taken from each bird to use for DNA sexing to analyse potential behavioural differences between sexes.

Results

Twelve karoro were captured, with 10 transmitters deployed. The mean and maximum daily distance travelled was 39.2 km (28.6 – 41.5 km), and 292 km (45.6 – 292 km), respectively. The mean and maximum distance from the colony was 10 km (4.2 - 17.6 km), and 41.8 km (14.6 – 41.8 km), respectively. The top three habitats used for foraging were short-rotation cropland (45%), high producing exotic grassland (28%), and riverbed (18%) (combined - river and gravel or rock habits).

Discussion

Although there were some similarities between individuals for distances travelled and habitat use and preferences, there was notable variation between sexes and individuals in both areas.

Concluding thoughts and Learnings

Karoro were spending most of their time foraging at short-rotation cropland, high producing exotic grassland, and the riverbed habitats. The limiting of additional food sources could aid in the control of karoro in areas where they have negative impacts on other braided river birds. Although a significant quantity of data was acquired, ongoing analysis of the data is required to gain further understanding around karoro habitat use and preferences. Future research is required to increase the sample size to allow for greater data saturation that will give a more detailed picture of individual variation and population-level foraging behaviour, that may assist with management and control of karoro.

Overview

For this research, ten transmitters were deployed on nesting karoro near the Hakatere/Ashburton River mouth as part of a pilot study that connects to an ongoing Environment Canterbury (ECan) project assessing the movements of karoro and how current control methods could be improved through timing or location changes. Movement data was used to analyse flight paths, foraging patterns, and habitat preferences of the birds throughout the breeding and non-breeding season. Additionally, feathers were taken from each bird and used to determine the sex of each individual for the purpose of analysing the data to assess for potential flight or foraging differences between sexes.

Background

Karoro/Southern black-backed gulls (*Larus dominicanus*) are a large native gull found throughout Aotearoa New Zealand, South America, sub-Antarctic Islands, and southern parts of Africa and Australia (Miskelly, 2013). Karoro are classified as an unprotected native and are considered 'super abundant' in many regions (Heather & Robertson, 2005; Bell & Harborne, 2019). They tend to nest in large colonies in a variety of environments, including coastal dunes, cliffs, domestic and commercial roofs, and riverbeds (Heather & Robertson, 2005; Bell & Harborne, 2019). Karoro are omnivorous opportunists, both scavenging and hunting fish, invertebrates, vertebrates, offal, carrion and landfill waste (Miskelly, 2013; Bell & Harborne, 2019). Moreover, they have been noted to display bold and predatory behaviour towards other birds nesting nearby, consuming entire nests of eggs and chicks (Bell & Harborne, 2019; Popenhagen, 2019). The bold and aggressive behaviour of karoro and other large gull species has likely contributed to their often-negative reputation.

In Canterbury, large colonies of karoro nest throughout various braided rivers, including the Hakatere/Ashburton River. A number of other bird species also nest on the riverbed in colonies or isolated pairs. Species, such as tarāpuka/black-billed gull (*Larus bulleri*), ngutu parore/wrybill (*Anarhynchus frontalis*), pohowera/banded dotterel (*Charadrius bicinctus*), and tara piroe/black-fronted tern (*Sterna albostriata*), nest and forage in similar areas to karoro, exposing them to predation by gulls and nest failure (BRaid, n.d.a; Popenhagen, 2019). Although nest predation by karoro is a natural part of the ecosystem, many of the other bird species are classified as 'in decline' or 'threatened' because of anthropogenic activities and introduced mammalian predators (Cruz et

6

al., 2013; O'Donnell et al., 2016). In contrast, karoro populations have increased over the past decades as they have exploited anthropogenic activities, such as offal and waste products from animal processing facilities and landfills (Powlesland & Robertson, 1987; Thierry et al., 2016; Popenhagen, 2019), causing additional pressure to already stressed species. The increase of karoro and the decrease of other braided river bird species has caused declines that have been amplified by land use change, riverbed encroachment, and gravel extraction (O'Donnell et al., 2016; Thierry et al., 2016; Popenhagen, 2019). This has resulted in karoro being labelled as a pest or nuisance species.

Aside from karoro preying on nests of declining or threatened birds, they also outcompete smaller species for the best nesting sites, particularly on gravel islands. Because of their large size and often dominant or aggressive behaviour, smaller species are left to breed on less suitable nesting sites (Popenhagen, 2019). Braided rivers are prone to sudden flow fluctuations and seasonal flooding. As karoro secure higher and less flood prone gravel islands, they tend to be less affected by spring floods. In contrast, smaller bird species are left to nest on lower islands or gravel areas that are more prone to flooding and can result in nest failure, causing the birds to expend more energy renesting (Thierry et al., 2016; Popenhagen, 2019). Breeding seasons with excessive and ongoing rain throughout the season may cause multiple nesting failures and can result in very few chicks fledged in areas of nesting sites more prone to flooding (Thierry et al., 2016).

Control

Around the world, control operations have been implemented for large gulls for more than half a century (Caithness, 1968; Oro & Martinez-Abrain, 2007). In Canterbury, Environment Canterbury has initiated the *'Southern Black-backed gull strategy for Canterbury'* (see Bell & Harborne, 2019), which outlines strategies for karoro in braided river systems, both short term and long term, to reduce the negative impacts of karoro in the Canterbury region. A number of control methods have been used to control karoro, including poison, sedation, shooting, egg sterilisation, and nest destruction (Thierry et al., 2016; Bell & Harborne, 2019).

Despite the long history of gull control across the globe, the initial benefits and long-term effectiveness of culling have been inconsistent. Although many culling operations succeed in reducing pest gull populations, the benefit to conservation species is often negligible (Harris &

Wanless, 1997; Oro & Martinez-Abrain, 2007; Scopel & Diamond, 2017). However, long-term continuous control of pest gulls tends to have higher effectiveness and benefit for conservation species (Hario, 1994; Scopel & Diamond, 2017). Moreover, other factors have been stated as a greater threat to the long-term survival of conservation species, including loss of habitat, habitat quality, invasive species (both plants and animals), and anthropogenic activities (Oro & Martinez-Abrain, 2007; Cruz et al., 2013; Thierry et al., 2016; Bell & Harborne, 2019).

Transmitters

The use of transmitters has increased on a variety of species as technology has advanced and smaller units have been developed. Transmitters have been used on various gull species to gain information on migration routes, foraging patterns and territories, and the use of habitat types (Shaffer et al., 2017; Borrmann et al., 2019, 2021; Maynard et al., 2021).

Shaffer et al., (2017) investigated the flexibility of foraging behaviour of western gulls (Larus occidentalis). They analysed two colonies in California, one residing on Año Nuevo Island approximately 1 km off the coast, and the other within the Farallon Islands approximately 45 km out to sea. Shaffer et al., (2017) noted the gulls from Farallon Island made more ocean trips and on average flew greater distances to forage, compared to the gulls on Año Nuevo Island that tended to fly shorter distances and forage more often over the land. Similarly, Borrmann et al., (2019) investigated the foraging patterns of great black-backed gull (Larus marinus) on Foehr Island, Germany. They found the majority of gulls in their study did share common feeding habitats, such as the mudflats located near the colony. However, Borrmann et al., (2019) also noted high levels of fidelity of individuals to particular foraging areas despite season changes and availability of prey species. Additionally, Kavelaars et al., (2018) examined the potential impact that GPS tracking may have on the parental care and offspring success of lesser black-backed gull (Larus fuscus). They found that there was no negative impact on the growth of chicks from parents with no transmitters, one parent with a transmitter, or both parents with a transmitter. Such findings are vital in determining the potential pros and cons of deploying transmitters, as negative impacts due to the additional weight of a unit could be highly detrimental to the future success of an individual.

In Aotearoa, there is very limited understanding and knowledge around daily distances travelled and how much time karoro spend foraging in different habitats. Currently, the majority of literature has only assessed maximum distances birds travel through resighted banded birds (Fordham, 1968; Rowe, 2013). Rowe (2013) noted that breeding adults tended to fly within a 50-100 km radius of 8 their breeding colony, compared to juveniles that averaged 100-200 km radius. Transmitter data on karoro has only been previously undertaken once in Wellington, as part of a pilot study for the Wellington airport in 2018 and consisted of 5 birds (Avisure, 2019).

DNA Sexing

The use of molecular analysis techniques has become increasingly accessible and useful for the genetic sequencing of species through direct DNA extraction (blood or tissue) or secondarily through environmental sample sequencing (Bantock et al., 2008; Vink & Kean, 2013). Many species have little, or no, sexual dimorphism and DNA sexing can offer a minimally invasive technique that can determine the sex of an individual through blood or tissue sample (Griffiths et al., 1998; Bantock et al., 2008). Although male karoro are generally larger than their female counterparts, they are not obviously dimorphic and male and female weights and measurements can overlap.

Objectives

The objectives of this research were to:

- 1. Pilot the methods of bird capture and transmitter deployment.
- 2. Determine the movements of karoro by observing;
 - a) the distances that they travel,
 - b) movements at the landscape level,
 - c) preferred habitat at the foraging sites,
 - d) colony flight frequency and speed,
 - e) similarities and variation between individuals,
 - f) travel to other colonies.

Methods

Study Area

The Hakatere/Ashburton River is a braided river that flows across the Canterbury Plains from Te Tiriti o te Moana/Southern Alps to the Pacific Ocean on the east coast of Te Waipounamu/South Island, Aotearoa New Zealand (Fig 1). Braided rivers often have a variable flow regime and can be prone to flooding. This creates a unique and rare ecosystem found in only a handful of places around the world (BRaid, n.d.b; O'Donnell et al., 2016). This unique ecosystem supports a variety of species that have adapted to a high disturbance environment, and successfully exploit the different environmental niches (Cruz et al., 2013). The Hakatere/Ashburton River receives around 1300-1800 mm of rainfall annually in each of its headwaters of the North and South branch, compared to approximately 680 mm annually in Ashburton township (Environment Canterbury, 2022; Macara, 2016). Upstream of Ashburton township, the river has a North Branch that is rain fed, and a South Branch that is largely lake fed with additional streams from the Winterslow and Alford Ranges feeding into the river near Ashburton Forks. Being a braided river, the Hakatere/Ashburton River has a fluctuating flow and is prone to seasonal flooding.



Figure 1. The Hakatere/Ashburton River (yellow) within Te Waipounamu/South Island, Aotearoa New Zealand. Sourced from ArcGIS online, ESRI.



Figure 2. The location of the karoro colony where 10 transmitters where deployed. Sourced from ArcGIS online, ESRI.

Transmitters

This research was conducted over the 2022-23 breeding season (Oct-Mar) on nesting karoro on the lower Hakatere/Ashburton River (Fig 2). Between 8-17 November 2022, a total of 12 breeding karoro were caught, weighed, leg banded, and assessed for their suitability to carry a transmitter. All birds were of good body condition, however, only 10 birds were heavy enough to carry a transmitter. Nine of the 12 birds had measurements taken and included; wing length, tail length, knee to toe, bill, head to bill tip, and moult. Additionally, 2-5 breast feathers were removed from each bird, for the purpose of determining the sex of the individual through DNA analysis (as there is no obvious dimorphism). This data was used to add to the bird banding records and to enhance our data by assessing any differences in movement patterns between the sexes.

Noose mats and drop-traps were used to capture birds nesting a few metres in from the edge of the colony, and all targeted nests contained 2-3 eggs. Drop-traps were propped up using a stick that was attached to a fishing rod. The fishing rods were kept under tension leading from the drop-traps to the bird hide that was set up ~10-50 m away. One or two people would then wait inside

the hide for the karoro to return to their nests and settle before gently winding in the fishing rod line and setting off the drop-traps.

The drop-traps were based on Mills & Ryder's (1979) design used to capture red-billed gull (*Chroicocephalus novaehollandiae*). The drop-trap frames measured 50 x 100 x 100 cm, and 60 x 120 x 120 cm using 6 mm round rod 304 stainless steel (Fig 3 A-B). The larger cage kept catching in the wind and setting off before a karoro could be captured, and so was reduced to 60 x 90 x 90 cm. The frames were covered in heavy duty canopy bird netting. An opening of 30-40 cm was made in the roof of the trap, and a 'sock' of netting material was attached to the opening to cover the hole and loosely tired in a knot. This enclosed the hole when the trap was set or during transportation, but allowed a safe and easily accessible opening to secure and carefully remove a captured bird once caught.



Figure 3. (A) A drop-trap set up on the lower Hakatere/Ashburton River over a karoro nest. (B) A drop-trap set off over a karoro nest.

Noose mats were constructed using a coffee sack, 5 mm nylon rope, and Maxima ultragreen 10 kg fishing line. The rope was sewen to the back of the coffee sack in a snake shape using a sewing machine, and the fishing line was sewn through the coffee sack and secured to the rope at one end and a slip knot loop was created at the other end.

The bird hide was constructed from a Kmart 2-person tent, coffee sacks, Rust-Oleum speciality camouflage spray paint (deep forest green and khaki), and two non-reflective green and brown camouflage nets, approximately 2.4 x 2.7 m each (Fig 4 A-D). The coffee sacks were unpicked and

resewn together longways to form a large mat to cover the tent, and an opening was made at one end to allow easy access in and out of the tent. The coffee sacks were then laid outside and sprayed in random lines or grass patterns to break up the solid colour and texture of the coffee sacks. The camouflage netting was green on one side and brown on the other. Each net was halved longways (green side out) to form two ~1.2 x 2.7 m rectangles and sewn together along the folded edge using excess hemp tread from unpicking the coffee sacks. Approximately 1 m of the folded edge was left unsewn at one end that overlapped the entrance of the hide to enable easy access in the field. By sewing the nets this way, it allowed for greater coverage of the net over the coffee sacks and leaving the outside ends open and free to adjust to give the best coverage over the hide. Additionally, small willow branches were interwoven into the camouflage netting in the field to help the hide blend into the surrounding environment.

All captured karoro were fitted with stainless steel 'S' bands for future identification and assessed for their suitability to carry a transmitter. Ten of the 12 captured karoro were fitted with a Druid Lego E unit, that were a mix of 2G and 3G units, weighing ~23.5 g and ~25.5 g, respectively (Druid Technology Co., Ltd., China). These weights are within the '3% of body weight rule' (Melville, 2011) for karoro, with the averaged sized female and male being 900 g and 1000 g, respectively. Transmitter units are often preened into the feathers surrounding the unit or covered by wing feathers when the birds are resting, However, the Druid Lego E units used in this study had an elevated solar panel that sat above the unit (Fig 5) and enabled greater solar rechargeability, even if the birds preened the unit into their feathers. Furthermore, the units transmitted via the cellular network allowing for data download to be conducted throughout the landscape without the birds having to return to a specific site to download to a radio hub.



Figure 4. The bird hide. (A) The hide entrance during construction. (B) The back of the hide on the lower Hakatere River. (C) The front of the hide with a fishing rod sticking out of the entrance. Lower Hakatere River. (D) The view from inside the hide, looking out towards the lower Hakatere River.



Figure 5. Druid Lego E units (2G and 3G) with the elevated solar panel. Unit dimensions are 68 x 21 x 26 mm, and weigh ~24-26 g.

Bands and transmitters were fitted to birds by a level 3 (L3), 2 (L2) bander, or level 1 (L1) under supervision by a L3 bander overseeing all fieldwork associated with the capture and attachment of devices and bands. These experienced banders are long-term Department of Conservation (DoC) staff with experience of attaching transmitters to several native and endemic species. Devices were attached via backpack harnesses in accordance with Melville (2011) and the Department of Conservation's SOP (Attaching radio and data-storage tags to birds: harness mounts) (DOCDM-708212). All birds were weighed and assessed for their suitability for transmitter attachment, birds that were deemed unsuitable were released.

The harnesses were made for backpack deployment using a 2 mm spun polyester cord (BK620) from Fineline Marine. The core of the cord was removed as part of the design and harnesses were fitted with a built-in weak link that is designed and tested to break if the harness gets caught on something, releasing the bird, and leaving the harness behind. The weak link was made with cotton thread that naturally breaks down over a 6–24 month period, depending on exposure to the elements and the behaviour of the bird (Avisure, 2019), and will eventually break and allow the transmitter to fall off the bird. As karoro are shore birds, they bathe and forage in water daily. Because of this, it is expected that the cotton weak links would degrade faster than a strictly terrestrial bird.



Figure 6. Pictures of karoro caught during the two weeks of transmitter deployment, lower Hakatere/Ashburton River. A) Wayne with his fitted transmitter. B) Crossbill's crossed beak. C) Copperfield while getting his transmitter fitted. D) Close up of Piranha's eye, eye colour and speckling varied between individuals.

Analysis

Quantitative data was collected from each transmitter and included GPS location data, time, date, acceleration (m/s), and elevation (m) for each data point. Data was analysed in the R statistical programme using glm (general linear model), ANOVA, Tukey test, and chi-square to assess flight paths, foraging habitat preferences, time spent foraging and roosting, and whether there are foraging or flight differences between the sexes.

DNA Sexing

Two to five breast feathers were removed from each bird for the purpose of DNA sexing. Each sample was stored in a small snap lock bag and labelled with a unique ID code (BBG-01-12). In the field, samples were stored in a chilly bin with ice packs before being transferred to a freezer and kept at -20°C until the DNA extraction process was conducted.

A Qiagen DNeasy Blood and Tissue Kit was used for the DNA extraction process. The tip of 2-3 feathers were cut and inserted into collections tubes provided in the DNA extraction kit. One to three feathers remained unused in the freezer for future use if the first extraction process failed for any reason. Following this, the instructions provided in the kit were followed, with the exception of adding 50 μ l buffer on the repeat of the final step instead of the full 200 μ l volume.

With the extracted DNA, PCR (Polymerase chain reaction) was undertaken to amplify the DNA in 3 main batches to create a 20 μ l reaction. In the first batch (BBG-01-14), each sample contained 2 μ l of template from the extracted DNA, 10 μ l of Dream Taq, 1 μ l of forward primer P8, 1 μ l of reverse primer M5 and 6 μ l of H2O. A previously tested DNA template (T28) was used as a positive control and water was used as the template in the negative control. For the second batch (BBG-17-30), each sample contained 4 μ l of template from the extracted DNA, 10 μ l of Dream Taq, 1 μ l of forward primer P8, 1 μ l of reverse primer M5 and 4 μ l of H2O. The third batch (BBG-31-37) contained 2 bird sample that did not work in the previous batches. Each bird sample was tested with 6 μ l of template from the extracted DNA and 8 μ l of template from the extracted DNA, 10 μ l of H2O for the 6 μ l DNA samples and 0 μ l of H2O for the 8 μ l DNA samples. Additionally, the positive control (T28) was tested at 2 μ l and 4 μ l of template in the third batch.

An initial denaturing step at 94°C for 8 mins was followed by 40 cycles of 54°C for 30s, 72°C for 30s and 94°C for 1 min. A final run of 3 cycles of 48°C for 2 min and 72°C for 2 min completed the

17

process. The main problem associated with poor amplification was solved by making a new working solution of the P8 and M5 primers.

PCR products were separated by electrophoresis for 180 mins at 60 V in a 4% agarose gel stained with Redsafe. The gel was then photographed using a BIORad GelDoc imaging machine. Each gel well contained 6 μ l of PCR template, with the first well containing the ladder. The presence of bands was assessed and determined by; one band for males (ZZ genotype), and two bands for females (ZW genotype).

Results

Captured birds

During the capture and deployment phase, all birds were caught using the drop-traps. Of the 12 karoro captured, 10 were heavy enough to be fitted with a transmitter unit. Karoro weights ranged from 822-1130 g (Tab 1). Nine of the 12 birds had other measurements taken (Tab 2). Wayne (#0603) was observed on 12 December 2022 flying as normal within the colony and landing at his nest. Unfortunately, Copperfield and Houdini stopped transmitting about one week after deployment and are currently assumed missing in action (MIA). It is unclear whether they have left the area and have gone somewhere with insufficient cellular network to transmit, or whether they are possibly dead, as a cull was undertaken in the area within a week of their last data transmission that was organised through ECan as part of the *Southern black-backed gull management strategy* (see Bell & Harborne, 2019).

Table 1. The unique bird ID, name, Tx no. (transmitter number), and sex (F=female, M=male) of each karoro caught for this study. *Copperfield and Houdini were classed as missing in action (MIA) after they stopped transmitting approximately a week after their transmitters were deployed.

| Bird ID | Name | Tx no. | Sex | Bird ID | Name | Tx no. | Sex |
|---------|--------------|---------|-----|---------|---------|---------|-----|
| BBG-01 | Eve | #045F | F | BBG-07 | Jasmine | #03FF | F |
| BBG-02 | Wayne | #0603 | М | BBG-08 | Xena | No unit | F |
| BBG-03 | Houdini* | #05AA | М | BBG-09 | Patty | #0460 | F |
| BBG-04 | Crossbill | No unit | F | BBG-10 | Hagrid | #0583 | М |
| BBG-05 | Copperfield* | #057C | М | BBG-11 | Piranha | #05B9 | М |
| BBG-06 | Āmio | #046B | F | BBG-12 | Tīwheta | #0475 | М |

| Bird ID | Name | Weight (grams) | Wing length (mm) | Tail length (mm) | Knee to toe (mm) | Bill (mm) | Head to bill tip (mm) |
|---------|-------------|-------------------|------------------------|------------------------|---------------------|-----------|-----------------------------|
| BBG-01 | Eve | 875g | - | - | - | - | - |
| BBG-02 | Wayne | 950g | 437 mm | 168 mm | 139 mm | 51.7 mm | 118.4 mm |
| BBG-03 | Houdini | 1050g | 436 mm | 157 mm | 145 mm | 51.3 mm | 122.7 mm |
| BBG-04 | Crossbill | 825g | 425 mm | 167 mm | 130 mm | 49.2 mm | 113.9 mm |
| BBG-05 | Copperfield | 1075g | 409 mm | 173 mm | 141 mm | 53.9 mm | 124.2 mm |
| BBG-06 | Āmio | 875g | - | - | - | - | _ |
| BBG-07 | Jasmine | 875g | 413 mm | 156 mm | 129 mm | 52.7 mm | 116.2 mm |
| BBG-08 | Xena | 822g | 410 mm | 156 mm | 128 mm | 51.7 mm | 116.1 mm |
| BBG-09 | Patty | 900g | 421 mm | 154 mm | 131 mm | 47.9 mm | 111.2 mm |
| BBG-10 | Hagrid | 1130g | 452 mm | 170 mm | 141 mm | 53.9 mm | 123.0 mm |
| BBG-11 | Piranha | 990g | - | - | - | - | _ |
| BBG-12 | Tīwheta | 990g | - | 164 mm | 135 mm | 53.5 mm | 121.1 mm |

Table 2. The bird ID, name, and weight of each karoro. Only 9 of the 12 karoro caught had measurements taken due to bird behaviour and field conditions. Lack of data are from birds that were showing signs of stress and were released.

DNA sexing

The first batch of PCR template was unsuccessful, with only one bird, BBG-08, showing a very faint double band (females are the heterogametic sex in birds). For the second batch of PCR template, a new working solution of the P8 and M5 primers was created, and the PCR and electrophoresis process was repeated. All samples in batch two were successful, except BBG-06 and BBG-10. Five of the captured karoro showed double bands indicating females (BBG-01, 04, 07, 08, and 09), and five of the birds showed single lines indicating males (BBG-02, 03, 05, 11, and 12). The third batch of PCR template successfully showed BBG-06 as female, and BBG-10 as male. Overall, there were 6 males and 6 females captured for this study (Fig.7A-B), with 6 males and 4 females fitted with a transmitter unit (Tab 1).



Figure.7 (A) The DNA sexing results of karoro BBG-01 to BBG-06 (F, M, M, F, M, F, +ve, -ve). (B) The DNA sexing results of karoro BBG-07 to BBG-012 (F, F, F, M, M, M, +ve, -ve).

Transmitter analysis

A) The distances that they travel

A total of 431,645 GPS points were collected from tagged karoro between November 2022 and April 2023. The majority of activity was during daytime hours (80.6%); however, 19.4% of activity was recorded at night. Daytime was considered as between an hour before sunrise and an hour after sunset. Foraging and flight data was separated by classifying foraging as stationary (\leq 1.4 m/s) and flying (travelling at \geq 3 m/s). Speeds between 1.4-3 m/s were excluded as it was unclear whether the birds were exclusively travelling or foraging.

Overall, the mean distances travelled by the karoro were similar (Tab 3). The mean distance travelled per day was 39.2 km (females 34.9 km and males 43.5 km). The maximum distance travelled in a day was 292 km by Copperfield. The distance travelled per day was not statistically significant between the sexes (ANOVA, P-value 0.2704). The mean distance from the colony was 10 km, and the maximum distance from the colony was 41.8 km by Āmio. Despite some similarities, the distance travelled per day and the distance from the colony between individuals varied widely (Tab 4).

| | All karoro | Females | Males |
|---------------------------------------|------------|---------|-------|
| Mean distance travelled per day (km) | 39.2 | 34.9 | 43.5 |
| Max distance travelled per day (km) | 292 | 223.6 | 292 |
| SD of distance travelled per day (km) | 28.7 | 23.1 | 32.7 |
| Mean distance from colony (km) | 10 | 10.8 | 9 |
| Max distance from the colony (km) | 41.8 | 41.8 | 36.9 |
| SD of distance from the colony (km) | 9.4 | 11.2 | 5.8 |

Table 3. The mean, maximum, and SD (standard deviation) of distances travelled per day, and the mean, maximum, SD of distance from the colony, from November 2022 to April 2023.

Table 4. The mean, maximum, and SD (standard deviation) of distances travelled per day, and the mean, maximum, and SD of distance from the colony for each karoro from November 2022 to April 2023. *Houdini and Copperfield were missing in action (MIA) a week after deployment.

| | Mean distance | SD of mean distance | Max distance travelled per |
|--------------|------------------------|--------------------------|----------------------------|
| | travelled per day (km) | travelled per day (km) | day (km) |
| Āmio | 41.5 | 30.1 | 223.6 |
| Copperfield* | 158.9 | 121.4 | 292 |
| Eve | 31.7 | 17.1 | 85.9 |
| Hagrid | 37.9 | 27.9 | 142.5 |
| Houdini* | 35.5 | 14.3 | 45.6 |
| Jasmine | 33.4 | 19.4 | 114.1 |
| Patty | 28.6 | 22.2 | 90.5 |
| Piranha | 37.2 | 23.2 | 170.3 |
| Tīwheta | 38.9 | 35.1 | 249.7 |
| Wayne | 53.2 | 30.7 | 186.4 |
| | Mean distance from | SD of mean distance from | Max distance from colony |
| | colony (km) | colony (km) | (km) |
| Āmio | 17.6 | 13.5 | 41.8 |
| Copperfield* | 10.1 | 5.1 | 19.4 |
| Eve | 5.7 | 3.7 | 27.1 |
| Hagrid | 8.3 | 5.6 | 27.7 |
| Houdini* | 7.5 | 4.6 | 14.6 |
| Jasmine | 8.3 | 8.9 | 37.8 |
| Patty | 4.2 | 3.1 | 19.4 |
| Piranha | 9.3 | 7.2 | 36.9 |
| Tīwheta | 6.6 | 4.4 | 27.7 |
| | | | |

B) Movements at the landscape level

The recovered GPS points were analysed against Land Information New Zealand's (LINZ) data layer, LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand. The GPS data points per habitat varied greatly between habitat types, and ranged from 3 to 146,063 (Tab 5). Gravel or rock had the highest number of GPS points at 146,063 (33.9%) data points, followed by short-rotation cropland (133,989, 31%), high producing exotic grassland (93,263, 21.6%), river (29,999, 7%), deciduous hardwood (9,413, 2.2%), and ocean (8,924, 2.1%).

To visualise the data within the surrounding landscape, the GPS data was projected into QGIS (Fig 8). Every data point was represented by a coloured dot on the map, and each bird was represented by a different colour. Upon visual inspection, a number of the areas with clustered data points were within the boundaries of singular paddocks. Additionally, there were a few clustered data spots along the riverbed at different locations. The highest concentration of these were east and south east of Lake Hood. Comparing these locations to the latest available map imagery from a seasonal flood in September 2022 (Fig 9), it is likely that these areas became riffles as the flood subsided.

| Habitat type | No. of | Habitat type | No. of |
|---------------------------------|--------|---|--------|
| | GPS | | GPS |
| | points | | points |
| Gravel or Rock | 146063 | Gorse and/or Broom | 1854 |
| Short-rotation Cropland | 133989 | Lake or Pond | 519 |
| High Producing Exotic Grassland | 93263 | Low Producing Grassland | 399 |
| River | 29999 | Urban Parkland/Open Space | 145 |
| Deciduous Hardwoods | 9413 | Orchard, Vineyard or Other Horticulture | 82 |
| Ocean | 8924 | Forest - Harvested | 80 |
| Built-up Area (settlement) | 2474 | Broadleaved Indigenous Hardwoods | 5 |
| Sand or Gravel | 2439 | Flaxland | 4 |
| Exotic Forest | 1990 | Surface Mine or Dump | 3 |

Table 5. List of habitat types and the number of GPS points at each habitat used by karoro on the lowerHakatere/Ashburton River from November 2022 to April 2023.



Figure 8. A map of the tagged karoro foraging locations around the lower Hakatere/Ashburton River, from 8 November 2022 to 23 January 2023. Coloured dots represent a data point and each colour represents a different karoro. The yellow oval indicates the location of the colony. Sourced from QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.org.



Figure 9. Possible location of riffle area post-flood. Map imagery of the Hakatere/Ashburton River in flood, South East of Lake Hood, September 2022. Insert map shows the transmitter colony location (yellow flag), and the location of the possible riffle area post-flood (yellow arrow). Sourced from ECan maps, Canterbury Maps, ESRI.

The GPS points within the colony area were removed from the data set to exclude any points associated with incubation, resting, or bathing. We compared the travelling and stationary GPS points for each habitat type for daytime and night-time activity. Excluding the colony area, the majority of karoro daytime activity (Fig 10) was largely spent in short-rotation cropland for both travelling and stationary movements, 49% and 45%, respectively. High producing grassland was the next most utilised habitat with travelling (36%) and stationary (28%), followed by gravel or rock habitat with travelling (3%) and stationary (18%). For night-time activity, excluding the colony area (Fig 11), the most utilised habit was gravel or rock with travelling (9%) and stationary (58%). Short-rotation cropland was the next most visited habitat at night with travelling (57%) and stationary (4%), followed by high producing grassland (32% and 8%) and river (2% and 22%) for travelling and stationary, respectively.



Figure 10. Daytime habitat use (excluding the colony area) by tagged karoro from the lower Hakatere/Ashburton River. The percentage of GPS points per habitat type while travelling (dark grey) and stationary (light grey).



Figure 11. Night-time habitat use (excluding the colony area) by tagged karoro from the lower Hakatere/Ashburton River. The percentage of GPS points per habitat type while travelling (dark grey) and stationary (light grey).

C) Preferred habitat at the foraging sites

Upon further analysis, we examined the daytime habitat preference while stationary (Fig 12). The main proportion of their time while stationary was within the gravel or rock (89%), and river (85%) habitats. The next most utilised habitat types were sand and gravel (50%), short-rotation cropland (50%), high producing exotic grassland (47%) built-up areas (45%). We performed a Tukey test to assess whether there were any statistical differences between each habitat type used by the karoro. We found that although many of the habitat type were statistically different (Tukey test)

from each other, there were also factors that were shared between a number of habitat types, and are represented as letters (Fig 12).



Figure 12. The percentage of GPS points per habitat type while stationary for all tagged karoro from the lower Hakatere/Ashburton River. The letters show whether each habitat type is statistically different from each other (different letters) or not statistically different from each other (same letters) (Tukey test, P-value <0.05).

Data was separated between males and females to assess any habitat preferences differences between the sexes. For daytime stationary data (Fig 13), gravel or rock (34% and 38%), and shortrotation cropland (31% and 32%) were the most utilised foraging habitats by males and females, respectively. High producing exotic grassland (males 20%, females 21%) was the third most foraged habitat type.



Figure 13. The percentage of daytime stationary GPS points per habitat type (excluding the colony area) for male and female karoro from the lower Hakatere/Ashburton River.

We then analysed the daytime travelling GPS points (Fig 14) to investigate whether certain habitat types were flown over more than others and whether this matched up with the preferred stationary habitats. Short-rotation cropland (45% and 47%) was the most common habitat type to be travelled over by tagged karoro. This was followed by high producing exotic grass (32% and 34%), gravel or rock (6% and 9%), deciduous hardwood (3% and 4%), and ocean (7% and 1%) for males and females, respectively.

28



Figure 14. The percentage of daytime travelling GPS points per habitat type (excluding the colony area) for male and female karoro from the lower Hakatere/Ashburton River.

D) Colony flight frequency and speed

We examined flight frequency and speed for daytime and night-time data for speeds of >1.4 m/s (Fig 15). Daytime flight frequency was close to 40,000 flight events at speeds up to 40 m/s. This was a much greater number of flights compared to the night-time flight frequency of 2,200 flight events at speeds up to 34 m/s.

Furthermore, we analysed whether the phase of the moon would impact flight frequency for either daytime or night-time flying (Fig 16). Although there was a statistical correlation between flight frequency and the moon phase, it was a weak correlation (glm, P-value 0.00706).



Flight frequency & speed - Daytime (>1.4 m/s)

Flight frequency & speed - Night time (>1.4 m/s)



Figure 15. Flight frequency and speed (>1.4 m/s) during the daytime and night-time. The daytime frequency y-axis scale (0-40,000) and the night-time frequency y-axis scale (0-2,500).



Figure 16. Flight frequency and speed (>1.4 m/s) at the new moon and full moon phases during the day (green) and night (blue). The day frequency y-axis scale (0-12,000) and the night frequency y-axis scale (0-800).

We examined flight frequency and speed at different times of the breeding season, incubation, young chicks, and fledglings. This gave us a snapshot of seasonal variation between different offspring life stages that reflect varying levels of parental commitment and resource demands. For example, nest protection during incubation, nest protection and resource demand for young chicks, and chick protection and resource demand for older chicks or fledglings. Wayne (#0603) was observed with one chick and two eggs on 12 December 2022, and so was chosen to be the example for the following graphs (Figs 17-19). The figures show varying flight frequencies and slight

variations in speed, depending on the offspring stage within the breeding season. Additionally, Wayne undertook more night-time flights in February when his chicks would have been fledglings and able to feed themselves, compared to earlier stages of offspring development.



Figure 17. Flight frequency and speed of Wayne (#0603) during incubation, 11-18 November 2022. Daytime data (green), night-time data (blue).



Figure 18. Flight frequency and speed of Wayne (#0603) when he had young chicks, 19-26 December 2022. Daytime data (green), night-time data (blue).



Figure 19. Flight frequency and speed of Wayne (#0603) when he would have fledglings, between 7-14 February 2023. Daytime data (green), night-time data (blue).

E) Similarities and variation between individuals

To examine individual foraging habitat preferences, we separated stationary data points to each individual karoro (Figs 20-21). Copperfield and Houdini were not included as they were MIA approximately a week after deployment. Seven habitat categories were used for individual habitat preference, and included high producing exotic grassland, ocean, riverbed, sand or gravel, shortrotation cropland, woody vegetation, and other. To simplify the graphs, the gravel or rock and the river habitats were merged into one habitat called 'riverbed' as both habitats fell within the riverbank margins, and as the Hakatere/Ashburton River is a braided river, the exact positioning of river and gravel or rock would likely change from year to year as the positioning of the braids move between flood events and seasons. Furthermore, the remaining minor habitat types were consolidated into 'woody vegetation' or 'other'.

All karoro spent the greatest proportion of their time foraging in the riverbed. Short-rotation cropland and high producing exotic grassland were the next highest utilised habitats. Jasmine was the only female that foraged in the ocean on a semi-regular basis. In comparison, all of the males except Wayne foraged in the ocean. Despite the similarities of preferred foraging habitats of the tagged karoro, the data also showed that each bird had different frequencies within those habitats indicating individual preferences (Fig 20).



Female daytime habitat use while stationary (<=1.4 m/s)

Figure 20. Individual daytime foraging habitat use for female karoro. A) Āmio, B) Eve, C) Jasmine, D) Patty. Habitat types from left to right, high producing exotic grassland, ocean, riverbed, sand or gravel, short-rotation cropland, woody vegetation, and other.



Male daytime habitat use while stationary (<=1.4

Figure 21. Individual daytime foraging habitat use for male karoro. A) Hagrid, B) Piranha, C) Tīwheta, D) Wayne. Habitat types from left to right, high producing exotic grassland, ocean, riverbed, sand or gravel, short-rotation cropland, woody vegetation, and other.

F) Travel to other colonies

Some birds may visit or roost at other sections of the riverbed. A few individuals not only had data points at their own nest site, but also >200 m up or down-stream near other tagged karoro nesting sites. However, one bird, Āmio (#046B) travelled ~35 km upstream to near Ashburton Forks to another colony after her nest was flooded in December (Fig 22). She stayed there for approximately a month and foraged in the surrounding farmland (Fig 23) before returning to the original colony in the lower section of the river. It is unknown if Āmio attempted to renest at the upstream site or not, as access to the river and colonies was limited.



Figure 22. Location of the colony where the transmitters were deployed (blue dot), and the location where Āmio (green) travelled to after her nest was flooded. The number in the green dot represents the number of data points within that area.



Figure 23. Location of the colony near Ashburton Forks colony where Āmio travelled to after having her nest was flooded in the lower Hakatere/Ashburton River. Her flight tracks (red). The number in the green dots represents the number of data points within that area.

Discussion

Captured birds

There are multiple methods for capturing bird species depending on the species, their habitat, or a researcher's preferences. Several studies involving the capture and deployment of transmitters on gull species have utilised walk-in traps, noose mats, drop-traps, nest-snare traps, and net launchers as methods to capture birds (Thaxter et al., 2014; Clark et al., 2015; Shaffer et al., 2017; Thaxter et al., 2017; Borrmann et al., 2019; Maynard et al., 2021). For this study, drop-traps and noose mats were used, however, only the drop-traps were successful for capturing karoro. Although individual birds showed interest in the noose mats, no birds walked close enough to be captured by them. It was not determined whether the noose mats were baited with unappealing options, were too conspicuous, or just the wrong method to use for karoro in the area.

Interestingly, once one bird had been captured by a drop-trap in one area of nests (approximately 5-10 m radius), no other birds would enter the drop-trap after it was reset over another nest in the same area. Other karoro with nests in the area would settle back down on their nests quickly, however, the karoro of the new nest with the reset drop-trap would refuse to go under the trap. Instead, it would circle around the trap, looking between its eggs and the trap, and sometimes looking at the trap. Consequentially, the drop-traps were reset 50-300 m away in a different part of the same colony or moved upstream or downstream to another colony where karoro had not seen the drop-traps before. This behaviour suggests, at minimum, a reasonable level of intelligence, as the birds can observe the consequences of others being caught by the drop-trap once and learn from it. To work around this, we set up both drop-traps in one area at the same time so we could maximise our catch rate per catching spot.

Intelligence is not uncommon among animals and has been investigated in a variety of bird species, including large gulls. Holman et al. (2019) observed herring gull (*Larus argentatus*) feeding on an introduced species of sea squirt (*Ciona intestinalis*), in Ireland. Prior to their observations, no gulls in the area had been noted to capture and consume the sea squirts via a multi-step process. The gulls were observed capturing sea squirts, shaking them repeatedly to loosen their cellulose-based external sleeve from their soft inner body, and then proceeding to grasp and extract the soft inner body and consume it, disregarding the outer sleeve (Holman et al., 2019). They witnessed up to 15 individuals of varying ages, displaying this foraging behaviour in the marina, but noted that despite several other gull species foraging in the marina, only herring gull were seen foraging for the sea

37

squirts (Holman et al., 2019). This novel foraging behaviour suggests high flexibility in foraging techniques and sources, as well as problem solving skills to be able to consume a relatively new species in their ecosystem.

Intelligent animals can make research or control operations difficult, as they can learn quickly and can become wary of field gear, baits, or even recognise individual people or vehicles (Cook et al., 2008; Cornell et al., 2012; Scopel & Diamond, 2017). As karoro are actively controlled throughout several rivers within Canterbury to protect other 'at risk' species, continued consideration and flexibility of control methods and timing needs to be given to reduce the likelihood of habituation. Several studies have investigated habituation of large gulls to multiple control methods. Scopel & Diamond (2017) examined the use and effectiveness of lethal and non-lethal control of herring and great black-backed gulls (Larus marinus) in the Gulf of Maine, USA. A large proportion of control in the region has centred around protecting islands for nesting tern species and benefits other species, such as common eiders (Somateria mollissima) and auks (Alcidae) (Scopel & Diamond, 2017). They noted that lethal control methods were more effective at discouraging predatory gulls from the islands and increased tern breeding success compared to non-lethal control methods. Furthermore, Scopel & Diamond (2017) highlighted two islands that had previously been controlled for large gulls that was ceased for almost a decade, and led to the complete abandonment of the islands by terns within 6-7 years. Consequentially, lethal control was reinstated and the terns returned to breed with some success within 2 years (Scopel & Diamond, 2017). These findings support ongoing lethal control of predatory gulls for the protection and breeding success of other species, bearing in mind that control operations should be flexible so large gull species do not become accustomed to methods that could reduce the effectiveness of control operations.

Similarly, Cook et al. (2008) investigated the reactions of large gulls to various control methods across several landfill sites in the United Kingdom. Their study aimed to assess the effectiveness of the various current methods used to deter pest birds from landfills, which could then be implemented effectively for the long term deterrence of birds. The most effective methods utilised in the study were falcons, distress calls, and lethal and blank ammunition. However, the gulls became accustomed to the distress calls over time which reduced their effectiveness (Cook et al., 2008). In contrast, the use of falcons and a combination of lethal and non-lethal ammunition appeared to become more effective over time as the threat of potential death persisted (Cook et al., 2008).

DNA sexing

The birds were caught between mid-morning to early evening and the sex ratio of captured karoro for this study was six males and six females. This suggests that karoro do not necessarily have set parental shifts during incubation. Other Charadriiformes have been noted to have designated day and night incubation shifts. Dowding & Davis (2007) stated that pohowera/banded dotterel males tended to incubate eggs at night, while the females tended to incubate during the day. The breeding plumage of male and female pohowera/banded dotterel is likely a contributing factor, as males have a more defined and brighter coloured band around their neck and chest that is more visible than the female's duller plumage (Pierce, 2013). Because of this, females likely blend in with their surroundings better during the day compared to males. Unlike pohowera/banded dotterel, karoro have very little sexual dimorphism, with the main differences being size and measurements between males and females. This may be one of the reasons karoro appear to not have set parental incubating shifts.

Transmitters

A) The distances that they travel

Overall, there was a significant quantity of GPS data gathered from November 2022 to April 2023. The majority of the transmitters worked well and consistently until Autumn when the daylight and sun intensity has reduced. It was unfortunate that Copperfield and Houdini were MIA within a short time after deployment, as it would have been interesting to assess how their behaviour and preferences were similar and different from the others. It is unclear whether they have relocated to another area where there is inadequate cellular coverage to transmit data, or that they may have died. Copperfield travelled the greatest distance in one day at 292 km, and it would have been interesting to see whether this was a regular pattern or just within the week he transmitted data. Other studies have deployed a similar number of units, often between 5-12 units, as pilot studies and have gained valuable information including migration paths, foraging preferences, and habitat use (Clark et al., 2016; Shaffer et al., 2017; Avisure, 2019; Borrmann et al., 2019, 2021; Maynard, 2021).

Although the mean distance travelled per day for females was 34.9 km, the mean distance ranged from 28.6 - 41.5 km. Patty, was the heaviest female at 900 g had the lowest mean daily distance of 28.6 km and the second lowest max daily distance of 90.5 km, only ~5 km further than Eve with a

max daily distance of 85.9 km. Āmio, had the highest mean and max daily distance travelled at 41.5 km and 223.6 km, respectively. Āmio's higher distances is likely contributed by her travelling upstream near Ashburton Forks after her nest was flooded in the lower section of the river. As it was unconfirmed if Āmio attempted to renest at the new location or not, this may have also influenced her movements. If she did not attempt to renest she may have travelled further each day as she had no offspring to return to. Continued data collection over winter and the coming breeding season will help determine whether this season's movements were an outlier or whether they were a true reflection of her individual behavioural patterns.

Likewise, the mean distance travelled per day for males was 43.5 km. Excluding Copperfield and Houdini, the mean daily distance ranged from 37.2 - 53.2 km. Interestingly, Wayne was the lightest tagged male at 950 g, yet he flew the highest mean daily distance (53.2 km) and the second highest max daily distance of 186.4 km. The heaviest male, Hagrid, had the second lowest mean daily distance at 37.9 km and the lowest max daily distance travelled. Tīwheta travelled the highest max daily distance of 249.7 km. Despite there being no statistical differences in the daily distance travelled, there is an element of variation between individuals.

B) Movements at the landscape level

There were 18 habitat types that the tagged karoro visited throughout the landscape surrounding their colony. The gravel or rock habitat was the most visited habitat (33.9%), followed by short-rotation cropland (31%), high producing exotic grassland (21.6%), river (7%), and ocean (2.1%). The river and gravel or rock habitats consisted of the habitat area within the riverbed. These habitats provide natural foraging habitat aside from coastal areas and the ocean. Additionally, the habitat types adjacent to the riverbed predominantly consist of agricultural farmland that offers supplementary habitat for karoro to explore and forage.

When the GPS points were projected onto a map (Fig 8), it was easy to see where the tagged karoro had been throughout the landscape. There were groupings of data points that sometimes fitted within paddock boundaries, suggesting that those paddocks were an area of high use by karoro for much of the time. Those paddocks may have been irrigated or ploughed at the time of heightened activity, as we have observed large flocks of karoro utilising such paddocks throughout the study period. Interestingly, there were also areas of high activity at certain locations within the riverbed (Fig 9). After analysing map imagery from recent flood events on the Hakatere/Ashburton River 40

from Canterbury Maps, it appears that those areas of riverbed had probably become riffle areas post-flood. Riffles provide areas of shallow flowing water that create favourable habitat for foraging aquatic prey, bathing, and roosting, all of which we had observed karoro utilising over this study.

C) Preferred habitat at the foraging sites

Excluding the colony area, it was unsurprising that the two most utilised habitats during the daytime were short-rotation cropland and high producing exotic grassland while stationary. These habitats extend over a large degree of the landscape, and often offer terrestrial prey assisted by anthropogenic activities (Bell & Harborne, 2019). This foraging behaviour is not uncommon among large gulls, Shaffer et al. (2017) investigated two colonies of western gulls (Larus occidentalis), California, USA. One colony was located on Southeast Farallon Island 45 km off the coast from San Francisco, and the second colony on Año Nuevo Island 1 km from the coastline northwest of Santa Cruz. Shaffer et al. (2017) noted that the Southeast Farallon Island gulls foraged in the ocean 69% of the time, compared to 71% of Año Nuevo Island gulls foraging on land. The geographical locations of Shaffer's et al. (2017) colonies influenced the foraging behaviour and habitat use of the gulls. The habitat use by tagged karoro in this study are likely to be influenced by habitat types in the surrounding landscape. In Canterbury, the landscape is highly modified towards urban and agricultural purposes (Bell & Harborne, 2019). Karoro from the New Zealand Subantarctic Islands may share closer foraging behaviours and preferences to the western gulls on Southeast Farallon Island compared to karoro breeding on the New Zealand mainland, due to their geographical isolation.

With such a high proportion of terrestrial food availability, it was interesting to see that the riverbed was the third most foraged habitat during the day. Braided river are ecosystems of high disturbance and niche areas as the variation between main braids, minor braids and side streams create a range of different habitat characteristics within the river (O'Donnell et al., 2016). Riffles of shallow flowing water create ideal habitat for aquatic invertebrates (O'Donnell et al., 2016), and we observed karoro utilising these habitats multiple times throughout the season. Further investigation into karoro use of the riverbed and its potential feeding sites would help shed light on what type of foraging is undertaken throughout the river, and what proportion of aquatic prey is being consumed, compared to other terrestrial prey species.

41

The daytime stationary habitat use between males and females was similar for most habitats, with females generally utilising the top three habitats slightly more than the males. However, the male karoro utilised built-up areas, the ocean, and the river at a higher rate compared to the females. Similarly, the daytime travelling data followed the same pattern, with males travelling over the ocean substantially more than the females. In contrast, night-time habitat use while stationary largely occurred within gravel or rock areas. The gravel or rock habitat sat within the riverbank margins and may have offered a 'safer' night foraging option close to the colony or possibly an offnest roosting location. A number of aquatic species are nocturnal or swim closer to the surface of water at night, and may provide karoro with a desirable food source after dark.

D) Colony flight frequency and speed

The variation between daytime and night-time flight frequency was significantly different, with daytime frequency about 18 times more frequent than night-time flights. This was expected as karoro are classified as a diurnal species. However, I was not expecting the night-time flight frequency and speed to be so high, as there is limited research around the visual range of karoro, especially at night. The night-time maximum speed was only 6 m/s slower (34 m/s) than the daytime maximum of 40 m/s. Because of this we analysed the data to assess whether the moon phase influenced the frequency of night-time flights. Although there was statical evidence to support a correlation between flight frequency and speed, and the moon phase, it was a weak correlation and overall was not an influencing factor (glm, P-value 0.00706). We assessed this because a higher moon illumination has the potential to increase visibility for birds and assist them to fly more often and at faster speeds on nights with a full moon compared to a new moon. If karoro did fly more often on nights with a full moon, then there could be a potential for increased harassment or predation of 'at risk' birds and their offspring by karoro. Due to limited time, it was undetermined whether these speeds were from birds rushing back to the colony after sunset in semi-light or whether their night vision is better than we anticipate. Further analysis of the data is needed to assess the timing and potential factors influencing these flights, such as sufficient night vision. Further analysis of the data regarding seasonal differences in flight frequency and foraging behaviour and preferences are required to gain a better picture of the preferences of karoro and how they change throughout the different seasons.

E) Similarities and variation between individuals

The transmitter GPS data showed that each tagged karoro had varying frequencies of foraging preference within each habitat type, despite the riverbed, short-rotation cropland and high producing exotic grassland being the top three foraging habitats for every bird. In general, the females appeared to use the top three habitats more compared to the other minor habitats. In contrast, the males appeared to utilise the minor habitats more in proportion to their use of the top three habitat types. This may be due to behavioural rolls or energy requirements of males and females at different times of the breeding season. Although both parents share the responsibility of incubation, Fordham (1964a) noted that male karoro generally does the majority of the nest protection while the female supports him and tends to the eggs if the male is defending the area around the nest. Because of this, the female may increasingly forage in known or easily accessible food sources to decrease the time she is away from her offspring and partner during the breeding season.

The karoro appeared to have individual areas that they visited on a regular basis. There were some areas that overlapped, but each bird appeared to have a foraging pattern that suggested a potential for territorial foraging behaviour. In a similar study, Borrmann et l. (2019) deployed transmitter units on great black-backed gull on the island of Foehr, Germany. They examined individual spatial behaviour and habitat use of seven individuals during incubation and chick rearing (Borrmann et al., 2019). They found minimal overlap in foraging territories between tagged individuals, even though the foraging habitat use was similar between each bird (Borrmann et al., 2019). Additionally, Borrmann et al. (2019) noted strong fidelity to foraging territories and flight direction when birds were leaving the colony. Similarly, Maynard et al. (2021) explored foraging movements and prey availability responses of great black-backed gull at an individual and group-level in Newfoundland, Canada. At the group-level, different foraging responses to changes in food availability throughout the breeding season were undistinguishable (Maynard et al., 2021). However, when they analysed the data at an individual level, there were a number of noticeable individuals responding differently to seasonal prey availability, although not all individuals changed their foraging movements to reflect these changes (Maynard et al., 2021). Our data supports the potential that this may also be the case for karoro in the lower Hakatere/Ashburton River.

Excluding the two birds that went MIA, it was interesting to see that all of the tagged karoro, except one female, Patty, foraged in the ocean at least once. Of the three females that foraged in the

43

ocean, they all utilised the coastal area <1.5 km of the shoreline almost exclusively compared to open ocean >1.5 km, with Jasmine being the only female travelling further than this at a maximum distance of 11 km from the coastline. Similarly, the males spent a large proportion of their ocean foraging within 1.5 km of the coastline, with two of the heaviest males, Hagrid and Piranha, travelling up to 21 km out to sea to forage. Wayne was the exception and only flew a maximum of 3 km out to sea. Considering that karoro are more coastal than open water sea birds, 21 km from the coastline is a substantial distance and it would be interesting to determine whether this foraging preference is linked to the individual's preference, fishing boats, the size of the bird, or just common practice for multiple karoro. Further analysis of the data and the deployment of additional transmitters would be needed to investigate this thoroughly.

F) Travel to other colonies

It is not uncommon for birds to visit or roost at other colonies within a river system or an adjacent area. Gurney (2022) studied the movements of tarapirohe/black-fronted terns *Chlidonias albostriatus*) from the Cass River and Lake Ohau in the Mackenzie Country, Canterbury. He found that the terns would regularly travel between colonies, and even roost at the other colony at times, despite the colonies being >40 km apart (Gurney, 2022).

When Amio's nest was flooded in December, she moved ~35 km upstream near Ashburton Forks. This was surprising, because although Āmio's initial nest was at the top end of the colony in the lower section of the Hakatere/Ashburton River, she chose to fly further away and almost certainly flew over other colonies on her way to the new colony. She could have easily moved 50-100 m downstream and renested within the same colony, which leads to the question, why? There are a number of potential reasons for her choice. First, the upstream colony may have been Āmio's natal colony. Second, she may have started breeding there as a first time breeder but was unsuccessful and so she relocated downstream to nest. But when she was flooded out, she chose to return upstream. Third, she may have successfully nested at the upper colony in a previous breeding season, so she knew the colony was a suitable place to renest. Fourth, Āmio may have decided to investigate a number of potential colonies along the Hakatere/Ashburton River on her way upstream and settled on that colony for another reason. We are unlikely to know how successful or how many breeding seasons Āmio has nested, as long-term observations are required to monitor breeding success and determining the age of a sexually mature karoro is practically impossible without coloured year bands fitted when they are fledglings or juveniles. However, many animals

return to the same or similar area to breed if they have been successful there before. This can be associated with multiple factors including; reliable food availability, limited predation, minimal presence of potential predators, or community protection (Finney et al., 2003; Rome & Ellis, 2004; Fernández-Chacón et al., 2013). Additionally, breeding pairs of gull species and other Charadriiformes have been observed leaving a colony and renesting in another colony if they have an unsuccessful clutch or clutches, both within a breeding season or following an unsuccessful breeding season or seasons (Fernández-Chacón et al., 2013; Thierry et al., 2016; Scopel & Diamond, 2017). Oro et al. (2021) noted that Audouin's gull (*Larus audouinii*) breeding for the first-time would often return to their natal colony to assess whether it was still a suitable and successful colony to breed in. Additionally, they also recorded a number of gulls investigating other colonies or empty uncolonised areas before choosing an area to settle in (Oro et al., 2021).

The act of karoro moving from one colony to another is not necessarily a negative action in itself. However, as karoro are highly mobile species and opportunistic generalist feeders, their travel within the riverbed or to other nesting sites can have a negative flow on effect. Karoro, aligning with other large gull species, are known for intraspecific predation on neighbouring eggs and chicks within their own colony or other karoro colonies close by (Fordham, 1964a, 1964b). Additionally, karoro can have a detrimental effect on 'endangered', 'threatened' or 'at risk' species nesting through interspecific harassment or predation (Thierry et al., 2016). Karoro have been recorded harassing and predating other braided river birds and their young, such as black-billed gull, dotterel, and black-fronted tern (BRaid, n.d.c; Thierry et al., 2016; Bell & Harborne, 2019). Further research is needed to better understand this behaviour and identify determining factors that may increase the likelihood of interspecific harassment or predation, so we can improve management strategies surrounding karoro and increase positive outcomes for declining endemic and native species.

Concluding thoughts and Learnings

Karoro are an intelligent native species that have adapted well to environmental changes. Capture of karoro for transmitter deployment is fairly straightforward, although it requires some flexibility to work around their ability to watch and learn quickly. There were differences in the frequency of data transmission from the units, but overall the transmitters worked well until daylight hours and intensity reduced to a rate that the solar panels were not effective at recharging. We would expect this to improve again as spring and summer approach. Initially while analysing the data, it appeared that the tagged karoro were flying largely at night and were less active during the heat of the day. However, after checking the data against light intensity it was determined that the data was in GMT time, not NZST, despite attempting to download the data in NZST. This highlights the need to verify data before making any assumptions. Once the data was validated, it was unsurprising that the dominating habitat types, short-rotation cropland and high producing exotic grassland, were the most engaged by karoro, however, the riverbed habitat was still highly utilised by karoro. Limiting additional food sources could aid in the control of karoro in areas where they have negative impacts on other braided river birds.

Unfortunately, only minimal seasonal data was examined during this study, but we are anticipating some interesting patterns in the data once analysed. Currently, the tagged karoro are continuing to gather data and ongoing analysis will be undertaken to better understand their use of habitats in the landscape and how that may change throughout the breeding and non-breeding season. This information may help with the management and control of karoro, with the intention to aid in the recovery of other braided river species that are in decline.

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