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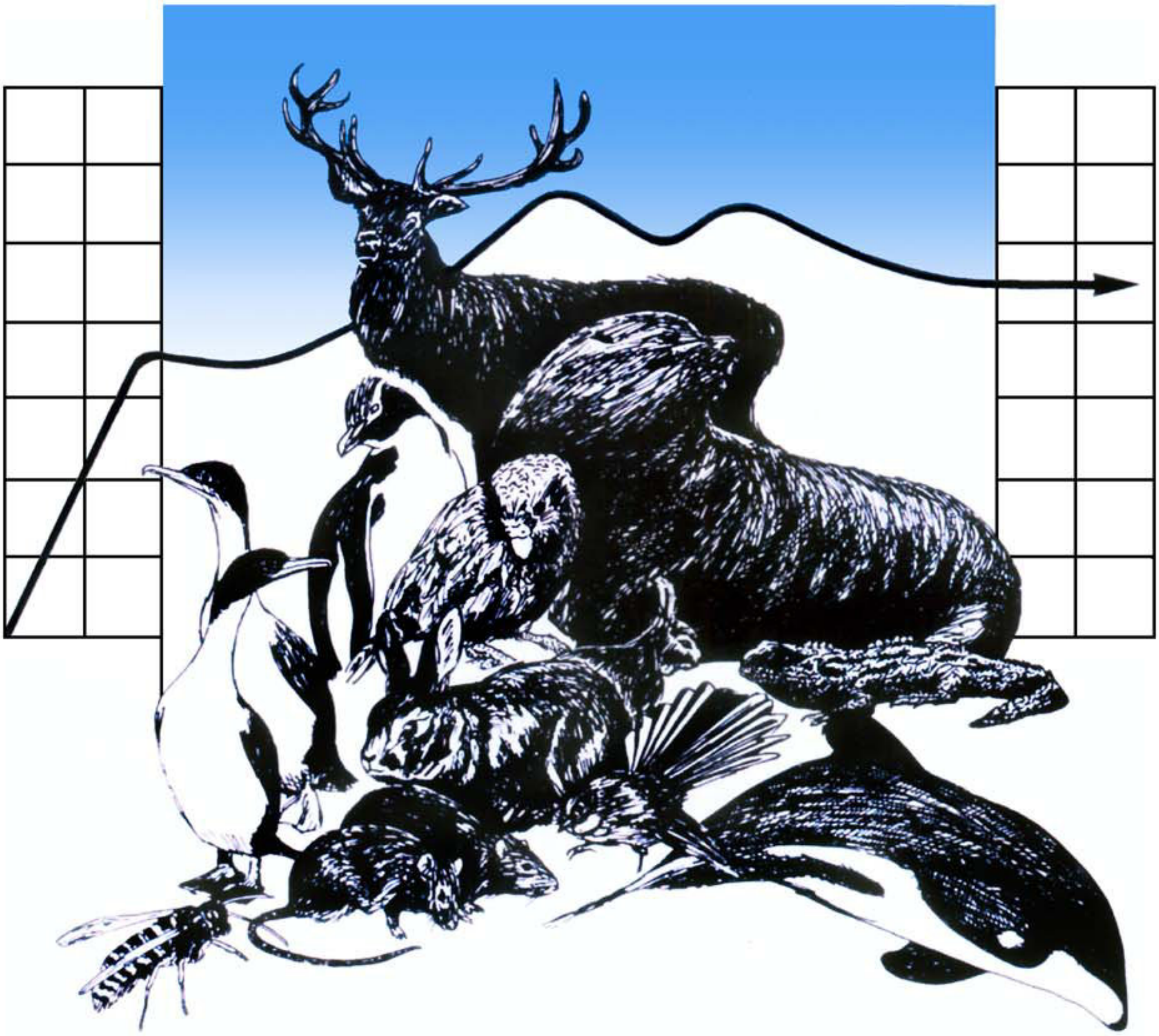

WILDLIFE MANAGEMENT

Investigation into the halt in population recovery of the southern New Zealand dotterel (Charadrius obscurus obscurus)

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Contents

Executive Summary

The southern New Zealand dotterel (Charadrius obscurus obscurus) was once a highly abundant wader species in the South Island of New Zealand however its breeding range is now restricted exclusively to Stewart Island. Cats (Felis catus) are thought to be their greatest threat and are thought to be responsible for a low of 62 individuals in 1992. After the introduction of predator management at important breeding sites numbers have subsequently increased and have plateaued at 270. The main aim of this study was to determine why numbers have plateaued. This was investigated by analysing the role of predators and nesting success between managed and unmanaged sites, in addition to analysing the projected population outcome from the documented population low using survival estimates obtained from a management area.

Surveys were conducted in managed and unmanaged sites (Table Hill and Blaikies Hill respectively) to determine the location of nests and adults as well as to estimate survivability of precocious young. Nests were monitored using trail cameras to analyse predation events and nest success. In addition matrix models were used to form projected population outcomes from the documented low. No nests were located at the unmanaged site but seven were located at the managed site therefore direct comparison between sites could not be undertaken. Of known egg outcomes in the managed site 41.5% were successful, 35.3% failed to hatch for reason other than predation and 23.5% failed due to predation. Therefore hatching success was low in the managed site. Cats were not found to predate incubating adults as was predicted, alternatively eggs were the target of predation by previously unidentified threats; a harrier hawk and white-tailed deer. Failure to hatch for reasons other than predation was the greatest threat to recruitment. Projected figures for today using a matrix model suggests adult survivability is high (>0.7 and <0.9).

Therefore, low recruitment from the younger stages of development and high adult survival may be causing the plateaued population seen today. Density dependent factors may also be a contributing factor however further analyses are required in this area. Due to the short term nature of this study

further research is needed over additional breeding seasons to further identify why southern New Zealand dotterel population numbers are no longer increasing.

Key words

Southern New Zealand dotterel, plateaued distribution, predation, hatching success, managed, unmanaged

1.0 Introduction

The New Zealand dotterel (Charadrius obscurus) is a large endemic wading shorebird (Dowding & Murphy 1993; Dowding 1994). Due to geographic, ecological, behavioural and morphological differences this species is thought to be comprised of two distinct sub species; the southern (C.o.obscurus) and northern (C.o. aquilonius) New Zealand dotterel (Dowding 1994). The northern sub-species has a widely spread population residing on the coastal habitat of the North Island. This sub-species is estimated to contain 1700 individuals and is subsequently described as nationally vulnerable (Hitchmough et al. 2007). In contrast, the southern New Zealand dotterel has a restricted distribution exclusive to Stewart Island. This sub-species crashed to a historic low of 62 individuals briefly in 1992 but has since increased and plateaued at just 270 individuals (Hitchmough et al. 2007). Consequently, the southern sub-species is described as nationally critical (Hitchmough et al. 2007).

In conservation the 50/500 rule has been proposed as a guideline for determining minimum effective population size for wild species (Jamieson & Allendorf 2012). An effective population of more than 50 individuals is needed in the short term to avoid inbreeding depression (Jamieson & Allendorf 2012). Additionally, an effective population of at least 500 individuals is required in the long term to maintain genetic variation for future adaptations to occur (Jamieson & Allendorf 2012). Genetic variation is maintained within a population through a balance of losing genetic variation by genetic drift and creation of variation by mutations (Jamieson & Allendorf 2012). This balance is thought to be achieved in populations of at least 500 breeding individuals. As southern New Zealand dotterel numbers are below 500 individuals this species is under continued threat of genetic drift and loss of genetic variation. Therefore at the current population numbers this species is at risk of losing long-term viability. Currently, the Department of Conservation (DOC) has a short term goal to increase the southern sub-species to at least 300 birds by 2014 (Dowding & Davis 2007). In addition, there is a long term recovery goal to achieve a population of 400 southern New Zealand dotterel that are self-sustaining or require minimal/sustainable management to exist on Stewart Island by 2030 (Dowding & Davis 2007). These goals will aid in the long-term requirement of a minimum viable population of 500 individuals required to sustain genetic variation.

1.1 Southern New Zealand dotterel ecology and breeding biology

The southern New Zealand dotterel exhibits annual seasonal movements from breeding sites to post breeding flocking sites (Dowding 1994). Flocks form in early February and persist until August (Dowding 1994). Flocks are known to form consistently at three coastal locations; The Neck at Paterson Inlet and Cooks Arm at Port Pegasus located in Stewart Island as well as Awarua Bay in Southland (Dowding & Murphy 1993; Figure 1). An advantage to flocking behaviour is the exploitation of food sources on tidal flats at low tide (Dowding & Murphy 1993). Contrastingly, over the breeding season, dotterels move inland to sub-alpine shrubland habitat (dowding & Murphy 1993). Breeding adults remain at these sites from October to the end of January (Dowding & Murphy 1993). Coastal breeding by this sub-species is a rare occurrence but there have been reports of breeding in the sand dunes of Mason Bay in the early 1900s (Guthrie-Smith 1914) and one reported fledged nest in 2012 (Paul Pers. Comm.). Adult dotterel are thought to express site fidelity to both flocking (Barlow 1993) and breeding sites (Phred Pers. Comm.).

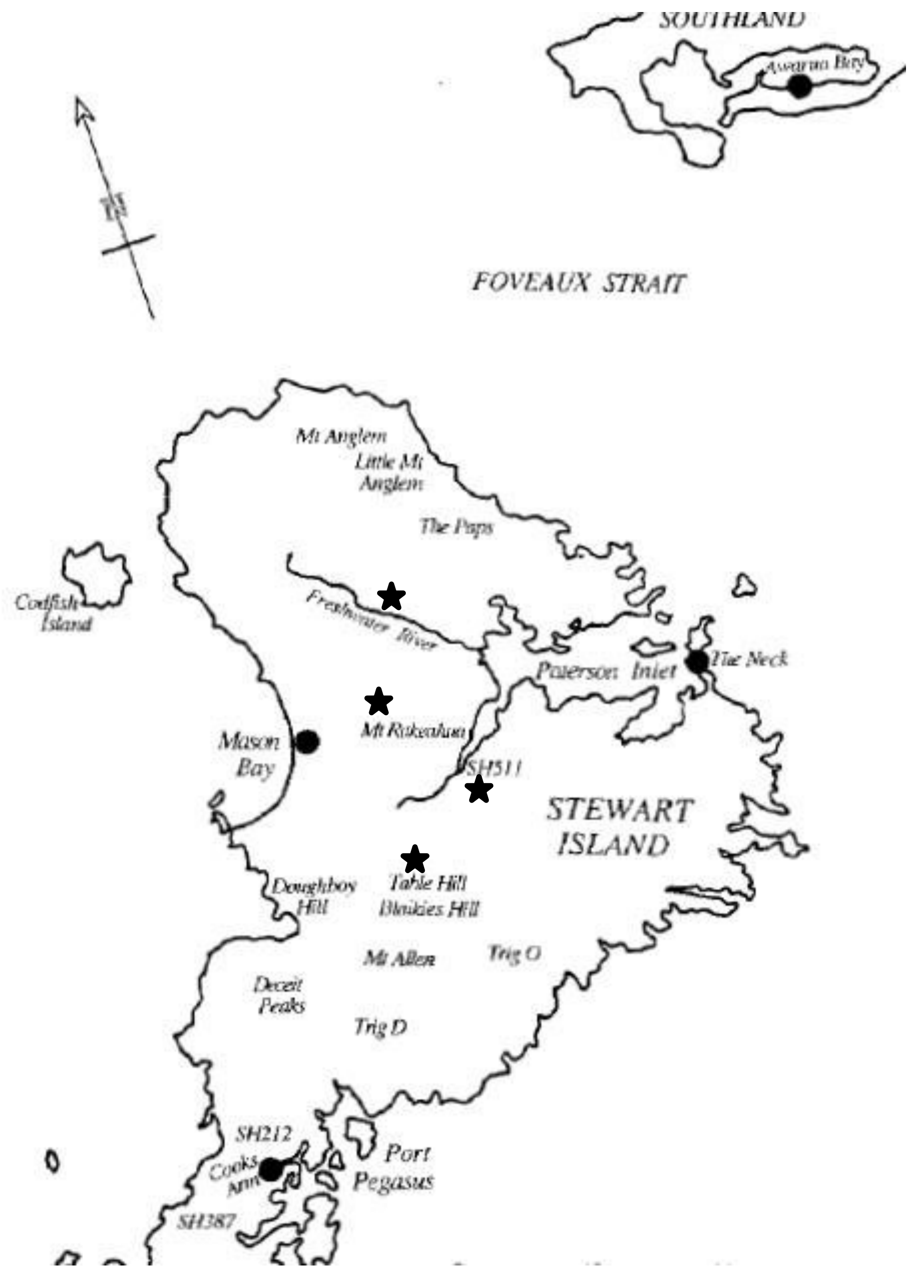

Figure 1: Flock sites of the Southern New Zealand dotterel as well as the location of Masons Bay where breeding has been found to occur. Map obtained from Dowding & Murphy (1993). Added is the managed breeding sites shown by stars; Table Hill, Mt Rakeahua, SH511 and Rocky Mountain.

There is little published research regarding the breeding biology of the southern sub-species. However, their lifecycle is thought to be similar to that of the northern sub species. Fledging occurs at six to seven weeks of age for the northern New Zealand dotterel (Dowding & Davis 2007). Sub-adults (juveniles) then wander for the first 18months to two years, before becoming adults (Dowding & Davis 1993). Once adulthood is reached breeding occurs annually (Dowding and Davis 2007).

Southern New Zealand dotterel clutches range from two to five eggs and are incubated for approximately 28 days (Dowding 1995). Chicks are also known to become precocious a short time after hatching (Ricklefs 1969). The southern New Zealand dotterel is known to be a long lived species with a lifespan of at least 12 years. There is also no distinct sexual dimorphism for this species (Dowding 1993; Dowding 1994),

1.2 Historic and current distribution of Southern New Zealand dotterel

Previous records reveal the southern New Zealand dotterel historically bred both inland and coastally over much of the South Island (Dowding 1999; Figure 2). However, hunting pressure from settlers over the last 100 years and predation by introduced mammals, such as cats (Felis catus), rats (Ratus spp.) and mustelids including ferrets (Mustela furo), stoats (M.erminea) and weasels (M. niualis), have restricted this sub-species breeding range exclusively to Stewart Island (Dowding 1999). There were several sightings of the southern New Zealand dotterel in Central Otago in the early 1950s, as well as the northern region of the South Island (Dowding & Murphy 1993; Dowding 1999). However, these individuals are thought to be non-breeding juveniles (Dowding & Murphy 1993; Dowding 1999).

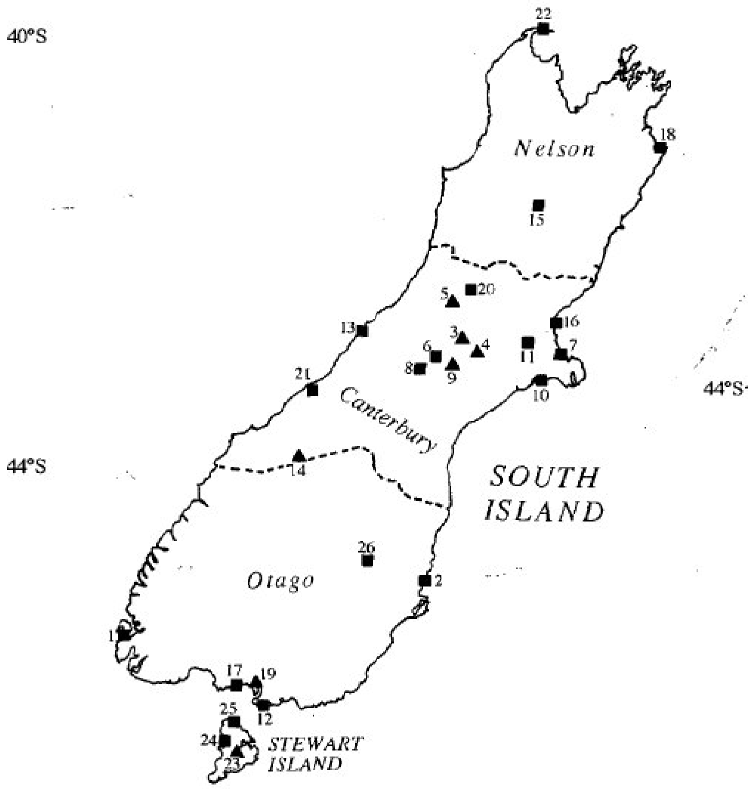

Figure 2: Dowding (1999) proposed distribution of southern New Zealand dotterel before 1940 based on written and museum records. Numbers represent the different locations where southern dotterels have been recorded and triangles are breeding birds.

It was estimated a population of 350 southern New Zealand dotterels were initially present on Stewart Island in the mid 1950's (Dowding & Murphy 1993). However, since this first description there was a huge reduction in dotterel abundances, with the lowest recorded number of 62 individuals being observed in 1992 (Dowding and Murphy 1993; Dowding 1994, 1997). This crash in southern New Zealand dotterel numbers is thought to be attributed to predation by feral cats (Felis catus) and possibly ship rats (Rattus rattus) (Dowding & Murphy 1993; Dowding 1995) and norway rats (Rattus norvegicus) (Dowding 1999). Following the crash in southern New Zealand dotterel abundances, trials into predator control were conducted in the early 1990's. However, management of cats and rats was officially initiated by the Department of Conservation (DOC) in 1995 at important breeding sites (Dowding & Murphy 2001). Cat and rat control is on-going and is currently conducted at four sub-alpine breeding sites today; Table Hill, Mt Rakeahua, SH511 and Rocky Mountain (Dowding & Davis 2007; Figure 1). Following the introduction of predator control the total abundance of southern

New Zealand dotterels has increased to 270 individuals. Consequently, this sub-species is described as reliant on predator control (Dowding & Davis 2007) and without it the average life expectancy is estimated at 5 years (Dowding 1997). However, despite continued management of mammalian predators, southern New Zealand dotterel numbers have plateaued at 270 individuals since 2006. Until this study, research has not been undertaken to determine why population recovery has halted.

1.3 Current threats to Southern New Zealand dotterel

There have been no recorded predation events by cats or rats however theory and previous literature suggests these mammalian predators are the greatest threat to the Southern New Zealand dotterel. This is supported by Harper (2004) who found rats comprise 81.2% of a cat's diet, however, when rat numbers are low the targeted prey of cats' switches and birds become a larger proportion of their diet. In addition, Harper (2004) concluded low abundances of southern New Zealand dotterels was most likely due to chance excursion events by male cats whilst birds were incubating nests. It is believed adult male dotterels are the night time incubators, which increases their vulnerability to predation by nocturnal hunters such as cats (Dowding 1997). Selective predation of incubating males, during the period of low dotterel numbers, is thought to have resulted in a sex bias of two or three females to every one male (Dowding & Davis 1993; Dowding 1997). As a result female-female pairs were formed (Dowding 1995). These pairs lay clutches containing infertile eggs which are incubated but fail to hatch (Dowding 1995). Therefore predation is believed to have not only reduced the number of individuals within the population but also the reproductive potential of the population through the removal of breeding individuals. Rats are also thought to pose a threat to southern dotterels particularly during masting events of Rimu when rat abundances are at their peak (Harper 2004). However, their specific role has not yet been defined.

1.4 Main aim and hypotheses

The main aim of this project is to investigate why the southern New Zealand dotterel numbers have plateaued below 300 individuals. As predators are thought to be the greatest threat to dotterel numbers this study aims to investigate their impact on the dotterel population between managed and unmanaged sites and the impact upon nesting success. Additionally, current population survivability estimates population will be used to analyse population recovery from the documented low. The following hypotheses are thought to be true for the southern New Zealand dotterel:

H1: Dotterel nests in managed areas suffer less predation and disturbance than dotterel nests in adjacent unmanaged habitat.

H2: Predation of adults, eggs and nestlings is greater when dotterels are bound to the nest rather than the precocious phase of breeding.

H3: It is also predicted that cats are the greatest predator of breeding dotterels.

H4: There is an equal number of nesting attempts between managed and unmanaged sites

H5: The survival rates of eggs to fledging and adults on nests predicts the dotterel numbers would have grown at the rate observed during the period of management from the documented population low

2.0 Methods

2.1 Study site

Research was conducted at two adjacent sites on Stewart Island, New Zealand during the 2012/2013 southern New Zealand dotterel breeding season. Sites were selected to directly compare a predator managed and unmanaged site. Table Hill (47°02′59″S 167°49′59″E) is the largest managed breeding site for the southern dotterels. This site has an altitude of 715m above sea level which promotes the growth of alpine shrubland. This habitat is dominated by cushion fields and herb moors and is the chosen breeding habitat for the southern New Zealand dotterel. As breeding occurs in an alpine habitat the area is very exposed and experiences highly variable weather at wide extremes. Southern New Zealand dotterel nests are aboveground in small bowls amongst the cushion plants (Dowding & Murphy 1993; Dowding 1994) and are lined with snow tussock (Chionochloa pungens) (Dowding & Murphy 1993; Dowding 1994). Nests are often located on small ridges or near small landmarks such as mutton-bird scrub.

Predator control of both cat and rats is undertaken on Table Hill; 1080 fishmeal pellets are used to control cats and Brombiolone blocks for rat management. Poison bait is loaded into bait stations spaced approximately 50-70 metres apart around the perimeter of the potential breeding and nesting habitat of the dotterels. The area under management is approximately 3.9km^2. Poison bait is changed every two weeks within all the bait stations and management is carried out from September just before egg laying begins until early February when winter flocks begin to form Research for this study was conducted in conjunction with changing of poison bait. This was the most feasible option due to remoteness of sites.

In contrast Blaikies Hill (47°3'0" N, 167°49'59" E) is an unmanaged site at which breeding of Southern New Zealand dotterel has also been recorded. Blaikies Hill is 443 metres above sea level. This site has similar habitat and contains potential breeding habitat close in size to that of Table Hill.

2.2 Data collection

Surveys were conducted to determine the location of adult southern New Zealand dotterel and nests on Table Hill and Blaikies Hill. Surveys were also used as a tool to assess the survivability of precocious chicks. A survey line was generated by GIS software Arcview 3.0 to allow surveying of the majority of southern New Zealand dotterel habitat for each site. The survey line allowed for surveying of 400m of a habitat at one time (200m either side of the line). The survey line was loaded onto a hand held GPS. Surveys were conducted at normal walking pace along the survey line, scanning for southern New Zealand dotterel using the surveyors own sight and binoculars. If a dotterel was sighted the bird was approached and behaviour analysed to determine if there was a single dotterel, a group of dotterels, a pair, a pair with chicks or a dotterel on a nest. The location was then marked on a hand held GPS with codes to describe behaviour. Locations of any dotterels heard and seen flying were also recorded. Adults with chicks or nests were more vocal. An adult would also try draw an intruder away from the nest with injury feigning or with crouched running whilst tilting their body and approaching that person. If nests or chicks were not present adults were much calmer in your presence. If a dotterel was seen in a location very close to one of a previous survey it was assumed it was the same individual and was marked as such. Dotterels may feed in tidal estuaries and flats during low tide. Therefore to maximise the identification of all individuals at both sites, surveys were conducted two hours either side of high tide (a total of four hours per survey). A survey was conducted approximately every two weeks during the breeding and nesting season on Table Hill. A total of four surveys were undertaken (8th November, 19th November, 4th December and 18th December). Due to bad weather a survey could not be done on the 9th of January as was intended. A fifth survey was also removed from the data set (22nd of January) as the breeding season had reached a completion. Whereas, Blaikies Hill was surveyed three times (8th November, 19th November, 20th Decemeber).

All nests found were monitored using trail cameras. This allowed the identification of predation events of adults, nestlings and chicks whilst tied to the nest as well as identification of predator species. Little Acorn trail cameras (Ltl-5210A 12MP) were strapped to wooden stakes and placed approximately one metre away from the nest with the back of the camera facing a westerly direction, as best as possible, to prevent weather and moisture damage. Cameras were also fitted with covers made from bait stations to protect them from weather damage. Trail cameras were activated by heat and motion and were set to film videos when triggered. Videos were formatted to run for 20 seconds and to be taken with one second intervals. Videos were also set to be of high quality. SD cards (16GB) and batteries from cameras were recycled every two weeks. Cameras were left out until chicks fledged or a predation event occurred. Therefore cameras were removed from nests when no eggs remained. Video footage was analysed for predation events on adults, nestling and eggs.

2.3 Data analysis

H1: Dotterel nests in managed areas suffer less predation and disturbance than dotterel nests in adjacent unmanaged habitat

No nests were located on Blaikies Hill therefore analysis of predation rates between managed and unmanaged sites could not be conducted. However descriptive analysis was undertaken to determine predation rates for nests on Table Hill. Nests were classed as either successful (all eggs hatched), failed (no eggs hatched), predated (all eggs predated), mixed fate (at least one egg hatched and at least one failed to hatch) or unknown (the outcome of the eggs was not captured on video). The mean number of eggs per nest was calculated for the season as well as standard deviation. In addition, the known outcomes of eggs was used to calculate the percentage of eggs predated, those which failed to hatch (for reasons other than predation) and those successfully hatched. Hatching success was calculated as the proportion of eggs that hatch/the number of eggs laid.

H2: Predation of adults, eggs and nestlings is greater when dotterels are bound to the nest rather than the precocious phase of breeding.

Descriptive analyses were used for nest and survey data collected from cameras on Table Hill. The total number of predation events on eggs, nestlings and breeding adults were recorded from nest video footage. Precocious survival was determined for both sites by recording the number of chicks seen during each survey. If chicks were seen in close proximity to a nest site then they were considered to be fledged from that nest.

H3: It is also predicted that cats are the greatest predator of breeding dotterels.

The total number of predation events by cats on dotterels bound to the nests on Table Hill were recorded from nest video footage. Other instances of predation on the nest were also recorded. The number of nests and eggs affected by predation were described as well as identification of the predators involved.

H4: There is an equal number of nesting attempts between managed and unmanaged sites

Surveys were used on both Blaikies Hill and Table Hill to identify all nesting attempts. The number of known nests was then compared between the two sites.

H5: The survival rates of eggs to fledging and adults on nests predicts the dotterel numbers would have grown at the rate observed during the period of management from the documented population low

Firstly the rate of increase for the managed population seen today was determined using four key variables. The first variable was the productivity or number of eggs produced per individual per year. The mean number of eggs per nest for the 2012/13 breeding season was calculated and produced a value of 3.14. This figure was then halved to determine the mean number of eggs produced per individual per year in a managed site (1.57). Secondly, the survivability of eggs to sub-adults (juveniles) was calculated. From the known outcomes of eggs in the 2012/13 breeding season, the percentage which successfully hatched was used for egg to fledgling survivability (0.35). Thirdly, the survivability of sub-adults to adults was calculated. This was not directly analysed within this study so the figure was obtained from the literature for wader species in general. Colwell (2010) states the juvenile (sub-adult) survivability is most often half that of adult survival. The final figure needed was adult survivability from year to year. This was also not directly analysed within this study therefore previous literature was used to determine this figure. Sandercock (2003) states wader species have a high adult survivability which could range from 0.7-0.9. This is a variable range therefore two simulations were run to determine projected populations sizes in managed populations from the documented low; the worst case scenario with an adult survivability of 0.7 and subsequent sub-adult to adult survivability of 0.35 and a best case scenario of adult survivability of 0.9 with a sub-adult to adult survival of 0.45.

These four key variables were then used to conduct a matrix model analysis using poptools version 3.2, in Microsoft excel 2010. The rate of increase (λ) for the New Zealand dotterel in a managed population was determined through a basic analysis for both the worst case and best case scenario.

Not all individuals within a population are breeders as sub-adults are present as well as non-breeding adults therefore the effective population is less than the census population. In 1995 when management was initiated the census population for southern New Zealand dotterel was 75 individuals. Therefore, this study assumes an effective population of 20 individuals taking into account juveniles, non-breeders and the sex bias within the population. A simulation was then run in Microsoft excel 2010 running from 1995 (the year management started) until 2013 (today when data was collected). To do this the effective population was multiplied by λ to determine the size of the effective population for each subsequent year.

To determine the modelled census population for years from 1995 to 2013, effective populations were then multiplied by the proportion of individuals which were effective from the original census population (75/20=3.5). Therefore the census population is estimated to be 3.5 times larger team the effective population. This simulation was run for both worst and best case scenarios from years 1995 to 2013 to estimate the census population. Model outcomes were compared to population trends actually seen today.

3.0 Results

H1: Dotterel nests in managed areas suffer less predation and disturbance than dotterel nests in adjacent unmanaged habitat.

Although data could not be collected to analyse this hypothesis, this study follows the assumption that this is true based on previous literature. As the original hypothesis could not be analysed, the focus became analysing outcomes of nests on Table Hill and how prevalent predation was on nests in this managed site.

A total of 22 eggs were laid in nests for the 2021/2013 breeding season. There were a total of 7 nests, therefore on average there were 3.14 eggs per nest with standard deviation of 0.69. Only one nest was completely successful with all three eggs hatching, two nests were of mixed fate and one was fully depredated (Table 1). In addition, one nest had no known outcome due to a lack of space on the camera SD card (Table 1). Whereas, the last nest (nest 7) had two eggs of unknown outcome for the same reasons as the previous nest. However, this final nest also contained an egg which had failed to hatch. A camera was left on the nest and a predation event by a white-tailed deer (Odocoileus virginianus) was recorded on this egg (Table 1). Therefore, in total there was a known outcome for 17 eggs and the fate of five were unknown (Table 1). Of the known outcomes 23.5% of eggs were predated (4 eggs), 41.5% failed to hatch (7 eggs) and 35.3% of eggs were successfully hatched (6 eggs) (Table 1). Of the eggs which failed to hatch, two were known to be infertile as small holes in the shells revealed the contents were infertile. However, the outcome for the remaining five eggs was unknown. A disturbance was also recorded at the managed site for which a spur-winged plover (Vanellus miles novaehollandiae) approaches a nest and is subsequently frightened off by a southern New Zealand dotterel. Predation did not occur during this disturbance.

H2: Predation of adults, eggs and nestlings is greater when dotterels are bound to the nest rather than the precocious phase of breeding.

There were no instances of predation on nestlings or adults whilst tied to the nest. However there were four eggs predated (Table 1). Therefore results show predation is targeted at eggs rather than nestlings or adult Southern New Zealand dotterel when tied to the nests.

Video footage confirms dotterel chicks become precocious a short time after hatching. Only one nest was completely successful and chicks and adults had left the nest within 24hours of the chicks hatching. There were two mixed fate nests. One of which, two chicks hatched and the remaining egg was incubated for a further six days before the nest was abandoned. The second mixed fate nest had only one fledged chick whilst the remaining three eggs were incubated for three days before the nest was abandoned. It was difficult to determine survivability of precocious chicks as they were rarely seen and periods between surveys were large. Therefore this hypothesis could not be directly analysed from the collected data.

H3: It is also predicted that cats are the greatest predator of breeding dotterels.

Video footage from the seven nests revealed no instances of adult dotterel being predated by cats whilst tied to the nest on Table Hill. Therefore this hypothesis was not supported. There was also no evidence of cats eating nestlings or eggs. Furthermore, rats were also never seen near the nests or predating adults, nestlings or eggs. No breeding dotterel or nestlings were predated whilst tied to the nests, however, there were two instances of egg predation within dotterel nests. The first was an entire nest of three eggs being predated by an Australasian harrier hawk (Circus approximans) (Table 1). Although the harrier is not seen to clearly consume the eggs, a video shows the hawk moving onto the nest. A subsequent video shows the same hawk eating something slightly further down the ridge. No nestlings were seen prior to the hawk approaching the nest and adults were present at the nest after the event, therefore it is assumed the hawk predated all eggs. The second predation event was by a white tailed deer (Odocoileus virginianus) on an egg which had failed to hatch (Table 1). Video footage clearly shows the deer consuming the whole egg. A deer, presumably the same one, approaches the nest the day after the predation event.

H4: There is an equal number of nesting attempts between managed and unmanaged sites

A total of seven nesting attempts were recorded and monitored on Table Hill however no nests were found on Blaikies Hill. However, there were adults found with chicks on separate surveys at Blaikies Hill. This suggests there were fewer nesting attempts on Blaikies Hill an unmanaged site compared to the managed site of Table Hill. However, when surveys were first conducted adults with chicks were found on Blaikies before nests were found on Table Hill. This suggests breeding may be occurring earlier on Blaikies Hill.

H5 The survival rates of eggs to fledging and adults on nests predicts the dotterel numbers would have grown at the rate observed during the period of management from the documented population low

The modelled proposed worst case scenario for the southern New Zealand dotterel was an increasing population from a λ of 0.925. It was modelled by 2013 the effective population was only 4.9 individuals with a census population of 18.4 individuals. Whereas, the best case scenario reveals an increasing population, λ of 1.103317, with an effective population of 117.3912 and census population of 440.21 individuals in 2013.

Neither of these two modelled scenarios accurately explains the plateaued population seen today. The figures produced vary widely to the 270 individuals seen today. Thereforethis hypothesis is not supported.

Table 1: The data collected for each of the seven southern New Zealand dotterel (Charadrius obscurus obscurus) nests on Table Hill for the 2012/13 breeding season. The fertility (fertile, infertile and X which means failed to hatch for unknown reasons) of each individual egg as well as predation events on each individual egg were recorded within nests. The total number of eggs, total number of chicks fledged and fate of each nest was also described for individual nests.

Nest	Total number of eggs per nest	Individual numbers for eggs within nests	Fertility of individual eggs	Predation of individual eggs	Total chicks fledged per nest	Fate of each nest
1	3	1	Fertile	No	2	Mixed fate
		2	Fertile	No		
		3	X	No		
2	2	1	Infertile	No	0	Failed
		2	Infertile	No		
3	4	1	Unknown	Harrier	0	Failed
		2	Unknown	Harrier		
		3	Unknown	Harrier		
		4	Unknown	Harrier		
4	3	1	Fertile	No	3	Successful
		2	Fertile	No		
		3	Fertile	No		
5	4	1	Fertile	No	1	Mixed fate
		2	X	No		
		3	X	No		
		4	X	No		
6*	3	1	Unknown	Unknown	Unknown	Unknown
		2	Unknown	Unknown		
		3	Unknown	Unknown		
7*	3	1	Unknown	Unknown	Unknown	Unknown
		2	Unknown	Unknown		
		3	X	Deer		

*Camera Sd cards ran out of free space and outcome of nests was not recorded

4.0 Discussion

4.1 Predation interactions and nesting success between managed and unmanaged breeding sites

Predation rates are assumed to be significantly lower in managed sites when comparing to unmanaged sites, due to selective elimination of predators. This assumption is true for previous studies on waders which experienced greater nesting success in managed sites due to reduced predation rates. Northern New Zealand dotterel were found to exhibit greater nesting success with the production of more eggs per season (Wills et al. 2003) and a greater number of chicks fledged per pair (Dowding 2001, 2007) in managed areas over unmanaged sites. Additionally, two New Zealand shorebirds the Pied (Himantopus himantopus leucocephalus) and Black stilt (Himantopus novaezelandiae) (Pierce 1986) and the Chatham Island oystercatcher Haematopus chathamensis have also expressed greater nesting success in managed sites (Moore & Reid 2009). The predation rate on nests could not be analysed between managed and unmanaged sites for the southern New Zealand dotterel as no nests were located on Blaikies Hill. However, before the introduction of predator management the adult mortality, of the southern New Zealand dotterel, was thought to be three times greater on Stewart Island compared to the northern New Zealand dotterel (Dowding 1997). The life expectancy has subsequently increased from five years to at least 12 years (Dowding 1997). This suggests predator control was benefitting the population. As the predator management strategy has not changed it is assumed the managed site will be experiencing greater nesting success due to lower predation rates. Further research is needed to determine if this assumption is true but for the purposes of this study it is presumed to be true.

Due to lack of nests within the unmanaged sites nesting success could only be analysed for the managed breeding site. Table Hill had only one completely successful nest, two were of mixed fate, one was fully predated and the remaining two were of unknown outcome (one of which had a known predation event on a single egg). The southern New Zealand dotterel exhibited low hatching success as only 35.3% of known egg outcomes resulted in fledging. This low hatch rate has been attributed to predation and failure to hatch for reasons other than predation. There were a total of two predation events recorded during the nesting phase in the managed areas. Both of these events targeted eggs rather than nestlings and breeding individuals from within the nest. A study by Saunders & Maloney (2002) found 85.7% of lethal events were on eggs for three ground nesting birds in the Waitaki. In particular predation of black stilt eggs was greater than that of breeding adults and nestlings when tied to the nest (Saunders & Maloney 2002). Predation is often identified as the most common cause of nesting failures (Ricklefs 1969), however only accounted for a small proportion of egg failures within this study (35.3% of known outcomes). The failure of eggs to hatch for reasons other than predation was the greatest cause of low hatching success for the southern New Zealand dotterel and accounted for 41.4% of the known outcomes of eggs. Southern New Zealand dotterel do not re-nest if a clutch fails during a breeding season. Therefore, low hatching success of eggs is detrimental for productivity and recruitment of the population.

As precocious chicks were rarely seen this resulted in an inability to compare predation rates between the nesting phase and precocious phase of breeding. The adults and chicks from the only successful nest abandoned the nest within 24hours of eggs hatching thus are described as nidifugous. Surveys were also conducted with large intermittent periods between each. These two factors reduced the ability to adequately assess precocious chick survival as individuals may have moved great distances in that time frame. However, the lack of chicks seen during surveys may also mean precocious chick survival is very low. Conversely, previous work suggests rapid growth during early life stages and small clutch sizes have evolved to reduce the occurrence of predation events (Shkedy & Safriel 1992). This may be emulated by the Southern New Zealand dotterel as clutches range from two to five eggs and are incubated for approximately 28 days (Dowding 1995). Chicks are also known to become precocious a short time after hatching (Ricklefs 1969). This may imply southern New Zealand dotterel experience increased vulnerability to predation during the early nestling phases in comparison to the precocious phase.

Feral cats did not predate breeding dotterel within the managed site. This is contrary to previous literature which suggests cats are the greatest threat to southern New Zealand dotterel by removing breeding individuals and most often the incubating males (Dowding 1997). The population recovery after the introduction of cat and rat management suggests these predators were previously a threat to southern New Zealand recovery. Other studies support cats being the greatest predators of ground nesting species. Cats were responsible for 43% of lethal predation events on ground nesting species in the Upper Waitaki Basin and targeted eggs, nestlings and adults on the nest (Saunders & Maloney 2002). This study instead found predation events were from previously unidentified threats which included an Australasian harrier hawk and a white-tailed deer. These predation events targeted only eggs from within the nests.

An entire nest containing three eggs was removed and consumed by an Australasian harrier hawk (Circus approximans). During surveys of Table Hill no harrier hawks were identified within the dotterel breeding habitat. Although the harrier is not seen to clearly consume the eggs, evidence from video footage draws the conclusion eggs are predated from within the nest. There have been no reported depredation events on southern New Zealand dotterel nests by harrier hawks previously but former research reveals they have been found to predate eggs from other ground nesting birds. Baker-Gabb (1981) found mammals were the most commonly selected prey for Australasian harrier hawks; however birds and their eggs were only fractionally less common. Harriers were also found to target prey less than 300g and less than 500g during the breeding season (Baker-Gabb 1981). Adult southern New Zealand dotterel weight ranges from 147-179g (Dowding 1994) therefore all life stages of this species have the potential to be targeted by harriers. However, most often vulnerable stages such as nestlings and fledglings of avian species are targeted (Baker-Gabb 1981). Wills et al. (2003) captured one instance of an Australasian Hawk consuming eggs from a northern New Zealand dotterel nest. However, events of this kind were very rare. Furthermore, during a five year study, harriers were also found to occasionally predate black stilt nests and were recorded to predate a black stilt chick, a hatching egg and a ceramic egg from nests (Sanders and Maloney 2002). In addition, Pierce (1986) found pied stilt eggs were predated by harriers. The rarity of these predation events suggests harriers do not actively seek out these nests to predate them but opportunistically feed upon them. Rodents were also discovered to be a large part of harrier diets (Baker-Gabb 1981). It could be that management is reducing rodent numbers and dotterel nests are now becoming a greater food source. Additionally, the hawk at the managed site may have been outside of its usual range as no hawks were seen prior to or after this event. Therefore, further investigation is needed to determine the role of harrier hawks on the southern New Zealand dotterel and the regularity of predation on southern New Zealand dotterel.

Furthermore, a predation event by a white-tailed deer (Odocoileus virginianus) was recorded for an egg which had failed to hatch and was abandoned in the nest. Our video footage clearly shows the egg being picked up intact and visibly ingested by the white-tailed deer. Presumably the same deer also appeared at the nest the day after the egg was consumed to potentially locate more eggs. Predation by a white-tailed deer has never previously been recorded for New Zealand ground nesting birds before. Therefore, this is a highly novel finding in the New Zealand environment. However, this type of feeding behaviour has been recorded in America. Pietz & Granfors (2000) found deer removed all the eggs from a nest containing four quail eggs. There have also been reports on deer predation on songbird nestlings in North Dakota (Pietz & Granfors 2000). White-tailed deer are believed to be opportunistic feeders but deliberately predated nests in North Dakota (Pietz & Granfors 2000). Therefore predation events by white-tailed deer may occur more often than what was seen during this breeding season. Whilst conducting research on Table Hill at least three deer were seen within dotterel habitat, therefore further study is needed to determine if deer target nests or opportunistically feed upon them. The return of the white-tailed deer to the nest may show recurring behaviour towards nest predation.

A Spur-wing plover (Vanellus miles novaehollandiae) was also filmed near a dotterel nest. Video footage shows a dotterel attempting to scare the plover from the nest. There was no evidence of predation by the spur-winged plover but footage clearly shows a disturbance to the incubation of the nest. Wills et al. (2003) found spur-winged plovers can destroy nests. Four Northern New Zealand dotterel nests were destroyed during the 1997/98 season by pecking one or two small holes in each egg (Wills et al. 2003). Whilst checking nests some eggs were found with small holes. However the reasoning for these small holes is unclear as SD cards were full and videos did not capture the event which caused this. Therefore further investigation is required to determine if spur-winged plovers are a threat to the success of the southern New Zealand dotterel.

In addition to predation events and nesting success, the number of nesting attempts between managed and unmanaged sites can also have important implications for population dynamics. In particular the number of nesting attempts is an important factor to consider when deciding on extensiveness of management and possible translocations. Greater recruitment has been identified in duck populations with predator management (Rohwer et al. 1995). If greater recruitment of breeding southern New Zealand dotterel occurs in managed breeding sites and recruited individuals show site fidelity numbers may greatly improve. This is provided nesting success is greater in managed sites. This may be true for southern New Zealand dotterel as they have been found to express site fidelity (Phred pers. Comm.). Consequently, unmanaged sites may be losing breeding individuals. As a result managed sites may need to be extended and translocations could be initiated to further improve nesting success. Table Hill had a total of seven Southern New Zealand dotterel nests over the 2012/13 breeding season. Contrastingly, no nests were located on Blaikies Hill although two adults with chicks were found on separate occasions. This suggests two nesting attempts occurred in the unmanaged site. Therefore, the unmanaged site may experience fewer nesting attempts. Surveys were designed to maximise the effort across potential breeding habitat to identify all nesting attempts in both sites. However, ability to identify dotterels to distances of 200m, as intended, would have been difficult. Therefore, a small proportion of nests may have been overlooked. Nonetheless, survey effort was consistent between sites therefore these sites are comparable. It is important to note chicks were found in the unmanaged site at the same time the first nest was discovered in the managed site. This may suggest the breeding season is occurring earlier in unmanaged sites. If this is true an accurate account of nesting attempts in the unmanaged area would not have been found for the 2012/13 breeding season. If in fact managed sites do exhibit greater nesting success and recruitment management area may need to be extended.

4.2 Low hatchability in southern New Zealand dotterel

During the 2012/13 breeding season the southern New Zealand dotterel expressed low hatching success with only 35.5% of eggs hatching and becoming precocious from known egg outcomes. Only one nest was completely successful and two were of unknown outcome. The remaining four nests all exhibited failure to hatch in at least one egg. The failure of eggs to hatch for reason other than predation, was the greatest cause for concern within dotterel nests (6 of 17 eggs or 41.5% failed to hatch). For two eggs it was known infertility was the cause. Whereas, the reasons for failure of another five eggs is unknown. Low hatchability for nests has been explained using a number of reasons including extreme weather, inbreeding, limited food supply, contaminants and predators. Mixed fate nests also attributed to low hatchability of eggs. As discussed predators play a small role in low hatchability for the southern New Zealand dotterel. However, the remaining proposed explanations were not investigated within this study.

Infertility was identified as the cause of failure in two eggs. Infertility is often described as a factor in low nesting success however the reasoning behind this infertility is rarely researched. However, for the southern New Zealand dotterel female-female pairs have been known to form when males are limited. These pairs produce eggs which are infertile and fail to hatch. However, clutches are normally large in these cases (4-5 eggs Phred. Pers, comm.; Dowding 1995) as both females will deposit eggs into the nest. There were only two eggs within the infertile nest therefore it does not seem likely it was a female-female pair. However, this species shows no distinct sexual dimorphism therefore it is impossible to determine morphologically if a pair consisted of all females or a male-female pair. DNA analysis would be the only way to accurately determine the sexes of each pair.

The southern New Zealand dotterel breeds at sub-alpine habitat on Stewart Island. Alpine sites often experience highly variable weather at wide extremes (Martin & Wiebe 2004). This habitat is also highly exposed with little tree vegetation to provide relief from prevailing weather. Therefore, breeding adults expend more energy for egg incubation and raising young in this highly fluctuating environment (Piersma et al. 2003). However, if weather was to be more severe in a given season resources are exhausted even further and fewer eggs survive these seasons. Effects of adverse weather are more prevalent in species which lay only single clutches per breeding season and have restricted breeding seasons (Martin & Wiebe 2004). Therefore, there is potential for this impact upon southern New Zealand dotterel. In addition, females may compromise body weight to produce a clutch during adverse seasons. During harsh breeding seasons females which compromised body condition to initiate breeding had low breeding success (Martin & Wiebe 2004). Furthermore, small eggs laid by light weight Pied Flycatcher (Ficedula hypoleuca) females could not incubate as long as heavier females and had eggs which were more sensitive to the cold (Järvinen & Väisänen 1983). Further research needs to be undertaken to determine if extreme weather was a factor in reduced hatchability in southern New Zealand dotterel

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Often adverse weather impacts upon the amount of food available within a given habitat. Due to the increased energy demand during periods of harsh weather more food is needed, however food is often restricted resulting in reduced body condition of individuals (Hogstedt 1981). Females in better condition can incubate eggs for longer periods which greatly reduces time spent away from the nest (Hogstedt 1981). Reduced clutch sizes can be seen in plovers when food is limited (Ricklefs 1969). However, it appears this is not an issue for this breeding season as Dowding and Murphy (2001) found the average clutch size for the New Zealand dotterel was three eggs which is very similar to the average of 3.14 this study calculated.

Low hatchability is exhibited in clutches of inbred females or when the zygote itself is inbred (Van Noorwijk & Scharloo 1981). The 50/500 rule predicts populations with less than 50 breeding individuals are likely to undergo inbreeding depression (Jamieson & Allendorf 2012). The number of effective individuals within the southern New Zealand dotterel population is assumed to be greater than 50 individuals when the census population is 270 individuals. Provided gene flow is occurring between breeding sites inbreeding is not expected to be an issue. In addition environmental contamination can be a cause of low hatchability. However, southern New Zealand dotterel are found in areas of no human development therefore it is highly unlikely contaminants are implicating hatching success in this species.

Mixed fate nests were identified as nest where at least one egg hatched and one egg fails. Two nests of this nature were identified on Table Hill. Infertile eggs amongst successful eggs were most often the last laid egg in the New Zealand shore plover (Davis 1994). Egg size progressively decreased with the laying of each egg within a clutch and later smaller eggs were less likely to hatch compared to earlier heavier eggs (Sánchez-Lafuente 2004). This indicates egg mass plays a key role in hatchability of eggs. This could be true for one mixed fate nest which successfully hatched two chicks but exhibited a failure of one egg to hatch. However, the remaining mixed fate nest had only one successful egg and three unsuccessful therefore is not explained by this.

4.3 Modelled projections for the southern New Zealand dotterel population during period of management from the documented low

Modelled projections for the southern New Zealand dotterel from the documented low do not accurately described the trends seen in the population today. The worst-case scenario predicted a population of 117 individuals in 2013. This population size is significantly smaller than what is seen today. Whereas the best case scenario predicts the census population would be at 440 individuals today. We can assume the data used for the number of eggs produced per individual per nest and egg to fledgling survival are reasonably accurate as they were collected from real data from the managed site during the 2012/13 season. However, survival rates for sub-adults to adults and adults from year to year have not previously been researched for the southern New Zealand dotterel. Also the effective population in 1995 was a guestimate. Therefore, figures obtained are based on estimates for waders as a whole therefore may not accurately describe the southern New Zealand dotterel figures but gives a general idea of trends which are most likely to be seen. The range of 0.7-0.9 adult survivability used in this study has been cited in previous literature therefore has been justified for use in this study. Additionally, Goss-Custard (1980) found adult survivability in small waders does not exceed 35% and is probably much less, whereas larger species have an adult mortality of less than 10%. These figures range from 0.65-0.9 which is similar to that of Sandercock (2003). As Sandercock (2003) is a more recent study data from this study was used. Additionally, breeding individuals on nests were found to exhibit high survivability which in support of these ranges over the breeding season.

This modelled data indicates adult survivability is likely greater than 0.7 as the population size today is greater than that predicted for the worst case scenario. However, adult survivability is expected to be below 0.9. This indicates adult survivability is high in the southern New Zealand dotterel and it is low hatching to fledgling survivability as well as low sub-adult to adult survivability which are having the greatest impact on the projected population abundance.

Furthermore, southern New Zealand breeding pairs are known to form and defend discrete territories. Goss-Custard (1980) found that territorial behaviour in waders can limit the availability of habitat for pairs to breed and up to 60% of the adult population can be non-breeders as a result of this. Therefore due to the restricted size of management sites, density-dependent factors may be impacting on the population's ability to increase above 300 individuals. This is then described as the management area having reached carrying capacity which is impeding an increase in population numbers. If carrying capacity has been reached predator managed sites would need to be extended for population growth to occur. This was not taken into account when conducting the modelled projections for 2013, if a density parameter was added the best case scenario may be more fitting to explain population trends during the period management for this species.

4.4 Conclusions

Predation rates are assumed to be greater in unmanaged sites in comparison to managed sites. The population increase seen with the implementation of predator management supports this assumption. Low hatching success through predation and failure of eggs to hatch as well as low sub-adult to adult survival were found to be the greatest threat to the recruitment of the managed population from both nest monitoring and modelling projections. Predation was previously identified as the main threat to southern New Zealand dotterel however cats were not found to be reducing breeding individuals within the population and instead eggs were targeted by a harrier and white-tailed deer and explained a portion of egg failures. The recovery of the population after management suggests cats and rats were a threat to this population but nest monitoring reveals they may no longer be a main factor impacting on the population as their numbers may now be held at a low level. The failure of eggs to hatch for reasons other than predation was identified as the greatest contributor to low hatching success. Infertility of eggs had an impact but a number of other factors may also determine the success of eggs. Adult survival is expected to be high based on modelled projections and outcomes from previous literature. Therefore, high adult survival and low recruitment into the population from eggs to fledglings and sub-adults to adults suggests few individuals are being added to the population and few are being lost. If numbers lost and gained are similar or equal this would explain the plateaued population size. Density dependent factors may also be contributing to the halt in population recovery but are yet to be analysed.

4.5 Management implications and recommendations

This study can be used as a pilot study for continued research and offers guidance for future management of the southern New Zealand dotterel. This was a sort term study over one breeding season therefore should be extended over a number of breeding seasons to accurately determine the frequency of predation and the identification of species involved in both the managed and unmanaged sites. This will determine if predation seen in this study were isolated events or regular occurrences. Both surveys and nest monitoring proved to be useful tools for determining predation rates and nest success and should be continued. However surveys should be conducted more frequently to determine precocious chick survival and to identify threats. The outcome of failed eggs should also be investigated in future. This will determine if egg failure is due to predation, infertility or death of an embryo.

Although cats and rats were found to have no impact on dotterel survival during the nesting stage in managed sites, the increase in dotterel numbers after the introduction of their management suggests they are highly susceptible to these predators and numbers may be well controlled at this point.

Therefore predator management still needs to be conducted at the beginning of the nesting season. Cat and rat camera traps should also be implemented to determine the frequency of these predators in managed and unmanaged sites.

There is not enough evidence to suggest management areas need to be extended presently, as recruitment is thought to be low. However, density dependent factors need to be taken into consideration to determine if this is restricting recruitment of individuals and population growth. If so management areas will need to be extended in future.

There is also a need to band adults and possibly chicks if possible. This will allow greater estimates of survival for precocious chicks, sub-adults and adults. Obtaining accurate estimates of these figures will highlight if it is indeed low hatching to fledgling survival and high adult survivability which is causing a plateaued distribution in population numbers. Steps such as artificial egg incubation (to prevent egg death) and nest cages (to prevent predation by deer and hawks) may be required if eggs are found to have low hatching success in the long term.

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