The effect of Norway rats on coastal waterbirds of the Falkland Islands: a preliminary analysis

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Abstract The Falkland Islands have been affected by anthropogenic-induced habitat modification including introduction of invasive species and grazing by livestock. Introduced Norway rats are known to have a large effect on native Falklands passerines but their effect on other native birds has not been explored. We investigated the effects of several environmental variables, including the presence of Norway rats and chronic grazing by livestock, on an assemblage of 22 species of coastal waterbirds by comparing species richness and relative abundance of birds among 65 rat-infested islands, 29 rat-eradicated islands and 76 historically rat-free islands. Bird count data from 299 km of coastline were used to estimate relative bird abundance, expressed as the number of individuals per kilometre of coastline for each species. Our study provided three key results. First, coastal waterbird abundance on islands historically without rats was twice as high as that on islands where rats were present. Second, bird abundance on rat-eradicated islands was intermediate between that of historically rat-free and rat-infested islands. Third, habitat modification by grazing appeared to reduce bird abundance in both rat-free and rat-infested habitats. From a conservation perspective, this study suggests that rat eradication programmes in the Falkland Islands are effective at restoring coastal waterbird abundance and would be even more so if carried out in conjunction with restoration of native coastal plant communities.

Keywords: cat, ecotype, eradication, grazing, marine, mouse, Norway rat, *Poa flabellata*, relative abundance, tussac, warrah

INTRODUCTION

The Falkland Islands are an archipelago of 477 islands (Falkland Islands Government, 2014) that differ in size, habitat modification and presence of introduced species. This creates unique opportunities to examine the effect of anthropogenic factors and stochastic events on the distribution and abundance of native species (Hall, et al., 2002; St. Clair, et al., 2011).

Human colonisation of the islands in the late 1700s led to considerable changes in native flora and fauna. Grazing by livestock caused a reduction of almost 80% in the coastal grasslands of tussac (*Poa flabellata)* (Strange, et al., 1988), which greatly affected bird species and populations (Strange, 1992; Woods, 1984; Woods & Woods, 2006). Major changes to bird populations are also attributed to the introduction of Norway rats (*Rattus norvegicus*), black rats (*R. rattus*), house mice (*Mus domesticus*), cats (*Felis catus*) and Patagonian foxes (*Lycalopex griseus*) (Woods & Woods, 2006; Falklands Conservation, 2006). Norway rats are now present on about half of the archipelago's islands (Tabak, et al., 2015a) and are known to have a large effect on the abundance and diversity of Falklands' native passerine species (Hall, et al., 2002; Tabak, et al., 2015b), while the black rat has been recorded on one island only. Cats are known to prey on thin-billed prions (*Pachyptila belcheri*) (Matias & Catry, 2008), although nothing is known of their impact on other Falkland bird species. Mice impact small burrowing petrels and some passerine species (Rexer-Huber, et al., 2013) and Patagonian foxes reduce the breeding success of coastal waterbirds (Poncet, 1998). Prior to the arrival of these invasive predators, the only terrestrial mammal was the endemic warrah or Falklands wolf (*Dusicyon australis*). Restricted to the two largest islands (East Falkland and West Falkland), this native canid may have been present for at least 70,000 years before being exterminated in 1876; craniodental evidence and first-hand accounts indicate that the warrah was an efficient predator, subsisting on penguins, geese and seals (Slater, et al., 2009). Beyond all doubt, it must have had a major impact on the distribution and abundance of all wildlife species on East Falkland and West Falkland.

The effects of introduced predators and their removal on passerine and seabird species have been relatively well documented for many islands world-wide (Ebbert & Byrd, 2002; Courchamp, et al., 2003; Rauzon, 2007; Kurle, et al., 2008; Towns, 2011; Veitch, et al., 2011), including the Falkland Islands (Woods, 1970; Strange, 1992; Woods & Woods 1997; Hilton & Cuthbert, 2010; Poncet, et al., 2011; Tabak, et al., 2014) where the eradication of Norway rats from 80 islands since 2001 provides a large-scale experiment for evaluating wildlife response to the removal of rats. Studies have shown that successful eradications result in a higher species richness of passerines (Hall, et al., 2002) and an increase in abundance of both passerines (Tabak, et al., 2015b) and invertebrates (St. Clair, et al., 2011). However, nothing is known of the impact of introduced predators on Falkland's shags, gulls, wildfowl, waders and birds of prey (referred to hereafter as coastal waterbirds) or of the response of these birds to rat eradication.

The evaluation of the subsequent recovery of native species and ecosystems following alien species eradication is an essential part of the process of determining the success of an operation (Courchamp, et al., 2011). In this study, we examined the potential effect of several environmental variables on the distribution and abundance of a coastal waterbird assemblage consisting of 22 species of ground-nesting, coastline-foraging birds. Using estimates of relative bird abundance (individuals per unit of coastline transect length) and species richness as the response variables, we compared bird populations on tussac islands that were historically rat-free, with those that were rat-infested and those where rats had been eradicated, and we examined bird response to habitat modification by grazing. We hypothesise that (1) the presence of rats would reduce bird abundance and species richness; (2) bird abundance on islands where rats had been eradicated would be higher than on rat-infested islands; and (3) long-term grazing of native habitats would reduce bird abundance and species richness.

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METHODS

Study area

The Falkland Islands archipelago (12,200 km^2) is situated approximately 500 km east of continental South America between latitudes 51°S and 53°S in the South Atlantic Ocean. It consists of the two large island masses East Falkland (6,480 km^2) and West Falkland (4,450 km^2), 475 smaller vegetated offshore islands (an island being defined as any vegetated land surrounded by water at low tide) and numerous associated rocks and stacks (Falkland Islands Government, 2014), totalling over 6,000 km of coastline. Surveys of all bird species were conducted on 168 offshore islands, and on East Falkland and West Falkland. The majority of islands included in this study were remote and uninhabited, requiring access by boat.

Coastlines surveyed were typical of most rocky offshore tussac islands with upper littoral and intertidal zones of gently to moderately sloping rock, shingle or boulder, occasional small sand beaches and short stretches of sheer cliff on exposed coasts (Strange, 1992). Coastline vegetation on ungrazed islands was dominated by the native grass tussac (*Poa flabellata*), which grows up to 3 m tall and forms dense canopies. On islands grazed by livestock, plant communities were dominated by short swards of grasses and herbs.

Data collection

Surveys were carried during the breeding season (September to May) between 2008 and 2014. All surveys were conducted in favourable weather conditions and by the same two observers (S. Poncet and K. Passfield). Environmental characteristics for each transect and each island, and the identity of each bird species and the number of birds detected were recorded following a standardised data collection protocol (Tabak, et al., 2015b). Surveyors walked along the coastline at a slow and consistent pace, noting birds that moved ahead or accompanied the surveyor to avoid counting the same bird multiple times. Counts were of adults and subadults; breeding status and social structure were also recorded. The geographical location of individuals, pairs and groups of birds was recorded using a hand-held global positioning system (GPS) receiver (Garminmap 62). Introduced predators were detected visually or by field signs typical for each species.

The sampling unit (transect) on each island consisted of a 100 m-wide swathe of coastline extending from approximately 20 m inland of the high tide mark out to approximately 80 m offshore. The inland distance of 20 m was determined on the basis that this is the maximum distance at which most birds would be visible or heard by an observer walking along the shoreline. Transect length was obtained from the surveyor's GPS track. Surveys involved walking at least 1 km of coastline.

For each transect we recorded the date, local time at the start and end of survey, transect length, observer name, wind speed and direction, cloud cover, temperature, precipitation, tide state, geographic region, grazing intensity and dominant vegetation.

For each island we recorded rat eradication status, island surface area and percent of island covered in tussac using data sourced from the Falkland Islands Biodiversity Database (Falkland Islands Government, 2014). Island coastline perimeter was obtained either from the observer's GPS track data or by using mapping software to measure coastlines on map sheets 1–29 (Directorate of Overseas Surveys, 1962).

Study species

All bird species (native, non-native, resident, vagrant and migratory) encountered on transects were recorded. The number of individuals of most species was also counted. Most shoreline species are of high to very high detectability and occur in habitats that are generally open to view from long distances (Woods & Woods, 1997), there being no trees or woodlands on the islands. Species that were not easily detected (burrowing petrels which nest underground) were not counted, and nor were penguins and black-browed albatross for which the coastline survey methodology was not suitable due to the amount of time required to count large concentrations of colonial seabirds.

In this study, 22 shoreline species were grouped to form an assemblage called coastal waterbirds. These were defined as any non-passerine species that relies on the littoral and sub-littoral zones for breeding, wintering and/or foraging, and they include waterfowl, waders, a bird of prey and some seabirds (Table 1). The majority of species are common and widespread around Falklands' coasts and forage predominantly on shoreline and inshore coastal habitats (Woods & Woods, 1997). Species detected on surveys that did not conform to this definition were passerines, southern giant petrels (*Macronectes giganteus*), upland geese (*Chloephaga picta*) and ruddy-headed geese (*C. rubidiceps*). The five introduced mammalian species recorded were feral cats, black rats, Norway rats, house mice and Patagonian foxes.

Data analysis

Relative abundance and species richness

Relative abundance of each coastal waterbird species for all 170 islands surveyed was estimated as the number of individuals counted divided by the total length of transects (in kilometres) walked on that island. Species richness of an island was defined as the total number of coastal waterbird species detected in transects on each island.

Ecotypes

The 170 islands were grouped into six different 'ecotype' categories based on several specific environmental variables (Table 2). Variables were the presence or absence of Norway rats (distinguishing between historically rat-free and rat-free following successful rat eradication), the presence or absence of heavy grazing, and the presence or absence of tussac-dominant vegetation along an island's coastline. The relative abundance and species richness for the coastal waterbirds was calculated for each of these ecotypes.

Effect of environmental variables on bird abundance and species richness

We modelled the relationship between response variables (total relative abundance and species richness of the coastal waterbird assemblage) and a number of potential driving environmental variables for a subset of 139 islands using Generalised Linear Models (GLMs). The predictor variables included in these models were the presence or absence of rats (excluding islands where rats had been eradicated), the presence or absence of heavy grazing, the percent of an island covered in tussac grass ("tussac cover"), island coastline perimeter and weather and tide at the time of survey. Data from the two largest islands East Falkland and West Falkland were excluded from these GLM analyses because the difference in coastline perimeter

Table 1 Summary of the abundance of all 42 passerine and non-passerine bird species recorded on coastal transects on 170 islands in the Falkland Islands.

Species	No. birds counted	No. of islands	% of islands
Falkland Island steamer duck* *Tachyeres bracypterus*	5,432	170	100
Kelp goose* *Chloephaga hybrida*	2,400	144	85
Blackish oystercatcher* *Haematopus ater*	752	140	82
Rock shag* *Phalacrocorax magellanicus*	5,668	131	77
Crested duck* *Anas specularioides*	2,143	133	75
Kelp gull* *Larus dominicanus*	1,726	125	74
Turkey vulture* *Cathartes aura*	687	120	71
Magellanic oystercatcher* *Haematopus leucopodus*	1,380	105	62
Tussacbird *Cinclodes antarcticus*	2,378	95	56
Upland goose *Chloephaga picta*	1,295	95	56
Black-crowned night-heron* *Nycticorax nycticorax*	670	93	55
Austral thrush *Turdus falcklandii falcklandii*	378	84	49
Black-chinned siskin *Carduelis barbata*	541	80	47
Dark-faced ground-tyrant *Muscisaxicola maclovianus*	364	70	41
Grass wren *Cistothorus platensis*	242	68	40
Dolphin gull* *Leucophaeus scoresbii*	762	60	35
Black-throated finch *Melanodera melanodera*	302	66	33
Striated caracara* *Phalcoboenus australis*	262	55	32
Cobb's wren *Troglodytes cobbi*	645	52	31
Snowy sheathbill* *Chionis albus*	796	51	30
King cormorant* *Phalacrocorax albiventer*	3,969	43	25
Long-tailed meadowlark *Sturnella loyca*	168	37	22
Ruddy-headed goose *Chloephaga rubidiceps*	145	35	21
Brown-hooded gull* *Larus maculipennis*	404	34	20
Southern giant petrel *Macronectes giganteus*	812	33	19
South American tern* *Sterna hirundinacea*	687	29	17
Falkland skua* *Catharacta antarctica*	97	27	16
Southern caracara* *Caracara plancus*	35	24	14
Two-banded plover* *Charadrius falklandicus*	332	21	12
Magellanic snipe* *Gallinago magellanica*	31	17	10
Speckled teal* *Anas flavirostris*	68	16	9
White-rumped sandpiper* *Calidris fuscicollis*	292	11	6
Rufous-chested dotterel* *Charadrius modestus*	71	8	5
Correndera pipit *Anthus correndera grayi*	14	6	<5
Red-backed hawk *Buteo polyosoma*	7	6	<5
White-tufted grebe* *Rollandia rolland*	5	4	<5
Peregrine falcon *Falco peregrinus*	3	3	<5
Silver teal *Anas versicolor fretensis*	10	2	<5
Chiloe wigeon *Anas sibilatrix*	4	2	<5
House sparrow *Passer domesticus*	68	1	<5
Domestic goose *Anser anser*	2	1	<5
Cattle egret *Bubulcus ibis*	1	1	<5
Total	36,048	170	

Species ranked by frequency of occurrence on the 170 islands surveyed.
* Species in the coastal waterbird assemblage analysed in this study.

Table 2 A comparison of relative abundance (mean ± s.e.) of the coastal waterbird assemblage counted using standardised surveys on 170 islands and six ecotypes during the period 2008–2014.

Island ecotype	No. birds counted	Birds/km	No. islands	Km of coastline	No. transects
I 'mainland'[1]	1,387	31 ± 2.6	2	44.98	18
II rat-infested tussac[2]	6,051	74 ± 4.8	57	82.27	64
III rat-free tussac[3]	11,775	156 ± 14.2	70	75.49	81
IV rat-eradicated tussac[4]	5,521	138 ± 9.8	29	40	32
V rat-infested non-tussac[5]	2,642	60 ± 4	6	43.97	23
VI rat-free non-tussac[6]	1,257	101 ± 7.3	6	12.41	10
Total	28,633		170	299.12	228

[1] Mainland East and West Falkland: grazed and/or massively modified by past grazing; Norway rats, mice and cats present; no Patagonian foxes.
[2] Tussac islands with Norway rats: tussac dominant along the coastline; not permanently grazed and/or not massively modified by past grazing; no cats, no ship rats, no Patagonian foxes, no mice.
[3] Tussac islands without Norway rats: tussac dominant along the coastline; not permanently grazed and/or not massively modified by past grazing; no cats, no ship rats, no Patagonian foxes, no mice.
[4] Tussac islands where Norway rats have been eradicated: tussac dominant along the coastline; not permanently grazed and/or not massively modified by past grazing; no cats, no ship rats, no Patagonian foxes, no mice.
[5] Non-tussac islands with Norway rats: little or no tussac; permanently grazed and/or massively modified by past grazing; no cats, no ship rats, no Patagonian foxes, no mice.
6 Non-tussac islands without Norway rats: little or no tussac; permanently grazed and/or massively modified by past grazing; no cats, no ship rats, no Patagonian foxes, no mice.

between these islands and the smaller islands resulted in a disproportionate influence on model output. The full model contained all covariates of interest, and an intercept term and was described as where the response variable was either relative abundance or species richness of the coastal waterbird assemblage. A Gaussian distribution with an identity link function was used to describe the relative abundance response variable while a Poisson distribution with a log link function was used to describe the species richness variable. We also ran all possible reduced models, containing all possible combinations using these covariates, and calculated Akaike Information Criterion corrected for small sample size (AIC_C) for each model. For each set of models, we conducted model averaging on the best models (those with $DAIC_C < 7$), to obtain a single ensemble model for relative abundance and species richness (Burnham & Anderson, 2002). All calculations and modelling were conducted using R v.3.2.2 (R Core Team, 2015).

The individual effects of each of the above covariates on the response variable were also analysed. Discrete covariates (rats and grazing) were analysed using Welch's two sample t-test; continuous covariates (percent tussac cover and coastline perimeter) were analysed using Analysis of Variance (ANOVA).

The effect of Norway rat status on bird abundance and species richness

We also analysed the relationship between response variables and the potential driving environmental variable of Norway rat status (rat-infested, rat-free and rat-eradicated) for a subset of 155 tussac islands of less than 10 km perimeter and less than 200 ha. Bird data for ecotypes II, III and IV (Table 2) were analysed using a Kruskal-Wallis test with a Bonferroni post-hoc test to assess the effect of rat eradications on bird abundance. A one-way ANOVA with Tukey HSD post-hoc test was used to assess ecotype effect on species richness (Table 3).

RESULTS

Data overview

A total of 42 bird species (of which 22 were classed as coastal waterbirds) and 36,000 individual birds were recorded along 299.12 km of coastal transects on East Falkland, West Falkland and 168 offshore islands (Table 1; Fig. 1). The majority (156) of these offshore islands were predominantly tussac-covered, uninhabited and ungrazed; the other 12 islands had little or no tussac cover and were

Table 3 Results of the Kruskal-Wallis test with Bonferroni post-hoc tests of effects of rat status on relative abundance and of the one-way ANOVA post-hoc tests of effects on species richness of coastal waterbirds, on 155 tussac islands of which 70 were historically rat-free, 57 were rat-infested at the time of survey and 28 had been successfully cleared of rats.

Coastal waterbird	Test used	Kruskal-Wallis and ANOVA results	Post hoc results (p-value; difference in mean)	
			Rat-infested vs rat-free	*Rat-infested vs rat-eradicated*
Relative abundance	Kruskal-Wallis with Bonferroni	$\chi^2 = 166.339$ df = 153.2 p = 0.000	0.000; -3.866	0.008; -2.794
Species richness	ANOVA with Tukey HSD	F (153.2) = 2.715 p = 0.069	0.485; 0.540	0.056; 1.417

Table 4 Model-averaged estimates for each parameter on relative abundance and species richness of the coastal waterbird assemblage on 139 islands for 214.15 km of coastline surveyed. Low magnitude of covariate values (i.e. values that are close to zero) indicate that the variable has a weak or insignificant effect on the response, while high absolute values indicate that the variable is important in predicting the response.

	Model-averaged estimates for coastal waterbirds				
	Intercept	rats (present)	heavy grazing (present)	coastline perimeter (km)	percent tussac cover
Relative abundance	140.07	-69.33	-4.46	-0.13	0.28
Species richness	8.07	0.04	-0.01	1.34	0.00

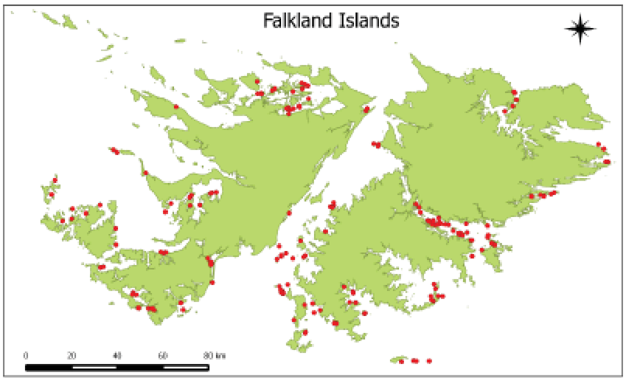

Fig. 1 The Falkland Islands showing islands where coastal bird surveys were undertaken.

grazed year-round by sheep (Table 2). Offshore islands ranged in size from 0.1 to 5,600 ha. The average length of coastline surveyed was 1.3 km; the entire coastline perimeter was surveyed on 58 of the smallest islands of less than 125 ha. Seventy six islands had one predator only (Norway rat); 63 had never had any introduced predators; 29 had been formerly occupied by one predator only (Norway rat) which had been subsequently eradicated and was absent at the time of bird survey. East Falkland and West Falkland, (collectively referred to as 'mainland') had cats, mice, Norway rats, permanent human settlements and year-round grazing by sheep and cattle. None of the islands had black rats or Patagonian foxes.

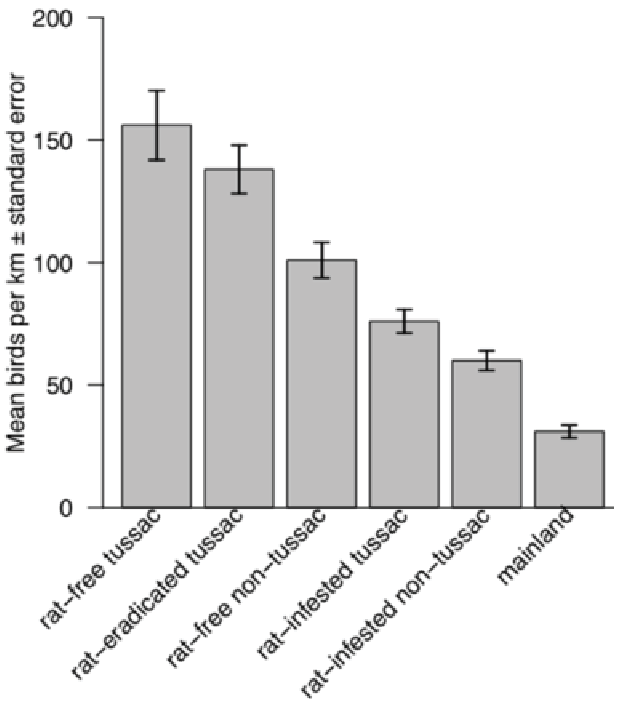

Fig. 2 The relative abundance (birds per kilometre of coastline surveyed) of the Falkland Islands coastal waterbird assemblage in six different ecotypes.

Coastal waterbirds accounted for 80% of all individual birds detected; species with the highest number of birds detected were the rock shag (*Phalacrocorax magellanicus*) and Falkland steamer duck (*Tachyeres brachypterus*), the latter being present on all islands (Table 1). Coastal waterbird abundance varied considerably between ecotypes. It was highest in predator-free tussac habitats, followed closely by rat-eradicated tussac habitat and lowest on the grazed (non-tussac) mainland coastlines where rats, mice and cats were present. It was twice as high in rat-free tussac habitat than in rat-infested tussac. A similar pattern emerged for non-tussac (i.e. grazed) islands where abundance in rat-free habitat was also nearly twice as high as that of rat-infested habitat. Overall, bird abundance in rat-free habitats, regardless of their tussac and grazing status, was higher than that in all rat-infested habitats. However, grazing also appeared to exert some effect, in that abundance was systematically lower in non-tussac habitat compared to tussac (Table 2, Fig. 2).

Effect of environmental variables on bird abundance and species richness

GLM analyses of the coastal waterbird relative abundance data from the subset of 139 islands (214.15 km of coastline) indicated that the model best supported by the data included the presence of rats (Table 4). Heavy grazing appeared to have a slightly negative effect on relative abundance; coastline perimeter of an island and the percent of an island covered in tussac had a negligible effect. Rats, heavy grazing and percent tussac cover had no effect on species richness. Coastline perimeter, however, may affect species richness, with more species being present on larger islands. The covariates depicting weather at the time of

Table 5 Results of Welch's two sample t-tests and ANOVA on the effect of rat presence, heavy grazing, percent of an island covered in tussac and coastline perimeter on the relative abundance of the coastal waterbird assemblage on 139 islands for 214.15 km of coastline surveyed.

	Welch's t-test		ANOVA
	t-value	p-value	F-value
Rats (present)	-4.63	0.0000	
Heavy grazing (present)	-2.85	0.0069	
Percent tussac cover			13.37
Coastline perimeter			6

Table 6 Results of Welch's two sample t-test and ANOVA on the effect of rats, heavy grazing, percent of an island covered in tussac and coastline perimeter on the species richness of the coastal waterbird assemblage on 139 islands for 214.15 km of coastline surveyed.

	Welch's t-test		ANOVA
	t-value	p-value	F-value
Rats (present)	0.47	0.6405	
Heavy grazing (present)	2.05	0.0513	
Percent tussac cover			0.77
Coastline perimeter			0.30

survey (i.e., wind speed, precipitation, cloud cover, and tide) did not appear in any of the best models (those with $DAIC_C < 7$), so we concluded that they did not affect bird abundance or species richness. The effects of individual covariates analysed using Welch's two sample t-test results indicate a highly significant negative effect of both rats and heavy grazing on the relative abundance of coastal waterbirds. ANOVA results show that relative abundance increased significantly with percent tussac grass cover on an island and decreased with coastline perimeter (Table 5). Welch's two sample t-test and ANOVA results indicate that species richness is not affected by rats, heavy grazing, percent tussac cover on an island or island coastline perimeter (Table 6).

Effect of Norway rat status on bird abundance and species richness

Kruskal-Wallis tests with Bonferroni post-hoc tests showed that there was a significant effect of rat status on coastal waterbird abundance (Table 3). Bird abundance differed significantly between rat-infested and historically rat-free islands and between rat-infested and rat-eradicated islands, indicating that rat eradication resulted in an increase in coastal waterbird abundance. There was no significant difference in abundance between historically rat-free and rat-eradicated islands, which may possibly indicate that bird populations had nearly fully recovered following eradications. Results from the one-way ANOVA showed no effect of rat status on species richness.

DISCUSSION

The presence of Norway rats was the most important factor in predicting the relative abundance of the coastal waterbird assemblage (Table 4). Rat presence had a strong and significant negative effect on bird abundance (Tables 3, 4 and 5). This negative effect and the significant recovery benefits of rat eradication are like those observed for passerines (Hall, et al., 2002; Tabak, et al., 2015b). In contrast, rats did not affect species richness of the coastal waterbird assemblage.

Heavy grazing and the percent of tussac cover on an island also had significant negative effects on coastal waterbird abundance (Tables 2 and 3). Previous work has shown that grazing has a negative effect on bird abundance (Batáry, et al., 2007). In the Falklands, grazing led to the disappearance of the majority of the coastline's original vegetation of tall native grasses and shrubs which, in a landscape devoid of trees, provided optimal breeding habitat for the majority of the islands' bird populations. The impact of grazing is reflected in the higher bird abundance of rat-free tussac coastlines (ecotype III) compared to rat-free non-tussac (grazed) coastlines (ecotype V; Table 2).

An indication of the effectiveness of rat eradications in restoring coastal waterbird populations is shown by the large difference in bird relative abundance between rat-eradicated and rat-infested islands (Table 2). Abundance levels on the former are nearly twice as high as on the latter and approximate those of historically rat-free islands (Table 3) indicating that significant increases in coastal waterbird populations are likely when rats are eradicated. The importance of rat-free tussac islands (ecotype II) for Falkland bird populations is clearly demonstrated by the statistically significant difference in relative abundance of coastal waterbirds on these islands compared with rat-infested tussac islands (ecotype III) where relative abundance is 50% less. However, it is the coastlines of East Falkland and West Falkland (ecotype I where Norway rats, cats and mice are present and the impacts of grazing and destruction of native habitats are widespread), that show the largest response with a five-fold reduction in bird abundance. The impact that mice and cats exert on coastal waterbird species of the Falklands is largely unknown (Matias & Catry, 2008; Rexer-Huber, et al., 2013), although negative impacts have been assumed (Johnson & Stattersfield, 1990). Suggestions that the likely impact of the endemic warrah (*Dusicyon antarcticus*) on bird abundance was continued by later anthropogenic mammal introductions (notably cats) (Hall, et al., 2002) is an important consideration in any assessment of the potential of East Falkland and West Falkland for future vertebrate pest eradications.

CONCLUSION

Our study of the effect of environmental variables, and notably predators and over-grazing of native vegetation, on coastal waterbirds has identified the potential for differences in relative abundance of these species to serve as indicators of ecosystem recovery following rat eradications and habitat restoration activities. It is a first step in understanding the range of environmental factors that influence the distribution and abundance of Falkland coastal waterbirds. However, caution is required when interpreting differences as they may be caused not only by the balance of predation effects of Norway rats upon birds or by grazing impacts and habitat alteration but also by other indirect effects such as annual oceanographic and climate variations, biogeographical factors, island size and mesopredator release of birds (Watari, et al., 2011).

Future work will aim to determine the impact of these factors on individual species. Additionally, conducting repeated visits on islands will allow for future models to incorporate estimates of each species' detection probability. An improved understanding of how coastal bird distribution and abundance is affected by ecosystem processes is essential for informing future eradications in the Falkland Islands and for monitoring other large-scale landscape-level ecological changes to the Falklands coastline and its inshore marine environment.

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