THE BREEDING BIOLOGY OF TERNS ON THE WESTERN ISLES IN RELATION TO MINK ERADICATION

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Ratcliffe N., Houghton D., Mayo A., Smith T. & Scott M. 2006. The breeding biology of terns on the Western Isles in relation to mink eradication. Atlantic Seabirds 8(3): 127-135. *American Mink were introduced to Lewis in the 1950s and '60s, and their range expanded south to colonise North Uist by the late 1990s. Mink eradication was initiated in 1999 and the islands were almost entirely cleared by 2004. The breeding biology of terns on the Uists prior to colonisation by mink and after eradication was compared with that on Lewis where mink were present during the entire period. The results showed that nest survival was significantly higher on the Uists compared with Lewis in 2005, and this was largely explained by lower mammalian predation rates in the Uists. However, there was no significant additive effect of mink occupation on productivity across years. Productivity was mainly affected by year, with little evidence of differences between archipelagos within years. However, productivity was low in the only two years when good sample sizes were available in both archipelagos, probably due to poor food supply or inclement weather. In these situations, the effects of mink predation would be expected to be compensatory, since they were taking eggs and chicks that would probably have starved subsequently. Improved annual monitoring of colonies on both Uist and Lewis needs to be conducted in order to investigate the interactive effects of mink removal and food availability on tern productivity in the Western Isles.*

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INTRODUCTION

American mink *Mustela vison* (hereafter "mink") feed on a wide variety of prey, including birds and their eggs and chicks (Dunstone 1993). They are amphibious and are able to reach islets within 2 km of the shore, and also those further offshore if linked by an island chain (Craik 1995). Incubating adults, eggs and chicks of small, ground-nesting seabirds (especially Black Guillemots *Cepphus grylle*, European Shags *Phalacrocorax aristotelis*, terns and small gulls) at such sites are vulnerable to direct mink predation (Folkestad 1982; Andersson 1992; Craik 1995, 1998, 2000; Kilpi 1995). The reduced productivity results in population declines through elevated adult mortality, low recruitment, and abandonment of affected sites (Kipli 1995; Craik 1997; Antolos *et al.* 2004).

Following colony abandonment, birds move to predator-free offshore sites (Folkestad 1982; Craik 1997; Nordström & Korpimäki 2004) or congregate in fewer, larger colonies (Clode & Macdonald 2002). Mink therefore reduce colony site availability and this may cause limitation of seabird populations even after direct predation has ceased. For example, productivity at offshore sites may be lower because of their remoteness from key foraging areas (Hall & Kress 2004), whereas that at large colonies may be depressed by elevated density-dependent competition (Birkhead & Furness 1985). However, the effects of mink on seabirds can be halted or reversed: their removal by trapping results in increased productivity, persistence of extant colonies, recolonisation of abandoned sites, and increased regional numbers (Craik 1998; Nordström *et al.* 2003; Nordström & Korpimäki 2004).

Mink were accidentally introduced to Lewis in the Western Isles of Scotland when they escaped from fur farms during the 1950s and 1960s (Dunstone 1993). Their range expanded throughout the island of Lewis and Harris (Hudson & Cox 1988), and by the late 1990s had spread further south to include the Uists island chain (Harrington *et al.* 1999; Roy 2006). The colonisation would undoubtedly have continued until all accessible parts of the archipelago were occupied but for the initiation of the Hebridean Mink Project in 1999, which removed mink from the Uists and South Harris with the aim of protecting nationally important ground-nesting seabird and wader populations (Moore *et al.* 2003). By 2004, few mink remained in the control areas and by the conclusion of the project in 2006, they had been successfully eradicated from them (Roy 2006). Meanwhile, the range and numbers of mink on North Harris and Lewis remained largely unchanged despite control measures, and recolonisation of South Harris and the Uists must be inevitable while this source population persists. Hence, the eradication programme was extended to North Harris and Lewis in September 2006, with the aim of protecting biodiversity there and preventing recolonisation of the Uists.

This paper describes the breeding biology of terns on the Uists in 2004 and 2005, and compares it with that on Lewis during 2005 in order to evaluate whether removal of mustelids has improved tern reproductive success. Data from previous published studies of tern breeding biology in the Western Isles are also included for comparison. The implications of the findings for mink management work in the Western Isles are discussed.

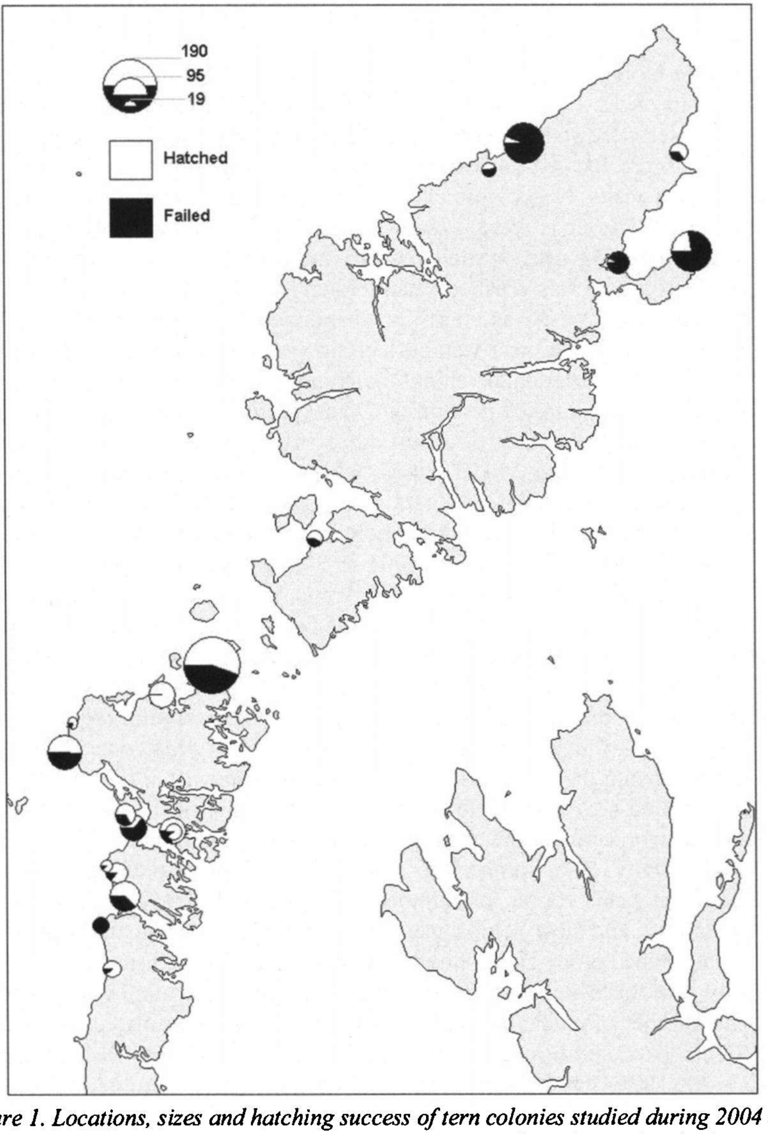

Figure 1. Locations, sizes and hatching success of tern colonies studied during 2004 and 2005 in the Western Isles. Pie sizes represent number of pairs (see key).
Figuur 1. Ligging, grootte en uitkomstsucces van sternkolonies die in 2004 en 2005 op de Western Isles bestudeerd werden. De grootte van de taartdiagrammen geeft het aantal paar aan (zie legenda).

METHODS

The breeding biology of terns was studied at selected sites in the Uists in 2004 and 2005 and on Lewis in 2005. The location of colonies studied is shown in Fig. 1. Colonies were visited every 3-5 days through May, June and July.

Nests were located and marked at each colony to determine their fate between repeat visits. Nests were classed as: "hatched" if chicks were present; "abandoned" if cold eggs were present; "eaten" if the nest was empty prior to the expected hatching date or shell remains indicating predation were present; "trampled" if the egg was crushed; "sandblown" if the egg was buried in sand, and "flooded" if the nest was empty or abandoned following a tidal flood. In cases where the fate of a nest was not certain (i.e. an empty scrape that could have been due to predation or chicks hatching and dispersing), the nest was classed as surviving up to the penultimate visit (Manolis *et al.* 2000). Daily nest survival rates (the probability of a nest surviving for one day) were estimated using a Generalised Linear Model (GLM) with a binomial error distribution and logit link, where the fate of the nest (survived or failed) was the response variable and number of days for which the nest was monitored was the binomial denominator (Crawley 1993). Year (2004 or 2005), species (Little Tern *Sterna albifrons* or Common *Sterna hirundo* and Arctic *Sterna paradisaea* combined), and mink presence for the region in which the colony was situated were defined as factors each with two levels. Variables were retained in the minimal adequate model if they explained a significant amount of the deviance, with model selection being conducted using *chi*-square tests and a maximum *alpha* of 0.05. Hatching success (the likelihood of a nest hatching at least one chick) was estimated by raising the daily nest survival rate to the power of the average tern incubation period (22 days; Cramp 1985). The asymmetrical lower and upper one standard error limits of the estimate are presented as LSE and USE.

Productivity (the number of chicks fledged per breeding pair) was estimated from peak counts of numbers of pairs and fledged chicks. Flush counts of adults and nest counts were made during the incubation period in order to determine colony size following Walsh *et al.* (1995). Flush counts were divided by 1.5 (Bullock & Gomersall 1981) to estimate the number of breeding pairs. The number of chicks fledged from the colony was estimated from either flush counts of fledglings or capture-mark recapture of near-fledged chicks (Walsh *et al.* 1995). Data on productivity and mink range were extracted from Clode & Macdonald (2002) and Rae (1999) for statistical comparison with current data. Productivity was estimated using a GLM with a Poisson error distribution and log link. The number of chicks fledged was the response variable and the number of pairs was defined as an offset (Crawley 1993). This procedure weights cases from each colony appropriately according to the sample size (i.e. number of pairs) and constrains predicted values to be greater than zero. Model selection was conducted as described for hatching success, except that the residual deviance was scaled (by the square root of the residual deviance divided by the residual degrees of freedom) in order to account for over-dispersion, and F-ratio tests were used to test the significance of terms (Crawley 1993).

RESULTS

Hatching success Average hatching success was 40.1% (LSE = 38.0, USE = 42.1) for all years and archipelagos combined. There were significant differences in hatching success between archipelagos, with that on the Uists (58.8%, LSE = 56.0, USE = 61.5) being significantly higher than that on Lewis and Harris (17.8%, LSE = 14.5, USE = 21.3; $\chi^2_1 = 110.2$, $P < 0.0001$). Spatial variation in hatching success between colonies is shown in Fig. 1. There were no significant effects of species or year once archipelago-dependent variation was explained.

Productivity Productivity varied between years ($F_{4,75} = 36.59$, $P < 0.001$, scale parameter 3.4). Productivity was highest in 1992, lowest in 2005 and intermediate in other years (Table 1). These overall annual variations were reflected by within-site trends, suggesting these fluctuations were not due solely to variations in the sites sampled between years. When controlling for year effects, productivity of Little Terns was significantly higher than that of Arctic Terns within years ($F_{1,74} = 4.65$, $P < 0.05$, scale parameter 3.32; Table 2). The difference between archipelagos was not significant ($F_{1,73} = 0.15$, $P > 0.6$, scale parameter = 3.34).

Causes of loss Of the 86 failed study nests at which cause of failure was established on Uists, 62% were depredated, 24% abandoned, 8% buried by windblown sand, 2% trampled by livestock and 2% flooded. Of the 190 failed nests on Lewis these figures were 74%, 12%, 0%, 2% and 12% respectively. Evidence of predation by mustelids was found mainly on Lewis, where a total of 21 eggs, 19 chicks and 29 adults were discovered in caches near four of the six colonies. Remains in one of these were more consistent with Otter *Lutra lutra* predation than with mink (C. Craik, pers. comm.). On the Uists, otter predation was evident on Berneray, in the far north of the archipelago, where six killed adults and a cache of *c.* 20 eggs were found, while at Aird a Machair in South Uist caches of eggs were found near a den site that from its size probably belonged to a Brown Rat *Rattus norvegicus*.

Table 1. Variation in sample sizes (colonies, pairs) and productivity (chicks per breeding pair) of terns in the Western Isles by species, year and archipelago. LSE and USE represent the asymmetrical standard error limits of the productivity estimates.

Tabel 1. Variatie in steekproefgrootte (kolonies, paar) en productie (kuikens per broedpaar) van sterns op de Western Isles per soort, jaar en archipel. LSE en USE geven de asymmetrische standaardfoutenmarge van de schattingen van de productie weer.

Species	Archipelago	Year	Colonies	Pairs	Productivity	LSE	USE
Arctic	Uists	1992	3	130	0.65	0.44	0.94
Arctic	Uists	1993	11	281	0.23	0.13	0.41
Arctic	Uists	2004	8	162	0.24	0.13	0.45
Arctic	Uists	2005	12	550	0.05	0.03	0.11
Arctic	Lewis	1992	2	840	1.04	0.70	1.55
Arctic	Lewis	1993	11	517	0.12	0.08	0.24
Arctic	Lewis	1999	21	1589	0.16	0.11	0.25
Arctic	Lewis	2005	6	1083	0.03	0.02	0.07
Little	Uists	2004	2	17	0.53	0.38	0.74
Little	Uists	2005	1	12	0.17	0.08	0.36
Little	Lewis	1999	2	15	0.20	0.10	0.39
Little	Lewis	2005	1	19	1.21	0.82	1.79

DISCUSSION

Hatching success was more than three times higher on the Uists than on Lewis and Harris. This could be explained by the fact that mink densities were much lower on the Uists than on Harris and Lewis because of the control programme in preceding years. This conclusion is supported by the higher mammalian predation rates on Lewis combined with evidence for mink presence at these sites in the form of caches, dens, spoor and scats. In contrast, on the Uists, severe mammalian predation was only noted at two sites, with gull predation, sandblow and abandonment causing most failures there. Hatching success on the Uists was still relatively low: in other studies; it generally exceeds 80% (for reviews see Hatch 2002, Nisbet 2002, Becker & Ludwigs 2004), indicating that conditions in 2004 and 2005 were unfavourable (see below).

Previous studies have shown that tern productivity is far lower in areas where mink occur than where they are absent (Craik 1998; Nordström *et al.* 2004), but this was not the case in Lewis compared with the Uists in 1993 and 2005; the only years when paired data were available. In 1993 and 2005, productivity was very low across both archipelagos, and this was probably due to inclement weather (Clode & Macdonald 2002) and reduced food availability (this study) respectively. Indeed, several species of seabird breeding in west Scotland experienced their worst year of productivity on record in 2005, with failures of auks, terns and Black-legged Kittiwakes *Rissa tridactyia* being noted throughout the inner and outer isles of western Scotland (Mavor *et al.* 2006). During such years, predation will be compensatory; with mink taking eggs and chicks that probably would have died subsequently from other causes such as exposure or starvation.

Predation would be expected to be additive in years when feeding and weather conditions are favourable, such that chicks that do not succumb to predation would survive to fledging (Newton 1998). In such years, the contrast in productivity between the Uists and Lewis would be expected to be evident, but this was not the case in 1992 when productivity was high on both archipelagos. Productivity was recorded at only two colonies on Lewis in 1992, and mink do not attack all colonies in suitable habitat within their range every year. For example, in south-west Scotland between 1990 and 2006, 58% of unprotected tern colonies were not mink-affected (J.C.A. Craik unpublished data). Hence, conclusions concerning the effects of mink on tern productivity cannot reliably be drawn from a small sample of colonies in areas where mink are present and absent.

Any benefits to terns of mink removal may be partially negated by recovery of feral Ferret *Mustela furo* numbers in some parts of the Uists. The numbers of ferrets were reduced incidentally in the Hebridean Mink Project, but numbers have begun to recover subsequently (Roy 2006). Ferrets in the Uists are distributed along the west coast (Roy 2006) where most of the Uists Arctic Tern colonies occur (Mitchell *et al.* 2004). Hence, Arctic Terns on the Uists may continue to suffer failures due to ferret predation, but Common Terns on the east coast, and both tern species on the Harris Sound Islands (between Harris and North Uist), will avoid this fate as they occur in sites that are unsuitable for, or inaccessible to, ferrets (Roy 2006).

Eradication of mink from Lewis and North Harris began in September 2006 and, if successful, will result in the whole of the Western Isles being free from mink. While our study provides little support for this initiative based on benefits for tern productivity, Rae (1999) reported that mink predation caused complete breeding failure at 13 of the 18 tern colonies present on Lewis in 1999, and reduced productivity at a further two. Furthermore, Clode & Macdonald (2002) found a reduction in the number of Arctic Tern colonies and extirpation of Common Terns, which they interpreted as a consequence of mink predation. Mink removal is therefore likely to improve productivity of terns on Lewis and may promote increases in their numbers and range; this, combined with putative benefits for other biodiversity and economic interests, provide justification for the project. We recommend further monitoring as part of the project so that the effects of mink management on tern productivity, numbers and range may be elucidated.

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BROEDBIOLOGIE VAN STERNS OP DE WESTERN ISLES IN RELATIE TOT VERDELGING VAN NERTSEN

De Amerikaanse nerts werd in de jaren '50 en '60 op Lewis geïntroduceerd en breidde zijn verspreidingsgebied zuidwaarts uit om North Uist in de late jaren '90 te koloniseren. Verdelging van nertsen begon in 1999 en de eilanden waren in 2004 vrijwel nertsloos. De broedbiologie van sterns op de Uist-eilandjes (de Uists) voor de kolonisatie door nertsen en na de verdelging van deze soort werd vergeleken met de broedbiologie op Lewis, waar nertsen de gehele periode aanwezig waren. De resultaten lieten in 2005 een significant hoger nestsucces op de Uists zien in vergelijking met Lewis, hetgeen grotendeels verklaard werd door lagere predatie op de Uists. Er was echter geen significant toegevoegd effect van nerts op broedsucces in de verschillende jaren. Broedsucces werd grotendeels beïnvloed door het jaar, met nauwelijks bewijs voor verschillen tussen eiland(groep)en in de verschillende jaren. In de enige twee jaren dat er goede steekproeven genomen konden worden, was het broedsucces echter lag; waarschijnlijk als gevolg van een slecht voedselaanbod of ongunstig weer. In deze situatie is te verwachten dat het effect van predatie door nertsen gering is, aangezien ze eieren en kuikens eten die waarschijnlijk verhongerd zouden zijn. Verbeterde jaarlijkse monitoring van de kolonies op de Uists en Lewis is wenselijk om het gecombineerde effect van nertsverdelging en voedselaanbod op het broedsucces van sterns op de Western Isles te onderzoeken.

REFERENCES

Andersson, Å., 1992. Development of waterbird populations in the Bullerö archipelago off Stockholm after colonisation by mink. Ornis Svecica 2: 107-118.

Antolos M., Roby, D.D., & Collis K. 2004. Breeding ecology of Caspian terns at colonies on the Columbia plateau. Northwest Science 78: 303-312.

Becker, P.H. & Ludwigs, J.-D. 2004. Sterna hirundo Common Tern. Pp 91-137 in: Parkin, D. (ed.). BWP update. The Journal of the Birds of the Western Palearctic. Vol. 6. Oxford University Press, UK.

Birkhead, T.R. & Furness, R.W. 1985. Regulation of seabird populations. Pp. 145-167 in: Sibley, R.M. & Smith, R.H. (eds.). Behavioural Ecology: Ecological Consequences of Adaptive Behaviour. Blackwell, London.

Bullock, I.D. & Gomersall, C.H. 1981. The breeding populations of terns in Orkney & Shetland in 1980. Bird Study 28: 187-200.

Clode, D. & Macdonald, D.W. 2002. Invasive predators and the conservation of island birds: the case of American Mink Mustela vison and terns Sterna spp. in the Western Isles, Scotland. Bird Study 49: 118-123.

Craik, J.C.A. 1995. Effects of North American Mink on the breeding success of terns and smaller gulls in west Scotland. Seabird 17: 3-11.

Craik, J.C.A. 1997. Long-term effects of North American Mink Mustela vison on seabirds in western Scotland. Bird Study 44: 303-309.

Craik, J.C.A. 1998. Recent mink-related declines in gulls and terns in west Scotland and the beneficial effects of mink control. Argyll Bird Report 14: 99-110.

Craik, J.C.A. 2000. Breeding success of common gulls Larus canus in west Scotland II. Comparison between colonies. Atlantic Seabird 2: 1-12.

Cramp, S. (ed) 1985. The Birds of the Western Palearctic. Volume IV: Terns to Woodpeckers. Oxford University Press, Oxford, UK.

Crawley, M.J. 1993. GLIM for ecologists. Blackwell, London.

Dunstone, N. 1993. The Mink. T and A.D. Poyser, London, UK.

Folkestad, A. 1982. The effect of mink predation on some seabird species. Viltrapport 21: 42-49.

Harrington, L.A., Grogan, A.L., Bonesi, L. & Macdonald, D.W. 1999. Survey of American mink Mustela vison, on North Uist. Unpublished report to Scottish Natural Heritage, Wildlife Conservation Research Unit, Oxford.

Hall, C.S. & Kress, S.W. 2004. Comparison of common tern reproductive performance at four restored colonies along the Maine coast, 1991-2002. Waterbirds 27: 424-433.

Hatch, J.J. 2002. Arctic Tern Sterna paradisaea. In: Poole, A. & Gills, F (eds). The Birds of North America, No. 707. The Birds of North America Inc., Philadelphia, USA.

Hudson, P. & Cox, R. 1988. Mink problems on the Outer Hebrides: a pilot study. Game Conservancy Report.

Kipli, M. 1995. Breeding success, predation and local dynamics of colonial common gulls Larus canus. Ann. Zool. Fenn. 32: 175-182.

Manolis, J.C., Andersen, D.E. & Cuthbert, F.L. 2000. Uncertain nest fates in songbird studies and variation in Mayfield estimation. The Auk 117: 615-626.

Mavor, R.A., Parsons, M., Heubeck, M. & Schmitt, S. 2006. Seabird numbers and breeding success in Britain and Ireland, 2005. Peterborough, Joint Nature Conservation Committee. (UK Nature Conservation, No. 30).

Mitchell, P.I., Newton, S., Ratcliffe, N., & Dunn, T. (eds) 2004. Seabird populations of Britain and Ireland. T & A.D. Poyser, London.

Moore, N.P., Roy, S.S. & Helyar, A. 2003. Mink (Mustela vison) eradication to protect ground-nesting birds in the Western Isles, Scotland, United Kingdom. New Zealand Journal of Zoology. 30: 443-452.

Newton, I. 1998. Population limitation in birds. Academic Press

Nisbet, I.C.T. 2002. Common Tern Sterna hirundo. In: Poole, A. & Gills, F (eds). The Birds of North America, No. 618. The Birds of North America Inc., Philadelphia, USA.

Nordström M., Högmander J., Laine, J., Nummelin, J., Laanetu, N. & Korpimäki, E. 2003. Effects of feral mink removal on seabirds, waders and passerines on small islands in the Baltic Sea. Biological Conservation 109: 359-368.

Nordström, M. & Korpimäki, E. 2004. Effects of island isolation and feral mink removal on bird communities on small islands in the Baltic Sea. Journal of Animal Ecology. 73: 424-433.

Rae, S. 1999. The effect of predation by mink on ground-nesting birds in the Outer Hebrides. Outer Hebrides (The Western Isles) Bird Report 1999: 105-113.

Roy, S.S. 2006. Mink control to protect important birds in SPAs in the Western Isles. Final Report to EU LIFE III – Nature, Brussels.

Walsh, P.M., Halley, D.J., Harris, M.P., del Nevo, A., Sim, I.M.W., & Tasker, M.L. 1995. Seabird monitoring handbook for Britain and Ireland. JNCC / RSPB / ITE / Seabird Group. Peterborough.