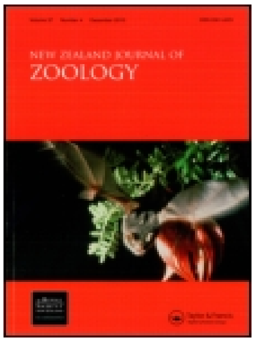

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Effectiveness of management on the breeding success of Chatham Island oystercatchers (*Haematopus chathamensis*)

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Abstract Conservation management of Chatham Island oystercatcher (*Haematopus chathamensis*) nests was carried out between 1998 and 2004 on the Chatham Islands, New Zealand. Video monitoring during three breeding seasons (1999–2001) from 21 managed and 28 unmanaged nests revealed that feral cats (*Felis catus*) and an introduced rail, the weka (*Gallirallus australis hectori*), were the main predators, responsible for 68 and 16% of fatal events respectively. Other fatal events resulted from predation by a red-billed gull (*Larus novaehollandiae scopulinus*), tidal overwash, and a sheep (*Ovis aries*). Each accounted for c. 5% of fatal events. Daily survival rate and nest survival probability for 126 oystercatcher nests varied with management, but was unrelated to year or use of video monitoring. Daily survival rate for nests in managed and unmanaged areas was 0.990 (95% CI: 0.985 to 0.994) and 0.959 (95% CI: 0.941 to 0.971), respectively. Nest survival probability was 0.757 (95% CI: 0.652 to 0.834) in managed areas and 0.249 (95% CI: 0.174 to 0.425) in unmanaged areas. Incubation at managed nests tended to proceed without incident whereas unmanaged nests succumbed to predation. Management in 1998–2004 improved breeding success to a mean of 1.04 compared with 0.37 chicks/pair/year in unmanaged areas. During 2002–04, however, management had less apparent impact because storm seas played a greater role and breeding success improved in unmanaged areas. In this study, video monitoring proved a useful means of identifying the main causes of nest failure during incubation, and so assisted in the formation of conservation management methods.

Keywords Chatham Island oystercatcher; conservation management; *Haematopus chathamensis*; nest survival; video monitoring

INTRODUCTION

The Chatham Island oystercatcher (*Haematopus chathamensis*) is endemic to the Chatham Islands (Baker 1973; Ornithological Society of New Zealand 1990; Marchant & Higgins 1993) c. 800 km east of mainland New Zealand (44°S,176°30′W). The species is classified as endangered because of its very small population (Birdlife International 2008); estimated $N = 313$ in 2006 (Moore 2008). New Zealand's Department of Conservation (DOC) ranks this species as nationally critical, making it a high priority for conservation management (Miskelly et al. 2008). Predation of eggs and chicks by introduced predators has been identified as a key threat (Davis 1988), as has trampling of nests by livestock (sheep (*Ovis aries*) and cattle (*Bos taurus*)) and the stabilisation of dunes by marram grass (*Ammophila arenaria)*, which reduces nesting opportunities (Aikman et al. 2001).

Oystercatcher breeding success is generally low in unmanaged areas, but varies annually. In 1987 and 1994–96 estimated productivity was 0.22 and 0.44 fledged chicks per pair per year (Davis 1988; Schmechel 2001). Intensive management action was taken between 1998 and 2004 to improve productivity and survivorship, with the aim of increasing the total population to >250 mature oystercatchers by 2010 (Aikman et al. 2001). This involved a programme of predator control, exclusion of livestock from nests, and relocation of nests above the high tide zone in two areas of northern Chatham Island that, combined, had 16 pairs of oystercatchers

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(Moore et al. 2001). Concurrent monitoring of the population was designed to measure the response of the oystercatcher population to management. Video monitoring of nests was employed during the breeding season from 1999 to 2001 to identify key threats to oystercatcher nests and assess the effectiveness of management.

Continuous monitoring of activities at avian nests via time-lapse video surveillance cameras is widely employed to identify predators, quantify the relative impacts of different species, identify the behaviour of predator and prey, and verify the type of sign left at nests (Innes et al. 1996; Brown et al. 1998; MacDonald & Bolton 2008). These visual data are also invaluable for increasing awareness of the problem of introduced mammalian pests in New Zealand and for advocacy of pest control (Innes et al. 1996). However, the technique has limitations because of the expense and labour involved. Many video studies also do not obtain sufficient sample sizes to quantify the relative impacts of different causes of mortality (Sanders & Maloney 2002). For precocial species (such as oystercatchers) the technique is useful only at the egg stage. Different predator species can be a problem for nesting birds in different years (R. Maloney, DOC, pers. comm. 1999). Despite these drawbacks, non-fatal encounters may also be a measure of the effectiveness of predator removal from managed areas.

This paper reports on (1) the outcomes and causes of failure at oystercatcher nests, (2) identities of predators videotaped at nests, (3) effects of cameras, (4) a comparison of daily survival rates and nest survival probabilities in managed and unmanaged areas during the period of video monitoring, (5) an assessment of the effectiveness of management in improving oystercatcher nest survival, and (6) oystercatcher breeding success in 1998–2004.

METHODS

Fieldwork centred on the north of Chatham Island (Fig. 1). Management years were between 1998 and 2004 (years refer to breeding seasons, e.g., 1999 refers to the 1999/2000 breeding season between October and February). Nests were managed in two adjacent areas (Maunganui-Tioriori and Wharekauri) where there were initially 16 pairs of oystercatchers on 16 km of coast (Bell 1999; Moore et al. 2001). Monitored but unmanaged areas in northern Chatham Island included Waitangi West, Whangamoe Inlet-Paritu, Matarakau and Okawa, where there were initially a combined total of 8–10 pairs of oystercatchers.

Management

Management included the use of traps, stock exclusion fences, and translocation of nests. A trap-line at Maunganui and Wharekauri was maintained from late September or early October until mid to late February (Moore in press). Most traps were set at the beach/dune edge, but some were also set behind the main dune and in a few cases on the edges of small patches of forest close to the beach. Traps were concentrated along beaches where there were oystercatcher territories plus alongside streams, tracks and fencelines which were considered to be pathways for prospecting predators. Control measures from September to February removed a variety of potential predators, particularly introduced cats (*Felis catus*) and weka (*Gallirallus australis hectori*), a flightless rail (Moore in press). After 2001, weka were released alive from cage traps at Maunganui at the request of local landowners. Existing stock fences at Wharekauri and Tioriori and portable electric fences were used to protect nests from livestock. Electric fences were placed around up to 28 oystercatcher nests per year in the managed areas where livestock had access to beaches.

Nest platforms were placed in some managed oystercatcher territories before the start of each breeding season. The platforms consisted of car tyres tied to plywood sheets, filled and covered with sand, and given a sparse decoration of seaweed or driftwood to imitate an oystercatcher nest site. These were designed to provide a raised nest site for partial protection from high tides and to allow easy relocation of the nest up the beach should high seas threaten to inundate the nest. Nests that were not on platforms were relocated by progressively recreating the nest bowl and moving the associated seaweed and driftwood up the beach, usually 1–3 m at a time. The decision to move a nest and the total distance it was moved was based on how close the nest was to the high tide mark, the width and slope of the beach, the proximity of high ground, and the perceived risk from high seas resulting from these factors. In vulnerable territories on narrow beaches a semicircle of marram grass was pulled and/or sprayed to allow relocation of nests into fore-dune areas.

Nest monitoring

Birds were marked with uniquely numbered metal bands as part of a long-term monitoring programme.

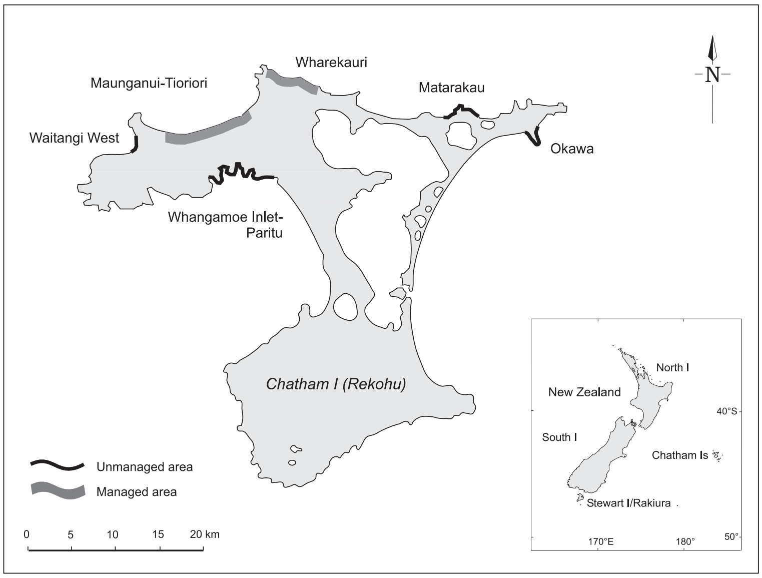

Fig. 1 Chatham Island oystercatcher (*Haematopus chathamensis*) study areas on Chatham Island, New Zealand.

Monitoring of breeding adults and of the survival and movements of juveniles were made possible by observations of individuals fitted with unique colour combinations of plastic bands on the tarsi.

To determine threats and causes of egg failure we monitored nests with time-lapse video equipment in managed and unmanaged areas of northern Chatham Island from 1999 to 2001. Four cameras were deployed so that a similar amount of footage was filmed in managed and unmanaged areas and, where possible, nests were selected where eggs had recently been laid. Each black and white infrared-sensitive video camera was housed in waterproof PVC tubing, mounted on a 0.5 m stainless steel stand alongside a low output infared night-light (wavelength 950 nm), and connected by buried cable to a time-lapse video recorder (Moore et al. 2001). If a nest failed, the camera was shifted to another recently formed nest in the respective managed/unmanaged zone.

Daily visits were made to both filmed and unfilmed nests in managed areas in conjunction with management activities. Nests were checked with variable frequency in unmanaged areas—approximately daily to twice a week in 1999–2001 and every 1–4 weeks in 2002–04 (the frequency of nest checks in 1998 is unknown). Causes of nest loss were determined by video footage at filmed nests and by sign (e.g., predator footprints and evidence of tidal overwash) at unfilmed nests. Data for 1998 were from Bell (1999) and O'Connor (1999).

Camera operating procedures and data collection were similar to those used in the Waitaki Basin on South Island, New Zealand (Sancha & Sanders 1998; Sanders & Maloney 1999, 2002). Knowledge about Chatham Island oystercatcher behaviour (S. O'Connor, DOC, pers. comm. 1999) and advice from workers studying other shorebirds (R. Maloney, DOC, pers. comm. 1999) suggested that a camera placed close to a nest was unlikely to cause abandonment or attract predators. Hence, during egg-laying or early incubation, cameras were placed in front of nests immediately rather than installing them at a distance and gradually moving them closer to allow the birds to become more accustomed to them. Initially, cameras were placed about 2 m from nests, but filming under infrared lights was more successful at 1 m distance. There was less glare when cameras faced south, away from the sun, and were placed close to the nest. The recorder and battery were hidden in the dunes behind the beach. Video tapes and batteries were changed daily, concurrent with trap checking in managed areas and tapes were viewed usually the same day. Tapes were viewed on fast-forward until a bird left the nest and the time of departure was logged on a recording sheet. These included partner changes at the nest or temporary departure of a bird for which no cause could be ascertained. The arrivals of species or individuals other than the monitored pair at the nest site were viewed on slow speed, and detailed notes made describing all events recorded.

Video interpretation

Protocol for interpreting video footage was similar to that used by Sanders & Maloney (2002). An event captured on film was defined as any visible threat (usually other animals) within 2 m of the nest excluding other oystercatchers and researchers. An event group was considered to be a series of visits by the same animal species (assumed to be the same individual except in the case of sheep) within a 30 min period. Individual cats were recognisable by their distinct physical appearance such as coat markings. Events were categorised as either (1) fatal: where a visit to the nest resulted in nest failure, (2) high risk: where a visit (<2 m) to the nest caused partial clutch mortality or posed a high risk of egg mortality or nest failure, e.g., an intruder sniffing or handling the eggs or nearly trampling the nest, or the sea washing close to or over the eggs, (3) low risk: where a visit apparently posed a low risk to the nest, e.g., an intruder (either a predator or a benign species, such as a little blue penguin *Eudyptula minor*) passed close to the nest, and in the case of predators no visible attention was paid to the nest, or (4) post-outcome: a visit to the nest after it had failed or the chicks had left the nest with their parents. We included post-outcome events to document late or return visits by predators or potential predators and scavengers. Oystercatchers left the nest for short periods many times a day for a variety of reasons, such as partner change-overs or territorial defence, and because of disturbances out of view from the camera. As it was seldom possible to assign a cause to these departures they were not classified as events. Hence only occurrences within the immediate vicinity of the nest (<2 m) and visible on camera were treated as events.

Nest survival analysis for nests monitored in 1999–2001

Daily survival rates (DSR) of nests in 1999–2001 were compared to test for effects of management (i.e., whether or not nests were subject to conservation management), and of employment of video monitoring and year (i.e., breeding season 1999, 2000, or 2001). An information-theoretic approach (Burnham & Anderson 2002) was used to evaluate the relative support of multiple models describing relationships between DSR of nests and these parameters. We began by building a set of candidate models that described competing hypotheses about nest survival of oystercatchers. Each model represented the DSR of the nest as a function of some combination of potential sources of variation: management, year, and employment of video monitoring. We considered adding another parameter, the number of nesting attempts made, but decided against including it because the number was less certain in the unmanaged than in the managed areas. Additive relationships between DSR and these independent variables were considered using the nest-survival module in program MARK (White & Burnham 1999) to evaluate the relative support for each candidate model. This module uses generalised linear models (McCullaugh & Nelder 1989) with a user-specified link function to generate maximum likelihood estimates of regression coefficients and their sampling variances and covariances. We used the logit-link function for analysis of nest survival. This approach extends the survival models developed by Mayfield (1961), Johnson (1979), and Bart & Robson (1982) by permitting direct evaluation of the influence of specific covariates on DSR (Dinsmore et al. 2002). Akaike's Information Criterion (AIC) and AIC weights (w_i) (Burnham & Anderson 2002) were used to evaluate individual models. Models with $\Delta AIC_c \leq 2$ were considered to have substantial support from the data, those with $2 \leq \Delta AIC_c \leq 4$ to have moderate support, models with $4 \leq \Delta AIC_c \leq 7$ to have minimal support, and models with $\Delta AIC_c > 10$ to have essentially no support (Burnham & Anderson 2001). Assumptions of the daily nest-survival models are: (1) homogeneity of daily nest survival rates (i.e., DSR varies only with specified covariates), (2) nest fates are correctly determined, (3) nest discovery and subsequent nest checks do not influence survival, (4) nest fates are independent, (5) all visits to nests are recorded, and (6) nest checks are conducted independently of nest fate (Rotella et al. 2004). Nests with unknown or ambiguous fates were not included in the analysis. Research and management activities were coordinated so that disturbance to incubating birds was kept to a minimum. A mean incubation period of 29 days was assumed when extrapolating estimates of daily survival to estimates of nest survival. Nest survival estimates were the product of all of the DSRs for the model over the mean incubation period (Mayfield 1961). Season dates among years were standardised by using the earliest date that a nest with eggs was located in any year as the first day of the season and the latest date that a nest with eggs was located in any year as the last day of the season. By these criteria, the nesting season ran for 133 days from 19 October to 28 February, and comprised 132 daily intervals for which DSR was estimated.

RESULTS

Video surveillance

Forty-nine nests were filmed during three summers (1999–2001), 21 in managed areas and 28 in unmanaged areas, for a mean of 15.98 (±10.60 SD) days (24-h periods) (range: 2–34 days). Filming over 783 days logged 434 days' data from managed areas and 349 days in unmanaged areas (Table 1). Twenty-nine days of footage were only partially interpretable because of infrared light malfunctions. Similarly, viewing conditions were sometimes difficult during daytime because of light reflection from the beach and/or water and grit on the lens, both of which affected the cameras' auto-iris and auto-focus functions. However, most images were clear enough to record activity at the nest.

Events at filmed nests

A total of 164 events was captured on film during 3 years of video monitoring (Table 2). Most events were classified as high risk ($n = 58$) or low risk ($n = 68$) (Table 2, Fig. 2). Nineteen events were fatal to nests, and a further 19 were recorded only after nests had failed or the chicks had departed (post-outcome). In all but the low risk category, more events were filmed in the unmanaged areas than in managed areas. Seventeen of 75 (23%) visits to active nests by predatory species (cats, weka, gulls, possums (*Trichosurus vulpecula*), rodents,

Table 1 Summary of 24-h video surveillance at Chatham Island oystercatcher (*Haematopus chathamensis*) nests in managed and unmanaged areas of northern Chatham Island during the 1999–2001 breeding seasons. Event = any visible threat within 2 m of the nest excluding other oystercatchers and researchers. Event group = a series of visits by the same animal species (assumed to be the same individual except in the case of sheep) within a 30-min period.

Management	Days filmed	No. of events	Median events/ day/nest	Mean events/ day/nest ± SD	Range (events/ incubation period)	Event groups	Median groups/ day/nest	Mean groups/ day/nest ± SD	Range (event groups/ incubation period)
Managed ($n = 21$ nests)	434	45	0.043	0.093 ± 0.137	0–13	42	0.043	0.088 ± 0.125	0–13
Unmanaged ($n = 28$ nests)	349	119	0.341	0.546 ± 0.682	0–20	109	0.373	0.487 ± 0.503	0–17
Total	783	164	0.125	0.361 ± 0.572	N/A	122	0.125	0.243 ± 0.286	N/A

Table 2 Threats and animals seen on film at or near Chatham Island oystercatcher (*Haematopus chathamensis*) nests in managed and unmanaged areas of northern Chatham Island during the 1999–2001 breeding seasons.

Event type	Cat	Weka	Gull	Livestock	Sea	Possum	Human	Other*	Total
Managed									
Fatal	0	0	1	0	1	0	0	0	2
High risk	1	0	0	0	1	2	1	0	5
Low risk	0	2	4	4	0	1	0	26	37
Post-outcome	0	0	0	0	0	0	0	1	1
Total	1	2	5	4	2	3	1	27	45
Unmanaged									
Fatal	13	3	0	1	0	0	0	0	17
High risk	4	4	0	32	3	5	1	4	53
Low risk	1	4	1	12	0	4	6	3	31
Post-outcome	6	8	0	3	1	0	0	0	18
Total	24	19	1	48	4	9	7	7	119
Grand total	25	23	6	52	6	12	8	34	164

*Includes penguins, plovers, starlings, rodents and hedgehogs. Events <2 m from nests were categorised as fatal (nest failure), high risk (partial clutch loss, eggs investigated, nearly trampled or washed by sea, low risk (animal paid no attention to nest), or post-outcome (after failure or chicks had departed).

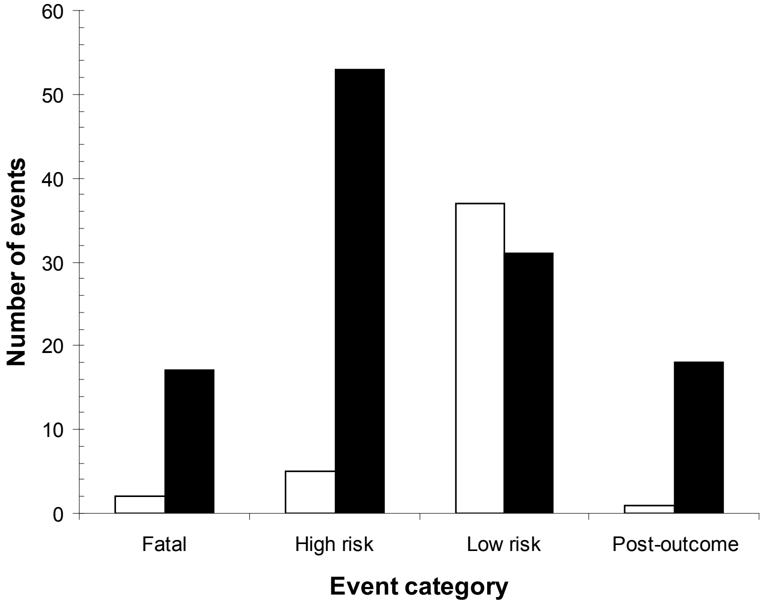

Fig. 2 Events captured on film at Chatham Island oystercatcher (*Haematopus chathamensis*) nests in managed and unmanaged areas of northern Chatham Island during the 1999, 2000 and 2001 breeding seasons. Fatal: nest failed. High risk: the occurrence of partial clutch mortality, or a high risk of partial clutch mortality or nest failure. Low risk: intruder did not visibly pay any attention to nest. Post-outcome: a visit to the nest after nest failure or departure of chicks. Black bars represent events at nests filmed in unmanaged areas and white bars represent events at nests filmed in managed areas.

spur-winged plovers (*Vanellus miles novaehollandiae*) and hedgehogs (*Erinaceus europaeus*)) and one of 65 (2%) visits by all other animals (sheep, cattle, humans, penguins, and other birds) resulted in nest failure at filmed nests.

Two fatal events were recorded in managed areas; one nest was preyed on by a red-billed gull (*Larus novaehollandiae scopulinus*) and another was washed away by high seas. All other fatal events were filmed in unmanaged areas, 16 as a result of egg predation (13 by cats and three by weka) and one nest was crushed by a sheep.

Five high risk events were observed in managed areas and 53 in unmanaged areas. High risk events involved cats, weka, possums, sheep, cattle, sea waves or foam, humans and rats (*Rattus* sp.—the species could not be identified from video footage, but both Norway rats (*R. norvegicus*) and ship rats (*R. rattus*) were caught in traps in the same areas). At a nest at Whangamoe a cat destroyed a three-egg clutch, one egg a night over 3 consecutive nights; the first two visits were classified as high risk as they did not cause nest failure.

There were 37 low risk events in managed areas, including 13 visits by spur-winged plovers to one nest within 3 days, and 31 low risk events in unmanaged areas.

Four events involved humans approaching nests; one event was categorised as high risk, as the person involved handled the eggs (Fig. 3), and the others were categorised as low risk. Four other events involved people walking past the nest at close range including one high risk event where a person walked close enough to pass between the camera and the nest.

All events involving cats, weka, possums, rodents, a hedgehog, and little blue penguins were nocturnal (except one involving a weka). All events involving cattle, humans, sheep, plovers, seagulls, and starlings (*Sturnus vulgaris*) (one low risk event) were diurnal, except two events involving cattle and one involving plovers at night.

In many cases the oystercatchers left the nest before the intruder was visible on screen. Oystercatchers departed the nest when approached by cats, possums and humans. Four of 19 (21%) visits by cats to active nests appeared to also be close calls for the incubating oystercatchers because they flew from the nest only 1–2.5 s before the appearance of the cat at the nest. During the other 15 visits by cats (79%) oystercatchers left their nests >7 s before the cats arrived. Oystercatchers incubated the eggs erratically during laying and the first few days after clutch completion. Some birds left eggs unattended for up to 9 h at a time, particularly at night. Unattended eggs were vulnerable to predation by weka—two fatal events followed 36–58 min after the oystercatcher departed the nest, and the third weka predation was only 27 s after departure. Oystercatchers generally did not leave the nest when approached by cattle, sheep, weka,

Fig. 3 Sample images from filmed Chatham Island oystercatcher (*Haematopus chathamensis*) nests including: **A**, nest predation by a feral cat (*Felis catus*); **B**, eggs handled by a possum (*Trichosurus vulpecula*); **C**, nest predation by a red-billed gull (*Larus novaehollandiae scopulinus*); **D**, a weka (*Gallirallus australis hectori*) walking past a nest; **E**, eggs handled by a human; **F**, disturbance of an incubating oystercatcher by sheep (*Ovis aries*).

spur-winged plovers, gulls or penguins. Sheep and cattle appeared to be curious and sniffed and nuzzled the incubating birds (Fig. 3), causing them and their partners to become agitated and display defensive behaviour. The birds pecked the intruders on the snout, but this generally only deterred cattle. The birds departed the nest only when they were physically pushed by these intruding animals.

Disturbance to nests

The level of nest disturbance (mean number of event groups per days filmed) was 5.5 times greater in unmanaged areas than managed areas during the 3 years combined (Table 1). However, the level of disturbance varied between years both within managed and unmanaged areas and also between individual nests. In 1999, unmanaged nests were 4.7 times more often disturbed ($\bar{x} = 0.248$ event groups per day) than managed nests ($\bar{x} = 0.053$ event groups per day) and 9 times more in 2000 ($\bar{x} = 0.433$ cf. $\bar{x} = 0.048$). By contrast, in 2001 the mean disturbance of managed nests ($\bar{x} = 0.162$ event groups per day) was only slightly higher than unmanaged nests ($\bar{x} = 0.155$ event groups per day) because of frequent visits by spur-winged plovers and little blue penguins at two managed nests. These birds passed by with little apparent interest in the oystercatcher nests. Some nests completed the incubation period without any disturbance ($n = 12$ nests) but others were more often disturbed (e.g., 17 events groups at one unmanaged nest and 13 at one managed nest). The mean duration of events (the period for which the disturbing agent was visible on film) was 9 min (±25 SD, range: <1–228 min, $n = 162$) and the mean duration that birds were away from the nest was 85 min (±126 SD, range: <1–468 min, $n = 68$).

Effects of cameras

Some oystercatchers were initially disturbed by camera installation at nests, although this was highly variable between pairs. The mean time between the completion of video set-up and the return of the bird to the nest was 34 min (±47 SD, range 2–293 min). The pair with the longest return time (up to 293 min, or c. 5 h) initially spent more time off the nest than on after camera installation before settling into more normal incubation shifts. For some nests disturbance was prolonged by the visibility of people checking nearby traps or returning past the nest to leave the area. Some oystercatchers may have reacted adversely to the infra-red light by spending long periods off the nest during the first few nights of filming, although this only occurred during clutch completion or early in the incubation period. At other nests where filming started later in incubation, the birds incubated almost constantly throughout the day and night.

Cats, possums, cattle, sheep, and humans investigated the cameras by looking at, sniffing, rubbing or climbing on them, usually after a visit to the nest ($n = 12$ events). Two of these events were after the nest had failed or the chicks had left the nest. A possum and a weka walked directly towards cameras during two events, and another possum climbed onto the camera; in all three cases they departed without visibly paying any attention to the nest. Other animal intruders came to the nest at an angle to the camera, suggesting that they were attracted to the nest rather than the camera or light.

Nest survival and effectiveness of management in 1999–2001

During the 3 years of video monitoring we followed the breeding success of all nests observed in managed and unmanaged areas, locating 129 nests in total. Mean clutch size was 2.13 eggs (±0.59 SD, range 1–3, $n = 129$) and the mean incubation period (from clutch completion to hatching) of nests with known laying dates was 29.4 days (±1.86 SD, $n = 50$). Seventy-five (58%) nests survived to hatching and 53 (41%) failed. The contents of one (1%) other nest disappeared close to the expected hatching time, but there was no conclusive evidence of hatching.

Of 79 managed nests, 58 (73%) survived and 21 (27%) failed, whereas of 50 unmanaged nests 17 (34%) survived, 32 (64%) failed and the outcome of 1 (2%) was not determined. The main apparent cause of nest failure during the 3 years was destruction by predators ($n = 17$, 32%), followed by tidal overwash ($n = 11$, 21%), inviability (infertility or early dead embryo) ($n = 7$, 13%), abandonment ($n = 5$, 9%), trampling by sheep ($n = 2$, 4%), and unknown causes ($n = 11$, 21%). The latter category included clutches that went missing, but the cause of failure could not be attributed definitively to predation, tidal overwash, or other events. It is likely that many disappearances were a result of predation. Some abandonments were weather-related, e.g., wind-blown sand covering the eggs. Of five nests that were abandoned, two may have been influenced by management activities, since the nests had been translocated repeatedly up the beach profile.

We analysed encounter histories for 126 of 129 nests (Table 3). We did not include three nests from the unmanaged sample in our analyses because either their fate was ambiguous or they did not have enough encounters for analysis of DSR. One nest had apparently been abandoned before we found it, a second nest disappeared before the second visit and a third nest disappeared at hatching time but no chicks were observed. Of the 126 nests included in analyses 49 were filmed and 77 were not, and we estimated that 82 were first attempts for their respective breeding season, 33 were second attempts, 9 third attempts and 2 fourth attempts.

Nest survival was best explained by a model with a constant daily survival rate that included the effect of management (Table 4). Support for this model was strong ($w_i = 0.612$). There was also substantial relative support for the additive effects of management and video monitoring (i.e., $\Delta AIC_c < 2$, $w_i = 0.236$), moderate relative support for the effects of management and year (i.e., $\Delta AIC_c < 4$, $w_i = 0.109$), and minimal relative support for the additive effects of all three variables (i.e., $4 \leq \Delta AIC_c \leq 7$, $w_i = 0.043$). The models that included only the effects of video monitoring or year had no support from the data (i.e., $\Delta AIC_c > 10$, $w_i = 0.00$). Summed values of model weights ($w_{+(j)}$) for each variable over all models indicate that overall the effects of video monitoring and year had little support from the data ($w_{+(\text{management})} = 1.00$, $w_{+(\text{video})} = 0.279$, $w_{+(\text{year})} = 0.152$). A likelihood ratio test between the management model ($S_{(\text{Management})}$) and the model including the additive effects of management and video ($S_{(\text{Management + Video})}$) revealed that the employment of video monitoring at nests did not significantly affect oystercatcher nest survival ($x^2_1 = 0.09$, $P = 0.76$). Similarly the effect of year ($S_{(\text{Management + Year})}$) did not significantly affect oystercatcher nest survival ($x^2_1 = 0.56$, $P = 0.76$).

DSR was high in managed areas (0.990, 95% CI 0.985–0.994, $n = 79$) and low in unmanaged areas (0.959, 95% CI 0.941–0.971, $n = 47$). The nest survival rate (i.e., the probability that at least one egg in a nest would survive to hatching) was 0.757 ($n = 79$, 95% CI 0.652–0.834) for managed nests and 0.294 ($n = 47$, 95% CI 0.174–0.425) for unmanaged nests.

Table 3 Total number, fate, and apparent causes of failure of Chatham Island oystercatcher (*Haematopus chathamensis*) nests during the 1999–2001 breeding seasons.

						Cause of failure*					
Year	Management	Video	Total nests	Survived	Failed	Predator	Livestock	Sea	Abandoned	Inviable	Unknown
1999	✓	✓	8	5	3	0	0	1	0	1	1
	✓		13	9	4	0	0	3	0	0	1
		✓	8	5	3	3	0	0	0	0	0
			9	1	8	0	0	7	0	0	1
2000	✓	✓	4	4	0	0	0	0	0	0	0
	✓		22	17	5	0	1	0	2	2	0
		✓	13	3	10	8	1	0	0	1	0
			5	3	2	0	0	0	0	0	2
2001	✓	✓	9	7	2	1	0	0	0	1	0
	✓		23	16	7	0	0	0	3	2	2
		✓	7	2	5	5	0	0	0	0	0
			5	3	2	0	0	0	0	0	2

*Apparent cause of failure in the case of unfilmed nests.
✓Indicates whether or not a nest was managed and/or filmed.

Table 4 Models of daily survival rate of Chatham Island oystercatcher (*Haematopus chathamensis*) nests during the 1999–2001 breeding seasons. Models are ranked by differences in Akaike's Information Criterion for small sample size (ΔAIC_c) values. *K* is the number of parameters. AIC_c is Akaike's Information Criterion corrected for small sample size. ΔAIC_c is the difference in AIC_c values between the current model and the model with the lowest AIC_c value. Factors in the model include management (present versus absent), video (present versus absent), and year (1999, 2000, 2001).

Model	K	AIC_c	ΔAIC_c	AIC_c weight (w_i)	Model likelihood
$S_{(\text{Management})}$	2	455.37	0	0.612	1.000
$S_{(\text{Management + Video})}$	3	457.28	1.91	0.236	0.385
$S_{(\text{Management + Year})}$	4	458.82	3.45	0.109	0.178
$S_{(\text{Management + Year + Video})}$	5	460.69	5.32	0.043	0.070
$S_{(\text{Video})}$	2	480.12	24.75	0.000	0.000
$S_{(\text{Year})}$	3	482.83	27.46	0.000	0.000

Breeding success 1998–2004

Monitoring of breeding success was more variable in unmanaged sites in 1998 and 2002–04 than in 1999–2001. However, a coarse determination of egg loss and overall chick output per nest was still useful for the entire management period (1998–2004). The 16–35 breeding pairs in managed areas fledged 17–35 chicks per year with a mean productivity of 1.04 chicks fledged per breeding pair per year (Table 5). Other annual breeding statistics were also correspondingly high, 50.1% (±16.3 SD) of all nesting attempts fledged at least one chick (nest success), 54.9% (±15.3) of eggs hatched (hatching success), 35.4% (±13.5) of eggs hatched chicks that survived to fledging (egg success) and 63.1% (±12.3) of chicks fledged (chick success). The 8–14 breeding pairs that were monitored in unmanaged areas had lower average annual levels of breeding success (productivity 0.37 chicks/pair/year, nest success 15.8% (±11.8 SD), hatching success 38.5% ± 13.6, egg success 14.4% ± 11.1, chick success 36.6% ± 23.9). The difference in breeding success between managed and unmanaged areas was greater during 1998–2001, including the 3 years of video monitoring, than in 2002–04 (Table 5). For example, in managed areas mean annual egg success decreased from 39.2 to 30.4% and productivity decreased from 1.18 to 0.85 chicks per pair between the two respective periods. In contrast, in unmanaged areas egg success increased from 6.7 to 22.0% and productivity increased from 0.23 to 0.61 chicks/pair/year between the two periods.

In unmanaged areas, the majority ($\overline{x}$ = 78.4% of eggs ± 21.4 SD, range 36–93%, n = 6 years, 12–28 eggs per year) of egg losses were in the predation/disappeared/trampled category (Fig. 4) and during the years of intensive monitoring most of these losses were attributable to predation. Eggs that disappeared without trace were probably also preyed on, except in 1999 when 55% of egg losses were caused by the sea. In 2004, some of the nest losses in unmanaged areas that were assigned to the "disappeared" category may have suffered washovers, which often happened in managed areas that year (Fig. 4) but monitoring was too infrequent to be sure. Three eggs in unmanaged areas were destroyed by vehicles and four eggs were trampled by livestock.

In managed areas more than half ($\overline{x}$ = 57.8% ± 31.7 SD, range 19–91%, n = 7 years, 15–109 eggs per year) of egg losses were due to failure of eggs to hatch. Most of these were infertile or had dead embryos and the remainder were abandoned, because of, for example, human disturbance, high winds covering nests with sand, or unknown reasons.

Table 5 Fates of Chatham Island oystercatcher (*Haematopus chathamensis*) nests in managed and unmanaged areas of northern Chatham Islands, New Zealand between 1998 and 2004.

	Pairs	Nests	Eggs	Chicks	Fledged	Chicks fledged/ pair	Nests that fledged chicks
Managed							
1998	16	23	50	24	18	1.13	13
1999	16	21	48	33	25	1.56	13
2000	20	26	59	37	19	0.95	14
2001	24	32	71	42	26	1.08	17
2002	28	32	70	46	35	1.25	21
2003	35	42	92	52	27	0.77	18
2004	33	71	143	34	17	0.52	12
Total	N/A	247	533	268	167	N/A	108
Mean ± SD						1.04 ± 0.34	
Unmanaged							
1998	10	No data	No data	No data	1	0.1	1
1999	10	17	32	10	0	0	0
2000	9	18	34	11	4	0.44	2
2001	8	12	24	10	2	0.25	1
2002	10	14	29	17	7	0.70	4
2003	14	20	36	17	11	0.79	6
2004	12	18	35	7	4	0.33	3
Total	N/A	99	190	72	29	N/A	17
Mean ± SD						0.37 ± 0.29	

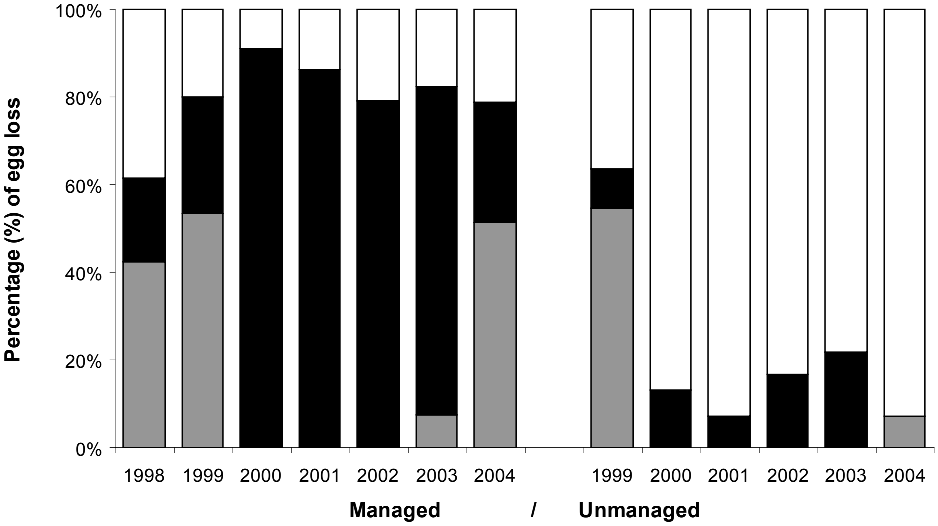

Fig. 4 Causes of egg loss in Chatham Island oystercatcher (*Haematopus chathamensis*) nests between 1998 and 2004. Grey bars represent eggs lost due to tidal overwash, black bars represent eggs that did not hatch or were abandoned, and white bars represent eggs that were preyed upon, trampled by livestock or disappeared. Nesting data for unmanaged areas in 1998 were not available and data were coarse for unmanaged nests in 2004.

Other egg losses resulted from tidal overwash ($\bar{x}$ = 22.1% ± 25.6, range 0–53%) or predation/disappearance/trampling ($\bar{x}$ = 20.1% ± 9.2, range 2–39%, Fig. 4). During stormy years (1998, 1999 and 2004) 42–53% of egg losses in managed areas were caused by the sea.

DISCUSSION

Predators

Before our study, records of predation on Chatham Island oystercatchers were rare and often determined by inference. They were confined to the more visible diurnal predators such as brown skuas (*Catharacta skua lonnbergi*), black-backed gulls (*Larus dominicanus*) or spur-winged plovers, or were suggested by the anti-predator behaviour shown by oystercatchers to other birds such as harriers (*Circus approximans*) (Davis 1988; Aikman et al. 2001). Spur-winged plovers are predators of New Zealand dotterels (*Charadrius obscurus aquilonius*) (Wills et al. 2003) and are suspected predators of Chatham Island oystercatchers (Schmechel & Paterson 2005). It was assumed that nocturnal predators, particularly feral cats, were a significant problem for oystercatcher nests on Chatham and Pitt Islands, but not on Rangatira (South East) and Mangere Islands where cats are absent (Gillies & Fitzgerald 2005). However, the relative importance of different predators was not known. Determination of nest fates based on nest sign can be difficult because nest sign is often absent or ambiguous (Brown et al. 1998). For example, we found that oystercatchers at filmed nests usually removed egg shells from nests after eggs hatched or were preyed on, thus leaving no sign for observers to assign nest fate at unfilmed nests.

Video surveillance confirmed that cats, weka and gulls are predators of eggs of Chatham Island oystercatchers. Losses could easily have been greater considering three (5%) of the 58 high risk events involved predation of partial clutches, and eggs were sniffed or handled by predators on 12 (23%) other occasions. Other high risk events involved cats, weka, possums, sheep, cattle, rats, the sea, and humans.

Cats appear to be the principal threat, as 16 different nests (33% of 49 filmed in all areas) were visited by cats resulting in 13 failures. At Okawa three different cats visited the same nest over the course of 3 days. In contrast, at a territory in Whangamoe Inlet-Paritu what appeared to be the same cat preyed on five nests during 2000 and 2001, despite the birds re-nesting in different localities. At other nests, a cat tried and failed to eat an egg, and two others sniffed at eggs, which suggests they were naive predators or not hungry. Because the mammalian predator guild is small on the Chathams and does not include mustelids we surmise that cats are the key predator of Chatham Island oystercatcher eggs in most years.

The main anti-predator strategy of Chatham Island oystercatchers is to temporarily abandon their well-camouflaged eggs or chicks, combined with distraction displays at the chick stage (Marchant & Higgins 1993). These strategies may be more effective against endemic diurnal avian predators such as harriers and gulls than for introduced mammalian predators which often hunt at night and use a combination of sight, hearing and smell (Dowding & Murphy 2001). On the New Zealand mainland, introduced rats, cats and mustelids have had a disastrous impact on shorebirds and several species are now threatened with extinction (Dowding & Murphy 2001; Miskelly et al. 2008). The Chatham Islands are no exception—cats were introduced by European settlers in the early 1800s (Gillies & Fitzgerald 2005) and probably had a key role in reducing the Chatham Island oystercatcher population (Moore 2008). Judging by the high level of egg predation by cats seen in our study cats have continued to keep the oystercatcher population low.

Weka and gulls were less of a threat and are probably more opportunistic predators than cats. Two of the three weka predations occurred early in incubation when eggs had been left unattended. At other times the oystercatchers stayed on the nest when approached by weka.

The use of video allowed us to quantify the causes of egg loss of Chatham Island oystercatchers. However, because chicks were mobile shortly after hatching we could only infer that chick predation had occurred based on the presence of cat footprints on beaches or, rarely, chick remains (wings or legs). More commonly chicks disappeared without trace. Once chicks were flying, at around 6 weeks of age, they were probably less vulnerable to cat predation. However, cats have an impact on all stages of the oystercatcher's life cycle. For example, it appeared that four attacks by cats at filmed oystercatcher nests posed a high mortality risk to incubating adult oystercatchers. On the Chatham Islands corpses of adult oystercatchers have occasionally been found that were probably killed by cats (Moore 2008). During Schmechel's (2001) study one member of a pair disappeared during a breeding season and she inferred that this was a result of predation. This seems a reasonable supposition considering that cats were the only predator found to kill adult shorebirds at nests on braided rivers in the Waitaki Basin (Sanders & Maloney 2002).

Video monitoring of 137 nests of shorebirds and terns during 5 years in the Waitaki Basin recorded 70 failures, mainly caused by cats, ferrets (*Mustela furo*) and hedgehogs (Sanders & Maloney 1999). There are no mustelids on the Chatham Islands and although hedgehogs were trapped at Wharekauri only one was seen on film as it quickly passed by a nest. In the Waitaki study 80% of visits to nests by mammalian predators resulted in eggs being removed or eaten and cats were responsible for 40% of nest losses.

Possums are important predators at nests of forest birds (Innes et al. 1999; Innes et al. 2004), but not in braided river systems (Sanders & Maloney 2002). During our study possums (n = 3 events) tried and failed to eat eggs which suggests they were naive predators or not hungry.

Other causes of mortality

Filming of Chatham Island oystercatcher nests confirmed that livestock cause egg losses. Forty events at filmed nests involved sheep, one (3%) of which destroyed the nest, and 29 (73%) of which were high risk. However, disturbance was restricted to a small number of nests—e.g., 27 (67.5%) of sheep events were at two nests in the same territory. Twelve events at filmed nests involved cattle, three of which were high risk.

Oystercatchers did not leave the nest when approached by livestock, suggesting that they did not perceive them as a direct threat. Sheep appeared to be less reactive than cattle to the defensive behaviour shown by nesting oystercatchers, although both investigated the birds by sniffing and nuzzling them. This forced the birds to leave the nest, leaving the eggs vulnerable to trampling or being broken during their panicked departure. Sheep on riverbeds have been filmed trampling the nests of banded dotterels (*Charadrius bicinctus*) and appeared oblivious to the defensive displays of the birds (Sanders & Maloney 2002).

Tidal overwash caused the loss of one filmed oystercatcher nest during our study. In addition, eggs were washed over or swept up the beach but remained intact and continued to be incubated. Previously, low lying fore-dunes in the Chatham Islands may have had a sparse cover of low-growing native plants among which oystercatchers would have nested, but have since been out-competed by the more vigorously growing marram grass introduced to stabilise the dunes. Marram grows in dense thickets that oystercatchers do not use for nests. In addition, marram consolidated the dunes resulting in steep-fronted fore-dunes that are maintained by storm waves. Consequently, many beaches in northern Chatham Island, particularly in some of the managed areas, are narrow and offer limited nesting opportunities for oystercatchers close to the high tide mark (Moore in press). Tidal action has been identified as a problem for many shorebirds around the world (e.g., Fleming 1990; Davis et al. 2001; Neuman et al. 2004; Morse et al. 2006). The use of marram to stabilise dunes has caused similar problems for hooded plovers (*Thinornis rubricollis*) in Australia (Park 1994) and Western snowy plover (*Charadrius alexandrinus*) in the United States (US Fish & Wildlife Service 2001).

Several additional causes of egg loss and nest failure were observed during our study but were not apparent during the period of video monitoring. Visits by people with dogs to oystercatcher territories resulted in disappearances of chicks and at least one adult. Vehicle use on beaches also resulted in the loss of at least three eggs and three chicks. Losses of eggs and chicks due to human activities on beaches, including those involving dogs and vehicles, have been observed in other studies of shorebirds (e.g., Buick & Paton 1989; Patterson et al. 1991; Marchant & Higgins 1993; Leseberg et al 2000; Lafferty et al. 2006; Sabine et al. 2008).

Video biases

More film footage was obtained in managed than unmanaged areas because managed nests were more successful, and so the cameras stayed in place longer. Unmanaged nests sometimes failed before a camera could be put in place. No nests were abandoned because of cameras, although this occurred in a similar study, possibly as a result of additional disturbance caused by catching and banding incubating birds (Sanders & Maloney 1999, 2002). During a video study of 32 American oystercatcher (*Haematopus palliatus*), no nests were abandoned as a result of camera installation (Sabine et al. 2005).

It is unlikely that birds can detect the infrared light used in these camera systems because of the nature of their colour vision, although a small amount of visible light which is emitted from the LEDs could be visible to the birds or attract predators (Innes et al. 1996). There was little evidence in our study that predatory animals were attracted to cameras or lights at oystercatcher nests, and video monitoring did not have a significant effect on daily survival rate. Fledging rates at filmed and unfilmed nests of kokako (*Callaeas cinerea wilsoni*) were similar, indicating no discernible negative effects of cameras (Innes et al. 1996). Brown et al. (1998) found that camera equipment did not influence predation rates at New Zealand forest bird nests, and similarly no effect of cameras or the type of light used (“visible” or “invisible” infrared lights) was found on nesting success of banded dotterels and black-fronted terns (Sanders & Maloney 1999).

Livestock may be attracted to cameras. For example, a consistent but non-significant trend of higher trampling rates was found at filmed than unfilmed nests in one study (Renfrew & Ribic 2003) and camera equipment appeared to attract cattle to nests in another (Nack & Ribic 2005). Two nest failures and one egg loss were attributable to sheep trampling during our study, one of which was filmed, but none was attributable to cattle. The animals may have been attracted to nests by camera equipment, since sheep were visible sniffing cameras during three events and cattle in one event, however, they appeared to be more interested in the birds than the cameras. The presence of camera equipment is also likely to have attracted humans—four events involved people approaching nests.

Effectiveness of management

Management dramatically reduced the incidence of predation of Chatham Island oystercatcher nests. Fatal events were recorded at two of 21 (10%) filmed nests in managed areas, compared with 17 of 28 (61%) filmed nests in unmanaged areas. Although potential predators were not completely removed from managed areas the low rates of predation observed on film combined with the high chick output indicate that the predator control regime was effective. In coastal grasslands of New Zealand, cats have home ranges of 150–200 ha, which may overlap depending on the abundance of food (Gillies & Fitzgerald 2005). A line of 76–125 traps concentrated at 50–100 m intervals at oystercatcher territories and likely access ways to the beachfront in northern Chatham Island presumably removed most of the resident cats at the beginning of each season. Ongoing trapping quickly eliminated any new migrants, and it was rare to note cat prints on the beach for more than 24 h before a cat was caught in a trap. The number of cats caught was highest in 1998–2000 (46–51 per year), but decreased in 2001–04 to 26–31 per year (Moore in press). A mean of 36.71 ± 10.78 cats and 539.57 ± 159.29 weka were trapped per year in 1998–2004.

Use of permanent and temporary fences reduced the incidence of livestock disturbance in managed areas, where no high risk events were recorded at filmed nests, yet they were numerous in unmanaged areas. However, eggs were occasionally destroyed at unfilmed nests in managed areas, e.g., one nest was trampled in 2000 when sheep broke through an electric fence. Some chicks were also trampled by sheep.

Relocating nests above the high tide mark during management undoubtedly contributed to improved breeding success, although the only fatal event caused by the sea during the period of video monitoring was at a managed site, and 16% of nests that were moved or raised were washed away (Moore in press). Several of the managed territories were on narrow beaches where it was unlikely that nests within 10 m of the mean high tide mark would last the 29-day incubation period without being washed over by wind-generated waves or spring tides. Relatively small (10 m) lateral movements of nests and the creation of cleared alcoves in the fore-dune permitted the elevation of nests by up to 1 m (Moore in press). This was beneficial in calm years, but during stormy years waves still washed over these sites and into the fore-dunes. Of 249 managed nests found in 1998–2004, 43% were manipulated by being moved ($\bar{x}$ = 6.7 ± SD 6.1, range 1–41 m, n = 86), raised on mounds (n = 14) or tyre platforms (n = 30) or a combination of all three methods.

Although management activities were conducted with a minimum of disturbance, two of 107 nests that were manipulated were abandoned. One of them was probably moved too far (41 m in exceptionally large increments of up to 8 m). On the other hand, without intervention it would have been destroyed by the sea. Despite this outcome the overall benefits of management have been shown to outweigh the potential costs.

Breeding success in 1998–2004

Intensive management in 1998–2004 resulted in higher breeding success than has been observed previously. The mean productivity of 1.04 chicks per pair per year with management was more than double that of previous years (Davis 1988; Schmechel 2001) and also more than that found in areas with no management. The benefit of management was greatest during the most detailed period of monitoring when nests were filmed (1999–2001). The daily survival rate of nests during this period was higher for managed (0.990) than unmanaged nests (0.959) and over the whole season these resulted in a large difference in the survival probability of nests (0.757 and 0.294 respectively). Similarly, the proportion of eggs that resulted in chicks surviving to fledge during the 3-year period was 40.3% in managed areas, but only 6.7% in unmanaged areas. However, in 2002–04 egg success in the two areas was more comparable (30.4 and 22.0% of eggs resulting in fledged chicks).

Annual variation in the distribution of egg loss between different causes in managed and unmanaged areas (Fig. 4) is likely the result, at least in part, of differences in the frequency of nest checks between these areas. Nest checks were made less frequently in unmanaged areas, particularly in 2004, and so causes of egg loss were more difficult to assign. Video monitoring identified definitive causes of nest loss (mainly predation by cats in unmanaged areas) but the data for 1999–2001 do not necessarily represent all years. The monitoring of nests over a longer period (1998–2004) showed that storm seas are an important cause of nest failure in some years, particularly in managed areas. Nevertheless, the 7 years of management in northern Chatham Island boosted productivity and helped drive a population increase from an estimated minimum of 144 birds in 1998 to 316 birds in 2004 (Moore 2008). During 2005–06, when management ceased in northern Chatham Island and moved to a small area on Pitt Island, the total oystercatcher population remained at about 313 birds (Moore 2008).

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