Evaluating the feasibility of Crested Auklet enhancement via habitat restoration at Gareloi Island, Aleutian Islands - summary report of 2011 summer field activity and discussion of new approaches

For

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&
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Executive Summary. Research to evaluate the feasibility of enhancing Crested Auklet populations on Gareloi Island, by removing vegetation to increase access to subterranean nest cavities at an established colony, continued during the summer of 2011 with commencement of fieldwork on June 14. Capture-mark-recapture (CMR) estimates showed a dramatic increase in estimates of individuals frequenting the surface after devegetation, with increases averaging 276% on manipulated subplots and 261% on control subplots), with very broad confidence limits on all estimates. On most plots, estimated numbers on the manipulated (identified with an “m”) devegetated subplot increased more than the undisturbed (identified with a “u”) control subplot. CMR estimates of the number of breeders on plots indicated decreases on most plots from 2009, averaging -86% on devegetated subplots and -59% on undisturbed subplots, with broad confidence limits on all estimates. The exception was subplot Du, which remained above 2009 numbers, but well below 2010 estimates. Broad CMR estimate confidence limits resulted from the small percentage (c.1%) of marked birds on study plots and difficulty reading color bands in the rugged terrain of the plots. Surface counts made by direct observation at the 2009 plots decreased somewhat from 2010 but remained above 2009 levels. Based on CMR estimates of breeding density and an assumed fledging rate of 0.5 chicks per breeding pair, an average of 15 chicks were estimated to fledge per 100 m^2 of colony surface area on the original study plots in 2011compared to 176 in 2009 and 117 in 2010 (see below for discussion of low 2011 breeding estimates). On average, 61% of marked birds seen on control subplots in 2010 and resighted again in 2011 stayed on the same subplot in 2011, and 71% of birds on devegetated subplots stayed put. However, 14 marked birds (13% of the 108 individuals with a clear plot preference in both years, all presumed to be breeding birds) moved to a completely different plot in 2011. Nest counts at the original 2009 study plots in averaged lower in 2011 on both control and devegetated subplots compared to previous years. There remains no consistent change in number of visible nests detected before and after experimental devegetation in 2009, but this may be due to annual variation in observer technique. Crested Auklet hatching success estimates ranged from 0.59 – 1.00 across plots, averaging somewhat higher in 2011 than measured in 2010, but the difference could be attributed to the relatively late date when most nests were found. Nevertheless, hatching success estimates on devegetated plots remain similar to those naturally occurring at long-term monitoring sites at other Aleutian Islands (e.g., at Buldir). On the 30 new plots, first surveyed in 2010 and devegetated at the end of the 2010 breeding season, surface

counts from Reconyx images showed that subplots had consistently higher levels of surface activity after devegetation, with about 2.3x more birds counted compared to the control subplots. Nest counts on the 2010 plots ranged from 0 – 20 Crested Auklet breeding sites, with no difference between devegetated and control subplots. No difference in productivity was detected between devegetated and control subplots, but feeding watches indicated a significantly higher rate of arrival of Crested Auklets returning with food for young on the devegetated subplots. A survey by ILJ of the 30 new plots devegetated in 2010 indicated that on average only 45% of the devegetated areas were suitable habitat for auklet breeding (i.e., rock with crevice openings, compared to close to 100% on the 2009 plots), with wide variability across plots (range: 1% - 100%), suggesting that future efforts might be better directed to high density areas with deep porous lava flows (i.e., as at the original 2009 plots).

Difficulties in quantifying Crested Auklet populations, density and breeding success are well documented in the published literature (Jones 1992, Gall 2002, Sheffield et al 2006, Renner et al 2010) and have been demonstrated in our three years of research or Gareloi. Ours was the first attempt to assess auklet density using CMR techniques and, while providing some useful estimates, the confidence limits on those estimates are extremely broad for reasons relating to auklet densities, behavior and habitat. While the research on Gareloi has demonstrated increases in auklet use of devegetated areas (both with CMR techniques and direct observation), it has faced the same problems as previous work in quantifying changes in breeding population size and density. The effects of encroaching vegetation on auklet colonies in the Bering Sea have been well documented (Roby and Brink 1986, Jones & Marais 2004, Jones & Hart 2006) making obvious the potential benefits of reducing or reversing vegetation succession on nesting habitat. Recognizing that precise estimates of changes in Crested Auklet numbers at devegetated sites between years and among plots may be impossible to obtain, we suggest here a simulation model to estimate the number of bird years produced by devegetation of an area of habitat, using rigorous estimates of breeding density and rates of habitat loss. The model would allow estimation of the anticipated benefits of devegetation while recognizing that the “unquantifiable” nature of many aspects of Crested Auklets will be part of both the development and monitoring of any restoration plan for the species.

For future capture-mark-recapture efforts to inform the model we recommend using coded VHF radio transmitters and logging receivers, allowing higher "resighting" rates, to make the necessary rigorous estimates of the numbers of breeding birds and their density on Gareloi. The rates of vegetation and peat accumulation on auklet nesting habitat needed for model input can be measured directly by visiting locations where vegetation cover was assessed in the past. Due to complexity and time requirements to successfully complete the field research protocol, it is recommended that in future, measures be taken to ensure that the field crew is at Gareloi with the camp set up and ready to commence research activities before June 1 at the latest.

Introduction

In 2009, a before-after controlled impact (BACI) experiment was initiated at Gareloi Island to test whether removal of vegetation overgrowth and peat from parts of an auklet breeding colony site would increase nesting opportunities for Crested Auklets (Conners and Jones 2009, Jones et al. 2010). Auklet (*Aethia* spp.) breeding density is limited by access to suitable naturally occurring crevices as they are unable to dig their own breeding sites. In the Aleutians auklets nest in rock crevices produced by coastal erosion (talus slopes and beaches) and in blocky and porous lava flows (http://www.mun.ca/serg/AAHab.html). Revegetation of exposed rock may occur within decades of a lava flow or rockslide produced by a seismic event, covering and eventually rendering sites unsuitable for auklet nesting activity by blocking access to crevices (Jones and Hart 2006). This is especially true in the Aleutians at the southern limit of the auklet breeding range with a mild, wet climate that facilitates plant growth and limits exposed rock. Kiska Island (site of a major lava dome eruption during 1966-1968) has the largest patch of fresh lava of any auklet colony in the Aleutians, but has introduced Norway rats (*Rattus norvegicus*) that depredate Least and Crested Auklets, sometimes severely. Rat-free Gareloi Island (with many auklets nesting in lava from a 1938 eruption) has the next largest amount of suitable breeding habitat, mostly covered with advancing vegetation (Jones and Hart 2006).

To evaluate the effectiveness of direct enhancement of breeding habitat structure at an active auklet colony, Crested Auklet activity was measured on four representative 100 m^2 plots (pairs of adjacent manipulated and unmanipulated subplots) delineated at Gareloi in 2009. Crested

Auklets were color banded in June and July of 2009, and surface counts measuring the ratio of banded to unbanded birds and breeding to nonbreeding birds were completed prior to vegetation and peat removal from one half of each plot (randomly selected) at the end of the 2009 auklet breeding season (Conners and Jones 2009). Subsequently, in 2010 (Jones et al. 2010) and 2011 (this report), activity monitoring continued on the four original plots and on 30 new plots in low density areas of the colony site.

Counting Crested and Least Auklet numbers and assessing population changes at their breeding colonies is difficult. Most auklet breeding sites (nests) are located in inaccessible rock crevices that can neither be observed nor counted, although at most sites at least some nests are visible (Jones 1993a,b). Birds are visible standing on the surface of the colony site during daily activity periods during the breeding season (Jones 1993a, b), with some individuals in a local population present daily and others rarely or never visible on the surface. Many individuals taking part in 'surface activity' are non-breeding birds and transients (Jones 1992). Surface counts vary greatly and unpredictably from day to day, within the season, and between years, with the relationship to the local breeding population weak and difficult to define (Jones 1992, Gall 2002, Sheffield et al. 2006, Renner et al. 2010). Although surface counts provide a measure of auklet activity at a site, they are not a proxy for local population numbers or for numbers breeding (Jones 1992, Gall 2002, Sheffield et al. 2006, Renner et al. 2010). Two studies have argued that capture-mark-recapture approach should be the best means of quantifying numbers (Jones 1992, Sheffield et al. 2006), but this has never previously been tried on a large scale at multiple sites or experimentally. Capture-mark-recapture uses a known number of marked individual birds and the ratio of marked to unmarked birds observed later to estimate numbers within a breeding colony. Our 2009-2011 study at Gareloi includes multiple methods of assessing Crested Auklet numbers, including counts of individuals on the surface, capture-mark-recapture estimates of numbers of individuals frequenting and breeding on study plots and counts of nests visible from the surface (Conners and Jones 2009, Jones et al. 2010, Jones 2011).

This report describes year three of a research project focusing on the utility of nesting habitat modification at Gareloi Island's southeast auklet colony. This project was undertaken with the assumption that breeding habitat is limited and decreasing at Gareloi due to encroaching vegetation blocking entrances to subterranean nesting cavities (Jones and Hart 2006). Our research tested the hypothesis that removal of vegetation would increase access to nesting cavities and increase the number of Crested Auklet breeding pairs and fledglings above what would occur at Gareloi in the absence of habitat manipulation.

In 2011, Crested Auklet fieldwork at Gareloi Island occurred during June 14 - July 29 and 1) measured auklet surface activity on the control and devegetated subplots established in 2009 using direct observations; 2) measured surface activity and breeding density at the same four study plots using capture-mark-recapture (color band resighting, using the c.150 birds marked on each plot in 2009); 3) estimated nesting density by counting active nest sites visible from the surface; 4) conducted the first post-manipulation surveys on 30 plots devegetated in 2010, located in low density areas of the Gareloi southeast colony . In this report we assess the progress of research efforts during 2009-2011 and consider approaches for future research.

1.0 Methods

The 2011 Gareloi Protocol (Jones 2011) outlines the activities originally planned for 2011 and their rationale – methods used during the field season are therefore summarized briefly here. Fieldwork was conducted during the period June 14 – July 29, 2011 (commencing 17 days later than in 2010).

1.1 Assessment at 2009 study plots A, B, C and D

1.1.1. Population estimates: surface counts and capture-mark-recapture (CMR)

We conducted counts on four of the eight subplots established in 2009 each day June 14 – July 6, except during high winds and rain, to obtain a mean value of the ratio that best reflected the true proportion of previously marked Crested Auklets on each plot. Counts were less frequent (each plot surveyed approximately once per week) July 7 – July 29 to allow time for feeding surveys at the 2010 plots as well (see below). Counts of banded and unbanded individuals were taken every 10 minutes for four hours during the daytime activity period (1100h - 1500h) through June and July and three surveys during 1.5 hours in the evening activity period (2100h - 0000h) in July. This provided both the ratio of banded to unbanded birds for CMR estimates, and also a mean total number of birds on the plot surface (analogous to counts made from Reconyx camera images on new 2010 plots). The number of Crested Auklet individuals using the surface of each subplot was estimated using the following equation:

$$N_{surface} = \frac{\text{Number of banded individuals seen at least once on the subplot}}{\text{Daily average proportion of birds seen on subplot that are banded}}$$

1.1.2. Breeding population estimates (CMR): In July, cumulative counts were performed continuously during four 30-minute intervals within the daytime activity period (1130h - 1200h, 1230h - 1300h, 1330h - 1400h, 1430h - 1500h), recording birds arriving with and without food, and with and without bands. We determined the total number of marked breeding birds, and measured the ratio of banded to unbanded breeders (‘breeders’ identified as individuals arriving at the study plot with a chick meal, as indicated by the presence of a distended throat pouch), to estimate the total number of breeding birds on each plot using the following equation:

$$N_{breeder} = \frac{\text{Number of banded individuals on the subplot seen delivering food at least once}}{\text{Daily average proportion of feeding birds seen on subplot that are banded}}$$

To estimate the number of chicks produced per plot we multiplied these estimates by a conservative Crested Auklet chick fledging rate of 0.5. We also compared the 2011 total counts of birds delivering food loads per hour (both marked and un-marked individuals) with those from the same plots in 2009 and 2010 to examine the effect of devegetation.

1.1.3. Re-sighting and movement of marked birds

We recorded all color band combinations observed during the daytime activity period between 1100-1500h HADST, during June and July, except during days of heavy rain and wind. In previous years, only individuals observed at least twice were included in analyses. This method is conservative and was not practical this year given that fieldwork began later than usual with less time for resighting surveys. We included all sightings of which we were confident in our identification, excluding sightings of band combinations that do not exist. For each marked bird we noted in which subplot it was sighted and whether it was carrying a chick meal.

To continue our analysis of Crested Auklet inter-annual movement at the 2009 plots we identified the subplot(s) frequented by each color-marked individual again in 2011. Only birds with a clear subplot preference (seen on only one subplot in 2011) were used in the movement analysis. We tallied birds that returned to the same subplot (e.g., Am to Am) as in 2009 and 2010, that moved from one subplot to another (e.g., Am to Au), and those that switched to an entirely different plot between years (e.g., Am to Cu). Throughout this report, devegetated subplots are indicated by ‘m’ for “manipulated” and control subplots by ‘u’ for “unmanipulated”, therefore Am is the devegetated side of plot A.

1.1.4. Crested Auklet nesting crevice counts and hatching success

Searchers attempted to locate all active Crested and Least Auklet breeding sites visible from the surface (indicated by the presence of an incubating adult, or an egg in an appropriate location) within plot boundaries. During the period June 14 – June 18, we located and mapped all accessible active breeding crevices within each of the four plots and recorded the contents of each following procedures outlined in Conners and Jones (2009). To compare the densities of breeding birds we present our data with that collected in 2009 and 2010. All active nests located during the crevice counts were marked on hand drawn maps following the 2009 and 2010 procedures (see Conners and Jones 2009) and were re-checked once (during the period July 11 – 21) to estimate hatching success on each half of the four study plots. Nests were considered to have hatched successfully if we found a chick or evidence of hatched eggshells during the second check. To partially control for differences in search effort between years and among plots we calculated the proportion of all crevices that were Crested Auklet crevices (i.e., number of Crested Auklet nests / total number of Crested and Least Auklet nests) within each subplot. We then used the ratio of this number for the experimental subplot to the control subplot for statistical comparisons. We did the same for Least Auklet nests.

1.2. Assessment of 2010 plots

1.2.1. Crested Auklet surface counts at study plots (Reconyx cameras)

To measure surface activity on the plots devegetated in 2010, 16 Reconyx time-lapse cameras were rotated approximately every four days (weather dependent) among the 30 newly established plots, maintaining a similar mean date of sampling for all plots. Cameras were programmed to take a digital image every five minutes between 0900 – 1500h HADST. Each plot was photographed for three days in June and three days in July, except when weather or equipment failure made this impossible. Two cameras were placed on tripods distant enough to capture either the control or devegetated subplot (approximately 20 meters from the center of each 10m x 10m subplot), ensuring both adjoining subplots were sampled for the same time periods. We counted the number of Crested and Least Auklets in each image to determine a daily maximum number for each species and subplot.

1.2.2. Crested Auklet nesting crevice surveys, 2010 plots

We searched each of the 30 new plots delineated in 2010 for visible Crested and Least Auklet active breeding sites (following the same procedures outlined in Section 1.1.5 for the 2009 plots) during June 18 – 29. We evaluated hatching success by re-visiting each active breeding site mapped in June during July 11 – 14.

1.2.3. Feeding watches at 2010 plots

We conducted auklet surface counts and feeding surveys at 15 of the 30 2010 plots during July, following the same methodology used to survey the 2009 plots. Cumulative counts were performed continuously during four 30-minute intervals during the daytime activity periods (1130h - 1200h, 1230h - 1300h, 1330h - 1400h, 1430h - 1500h), recording birds with and without food (‘Breeders’ identified as Crested Auklets arriving at each study plot with a chick meal as indicated by the presence of a distended throat pouch), and calculating total counts of birds delivering food loads per hour.

1.2.4. Spatial extent of response to devegetation (“halo effect”)

To assess the spatial extent of the impact of devegetated subplots, we randomly selected 10 of the plots devegetated in 2010 for the establishment of new halo plots. For each selected plot, we delineated a new 10m x 10m subplot immediately adjacent to the unmanipulated subplot, and another 10m x 10m subplot randomly located > 50m from the devegetated subplot. Each of these subplots was monitored using Reconyx cameras capturing a digital image every five minutes between 0900 – 1500h HADST. See section 1.2.1. above for details of Reconyx camera methodology.

1.3. Survey of the colony site in 2011 by Ian Jones

A full assessment of auklet breeding density near the 2009 and 2010 plots by Ian Jones (ILJ), similar to one he conducted in 2006 (Jones and Hart 2006) was not completed as auklet surface activity had largely ceased by the time of his arrival (July 18). ILJ's assessment focused on auklet breeding at the 2010 devegetated plots, an assessment of overburden placement, and scouting locations for further vegetation removal. ILJ visited each of the 30 2010 devegetated subplots and estimated the proportion (%) of the modified area containing exposed habitat suitable for Crested Auklet nesting. For comparative purposes this was also done for the original 2009 devegetated subplots, and on all plots ILJ looked for evidence of overburden (removed grass and peat) covering auklet breeding habitat adjacent to the modified areas. Overburden removed during devegetation of subplots and placed elsewhere in the colony was considered important since, if it decreased access to existing breeding sites in an adjacent area, the number of new breeding sites produced by a vegetation modification is affected. ILJ also looked for evidence of revegetation (species and % cover) on the 2009 devegetated plots to gauge the rate of plant succession two years after devegetation. This was also done on the 30 subplots devegetated in 2010.

1.4. Proposed model for evaluating Crested Auklet restoration

ILJ began a graphical formulation of a simulation model to estimate the number of Crested Auklet bird-years produced by vegetation removal on Gareloi. The model takes a slightly different approach than previously considered, in that it aims to include longer-term plant succession (empirically derived rate) and a longer term (decadal) time span for restoration. Rather than assuming that large numbers of new birds need to be created in the short term (requiring a very large area of vegetation removal), the model is based on cumulative bird years over a long time span, using the mean fledging estimate for this species (0.5 chicks fledged per pair per year, Bond et al. 2011) taking into account the recruitment rate of new breeders and the gradual decline in habitat quality due to plant succession.

2. Results

2.1. Assessment of 2009 study plots A, B, C and D

2.1.1. Population estimates: surface counts and capture-mark-recapture (CMR)

During June 14 – July 26, 2011 we made 2145 individual point count surveys of marked and unmarked Crested Auklets, approximately 268 counts on each of the eight subplots. Overall, there was an average of 0.07 marked birds and 6.15 unmarked birds present on the surface during each ten-minute count. Within each subplot, the mean proportion of marked birds standing on the surface was as follows: Am: 0.015, Au: 0.006, Bm: 0.032, Bu: 0.004, Cm: 0.008, Cu: 0.024, Dm: 0.023 and Du: 0.014 and the mean number of individuals using each subplot ($N_{surface}$) was estimated (Table 1). CMR estimates of the number of individuals on each subplot increased between 2009 and 2011 on all plots (averaging +276% on manipulated plots, +261% on control plots, Table 1), with very broad confidence limits on all estimates. On most plots, $N_{surface}$ on the devegetated side increased more than the control side, with the exception of Plot D. Devegetated subplots showed increased numbers compared to 2010 estimates (average +23%), while control subplots showed a decrease in surface use (average -46%). Plot D was again the exception, showing a decrease from 2010 over the whole plot. Overall we observed a year to year increase on the devegetated plots, while the control plots have fluctuated (Fig 1). However, surface counts made directly by observers showed consistent declines in the average number of Crested Auklets standing on the surface and in the daily maximum surface count on all subplots between 2010 and 2011. Devegetated subplots had generally higher surface activity than control subplots (Fig 2; Fig 3).

2.1.2. Breeding population estimates (CMR)

During June 30 – July 26, 2011 four half-hour continuous counts of all individuals landing on each plot were performed during each day of surveys, resulting in 152 half-hour counts, approximately 19 half-hour counts on each of the eight subplots. Overall there was an average of 0.20 marked and 3.65 unmarked birds arriving at the plots with chick meals during each half-hour count. Within each subplot the mean proportion of Crested Auklets delivering food loads that were banded was: Am: 0.05, Au: 0.12, Bm: 0.08, Bu: 0.03, Cm: 0.11, Cu: 0.03, Dm: 0.03, and Du: 0.02. Thus, the mean number of individuals that successfully hatched chicks ($N_{breeders}$) was estimated (Table 1). CMR estimates of $N_{breeders}$ in 2011decreased on most plots from 2009 (averaging -86% on devegetated subplots and -59% on undisturbed subplots; Fig 4) with broad confidence limits on all estimates, with the exception of plot Du, which remained above 2009 numbers, but well below 2010 estimates (Table 1). If we assume a conservative estimate of fledging success of 0.5 chicks fledged per egg hatched (appropriate for Crested Auklets in the

Aleutians; Fraser et al. 1999, Knudtson & Byrd 1982), Crested Auklet chick production at the four study plots in 2011 was Am: 20, Au: 15, Bm: 17, Bu: 6, Cm: 8, Cu: 4, Dm: 16, and Du: 31 (based on CMR derived estimates of breeding pairs). The estimated average chicks fledged per 100 m^2 is 15 overall and 15 and 14 respectively for the modified and unmodified subplots. We observed lower rates of chick provisioning in 2011 compared to previous years, with no effect of plot treatment ($\chi^2_{1,72} = 1.34$, $p = 0.247$; Table 2).

2.1.3. Re-sighting and movement of marked birds

In 2009 a total of 614 adult Crested Auklets were trapped and marked with unique combinations of three colored leg bands. During June 14 – July 26 2011 we resighted a total of 192 unique band combinations (31% of individuals originally banded), 90 of which were observed multiple times. Out of all resighted individuals 26 (14%) were seen carrying a chick meal. Of the individuals seen multiple times in 2011: 14% occurred on both sides of a plot (e.g. Am and Au), 29% were observed on two separate plots, 38% were seen only on a devegetated subplot, and 18% were seen only on a control subplot. Most color-marked Crested Auklets (71%) were seen on the same plot on which they were originally marked.

From 2009 to 2011, on average 56% of birds on control (unmanipulated) subplots remained on the same subplot, compared to 66% for birds on devegetated subplots. Of the 153 individuals seen on only one subplot in 2011, a total of 27 birds had moved to a completely different plot from 2009 (10 to control subplots and 17 to devegetated subplots). A total of 15 birds moved within plots, 11 from the control side to the devegetated side and 4 from the devegetated side to the control side (Table 3).

From 2010 to 2011, on average 61% of birds on control subplots remained on the same subplot, compared to 71% for birds on devegetated subplots. Of the 108 individuals seen in 2011 that were observed and had a plot preference in 2010, a total of 14 birds moved to a completely different plot from 2010 (four to control subplots and ten to devegetated subplots). A total of three birds moved within plots, one from the control side to the devegetated side and one from the devegetated side to the control side (Table 3).

2.1.4. Crested Auklet nesting crevice counts and hatching success

In 2011, we marked between 11 – 44 active breeding crevices on each of the subplots, with the majority of those crevices being occupied by Crested Auklets (Table 4). Nest counts in 2011 averaged lower on both control and devegetated subplots compared to previous years. There was no clear pattern in crevice count change over time – and no consistent change in number of visible nests was detected before and after devegetation. The proportion of total nests occupied by Crested Auklets was higher on the devegetated half of plots C and D, and on the control half of plots A and B (Table 5). We found no significant differences in this proportion among years ($F_{5,18} = 0.33$, $p = 0.89$).

Hatching success was calculated for each of the eight subplots and compared between 2010 and 2011. Hatching success ranged between 0.61 – 1.00 in 2010 and 0.59 – 1.00 in 2011 and was generally higher in 2010 (Table 6). However, hatching success estimates are affected by the date when nests are found compared to hatching date – this varied among years and the date nests were found was later in 2011 than 2010 (see Discussion). Chi-square tests revealed significant differences between 2010 and 2011 at subplots Au and Du, showing an increase in the number of failed Crested Auklet nests at both of those subplots (Table 7). A significant difference between overall hatching success at manipulated and unmanipulated subplots was also observed during 2010, significant differences were not found in 2011 (Table 7).

2.2 Assessment of the 2010 study plots

2.2.1. Crested Auklet surface counts (Reconyx cameras)

Devegetated subplots had consistently higher levels of surface activity after manipulation (interaction effect between Year and Treatment). Although the magnitude of the difference was not large in terms of individuals, the devegetated plots had about 2.3x more birds counted (average maximum daily counts of Crested Auklets: 4.35 on devegetated, 1.88 on control; $\chi^2_{1,672} = 33.4$, $p < 0.001$, Table 8; Fig. 5). A similar pattern was seen for Least Auklets (5.52 on devegetated, 1.29 on control; $\chi^2_{1,675} = 51.49$, $p < 0.001$, Table 8; Fig. 6).

2.2.2. Crested Auklet nesting crevice surveys

In 2011, we found between 0 – 20 active breeding crevices on each of the subplots, with the majority of those crevices occupied by Crested Auklets (Table 9). We found no differences in the proportion of total nest crevices that were occupied by Crested Auklets between the control and experimental subplots between 2010 and 2011 (Table 10; $F_{3,104} = 0.71$, $p = 0.55$).

Hatching success was estimated for each of the 60 plot halves in 2011. Hatching success ranged between 0.00 – 1.00 (mean devegetated plots : 0.54; mean control plots: 0.60; Table 11). Chi-square tests revealed no significant differences between the control and experimental plots ($\chi^2 = 1.07$, df = 1, p = 0.30).

2.2.3. Feeding watches at 2010 plots

We observed significantly higher numbers of Crested Auklets delivering chicks meals on the devegetated plots compared to the controls (devegetated: average 3.83/hour, control: 1.27/hour; $\chi^2 = 4.51$, df = 1, p = 0.034). Feeding watches were not conducted on these plots in 2010.

2.2.4. Spatial extent of response to devegetation ("halo effect")

High winds and technical difficulties at the new "halo" plots severely limited the amount of data collected, and therefore those results are not reported here.

2.3. Ian's survey of the colony site in 2011

Based on ILJ's assessment of the plots devegetated in 2010, on average 45% of the devegetated area was suitable habitat for auklet breeding (i.e. rock with crevice openings), with wide variability across the plots (range: 1% - 100%, Table 12, Fig. 7). All four of the 2009 plots had >95% of their area as suitable breeding habitat for Crested Auklets. Previously removed overburden (the peat and vegetation pulled from the devegetated plots) placement on areas adjacent to plots, that ILJ believed might have previously supported auklet crevices, occurred on 20 (66%) of the 'new' 2010 plots. However, the areas affected were limited, averaging less than 5 m^2 beside any plot, compared to 100 m^2 cleared (Table 12). No removed overburden was believed to have impinged on auklet breeding habitat near any of the 2009 plots.

2.4. Proposed model for evaluating Crested Auklet restoration

ILJ proposes a simulation model to estimate bird-years produced by a given area of complete vegetation and peat removal on the ‘new lava’ (surrounding the 2009 plots A-D) of the southeast colony at Gareloi. This area of the colony is located on relatively homogeneous lava deposits from the 1938 eruption and has the highest densities of breeding Crested Auklets of any location at Gareloi Island (Jones and Hart 2006). The rationale of the model is that habitat quality in this area is in decline due to plant succession and overgrowth and although auklet breeding density is currently still high, it will not remain so for very long and will be low by 100 years post-eruption (e.g., a meadow, Jones et al. 2001). The aim of the restoration effort is thus to return areas of this lava flow to a state similar to that in 1938 (i.e., completely un-vegetated) and thus delay the inevitable return to a meadow. The proposed model will produce an estimate of the extra bird-years produced by devegetation of a known area of the new lava, with a previously empirically derived estimate of mean Crested Auklet breeding density (Conners and Jones 2009, Jones et al. 2010) and future parameter estimates quantifying the rate of habitat quality decline related to plant overgrowth. This requires using plant ecological methodology to examine the relationship between age since lava deposit, plant cover, and crevice accessibility. The number of bird-years created by a vegetation modification is described by the area between two curves, one being the ‘natural’ conditions of Crested Auklet decline and the second being Crested Auklet numbers (also similarly declining) in an area restored to close to 1938 conditions (Fig. 8). We assume for the illustration that we are considering an area of 400 m^2, with mean density of 350 pairs per 100 m^2 (previously measured at Gareloi by Conners and Jones 2009). ILJ proposes that an experienced simulation modeler be consulted to further develop this modeling approach.

3. Discussion

3.1. Assessment of 2009 study plots A, B, C and D

3.1.1. Population estimates: surface counts and capture-mark-recapture (CMR)

As in previous years, CMR analysis was somewhat hampered due to the small proportion of color-marked individuals on study plots, and the difficulty of reading color band combinations of marked birds on the plots. These factors lead to very broad confidence limits on population estimates, which must be interpreted with caution. CMR estimates of the number of individuals present on each subplot increased between 2009 and 2011, although surface use of devegetated subplots seems to be increasing more consistently than use of control subplots, which has decreased since 2010. This supports the hypothesis proposed in 2010 that the increases observed on all plots were due to inter-annual variation in colony attendance, and that after two years a pattern is emerging showing a positive effect of devegetation. It should be noted that the relaxation of criteria for banded bird resighting could have artificially inflated the 2011 CMR estimates relative to previous years. However, this bias would affect all treatments equally and is unlikely to be large enough to change the overall patterns observed, especially given the broad confidence limits involved.

While capture-mark-recapture estimates of bird numbers are clearly required to make inferences about auklet population changes (Jones 1992, Sheffield et al. 2006) in relation to experimental vegetation modification, and a large effort has been made using color-banded birds, after three years of resighting effort we identified several limitations of the color-banding approach unique to Gareloi. In particular, the terrain on our Gareloi study plots made it extremely difficult to resight birds compared to study plots at Buldir, Kiska and Kasatochi – where plots were established with an observation blind close to the plot and clear lines of sight to all parts of the plots. This appears to be an unavoidable issue for color band resighting at Gareloi, where auklets use a lava flow with an unusually irregular surface and terrain dictates that observation posts must sometimes be quite far from the plot. However, a different form of individual mark (coded VHF radio tag) offers an alternative to color bands (more on this below).

3.1.2. Breeding population estimates (CMR)

Due to the addition of feeding surveys on the 30 new plots in July 2011, the survey effort at the four old plots during this period was reduced. This reduction in surveys during the chick provisioning period compared to previous years meant fewer observations of color-marked individuals delivering food and explains why CMR $N_{breeder}$ estimates were much lower in 2011. It also makes it impossible to compare these numbers with data from previous years in any meaningful way. However, we observed lower rates of chick provisioning in 2011 compared to previous years, which should not have been affected by the reduction in survey effort, as surveys were spread over the entire chick provisioning period and values averaged for the season. This suggests that, while surface activity remained high, 2011 might have been a year of reduced reproductive success, as a number of the measures of breeding success all declined, although we can’t rule out an effect of observer bias and difficulties associated with the CMR breeding estimates.

3.1.3. Re-sighting and movement of marked birds

In 2011, we continued to observe low levels of inter-annual movement between and within plots. The overall pattern of this movement suggests a preference for devegetated subplots, with birds less likely to leave, and more likely to move to a devegetated area. Movement could indicate established birds moving to a new plot to breed, or nonbreeders still prospecting for a nest cavity. This assessment is consistent with the high intra-annual movement in 2011, when 29% of individuals were observed on multiple plots. It is worth noting that much of this movement was between nearby plots C and D (approximately 51m between plot centers) and plots A and B (approximately 44m between plot centers), and some of the individuals that moved were seen delivering chick meals so are presumably active breeders. It is possible that Crested Auklets breeding in one area are spending time on the surface of a nearby area where perhaps better social pads (elevated areas of level substrate with flattened vegetation used for display and social aggregation) are available, or some other feature of the surface habitat is more favorable. This could also explain some of the increases in surface use of control plots if individuals that prefer to breed in devegetated habitat still prefer to congregate on adjacent vegetated areas. Movement is another phenomenon that is difficult to measure using color bands, so here again we believe an alternative (coded VHF radio tags) needs to be employed to address this question properly.

3.1.4. Crested Auklet nesting crevice counts and hatching success

Due to delays in reaching the field site, we were unable to begin searching for nests until June 14, only ten days before the earliest observed hatching. Ideally, productivity crevice searches must begin before the peak of *laying* (c.May 25 at Gareloi in 2011) for rigorous estimation of hatching success (e.g., Fraser et al 1999). Therefore nest counts and estimates of hatching success obtained were heavily biased, having missed any nests that failed earlier in the season. We found no indications that the number of active nests visible from the surface has increased on the experimental plots after vegetation modification, but 2011 data are not ideally comparable with data from previous years because of the difference in timing and intensity of searcher effort (in addition to any differences in searching ability among different observers in different years). As pointed out in earlier reports (Conners & Jones 2009, Jones et al. 2010) most auklet nests are not visible from the surface and the utility of counts of visible nests is uncertain.

3.2. Assessment of 2010 plots

3.2.1. Crested Auklet surface counts at study plots

Although we did see a significant increase in number of both Crested and Least Auklets active on the surface of the 30 low density plots based on the de-vegetation treatment, the magnitude of the increases was not large. It is possible that there has been a delay in colonizing this new habitat from neighboring high density areas and that a second year of data will show continued improvement, but it is equally likely that there isn't enough suitable habitat on some of these plots to allow much nesting (see discussion of ILJ's surveys below).

3.2.2. Crested Auklet nesting crevice counts and hatching success, new plots

Nest counts on the new plots were affected by their initiation late in the season as discussed above. Surveys started even later than on the old plots, and we were unable to complete all crevice counts before chicks started to hatch. Similar to observations from 2010, relatively few active nest crevices were located in the 2010 plots, with no significant difference between control and experimental plots, corroborating the lack of large increases seen in the surface count data. There were, however, a couple of plots in which there were several nests on the devegetated subplot and none on the control subplot, which are not represented in our data analysis due to the way nest proportions were calculated relative to the control subplot.

3.2.3. Feeding watches at 2010 plots

We observed significantly higher rates of chick provisioning on the devegetated subplots than the control subplots (unlike the 2009 plots), but the magnitude of the difference was not large. Any increase in use of the manipulated areas in low density regions of the colony seems to be minor at best, at least one year post-modification. As with the 2009 plots, prospecting behavior and settlement of auklets mean that increases would first be expected two years after devegetation.

3.3. Ian's survey of the colony site in 2011

Based on ILJ's assessment of the plots devegetated in 2010, much of the problem in manipulating habitat in the low-density areas of the colony concerns the difficulty of selecting locations with enough suitable habitat to justify devegetation. Even with improved access to subterranean crevices, most of these areas are unlikely to support large numbers of Crested Auklets. On average, only 45% of the area of the new plots was rocky and the majority of the areas devegetated in 2010 were dirt with no possibility for auklet nesting. This is in contrast to the four plots from 2009 (ABCD) that were nearly 100% suitable auklet breeding habitat. Therefore we believe that restoration efforts should focus on the high density areas of the 1938 lava flow where the four original plots were located. Evidence of plant regrowth on any plot, even the 2009 plots, was minimal – suggesting that the vegetation modification does take areas back to their state following the 1938 volcanic eruption. This leads ILJ to propose a modeling approach (Fig. 8, next paragraph) and a restoration effort (vegetation and peat removal) involving a single large patch (1 – 2 Ha) of the 1938 lava flow at the Southeast colony site near the 2009 plots.

3.4. Proposed model for evaluating Crested Auklet restoration

From our efforts during 2009-2011 we have learned a great deal about the challenges of measuring changes in auklet numbers. Although much is known about auklets in the Aleutians, ours was the first attempt to measure temporal variation in surface attendance and breeding density. Our capture-mark-recapture approach has produced quantitative numbers (individuals and breeders), but confidence limits on our estimates are so large as to preclude having enough statistical power to make strong inferences about changes in auklet numbers linked to devegetation (Table 1). Our capture-mark-recapture (CMR) population estimates have been hampered by low resighting rates – a result of the difficulty of seeing and reading the bands of marked birds in the convoluted lava habitat present at the 2009 plots and at Gareloi in general. Color bands have been easy to resight at Buldir and Kiska because observations were made from close range (< 5 m) from blinds with an unobstructed view of the study plots. We were not able to duplicate this ideal situation at Gareloi – suggesting that a different approach to marking birds is called for (see Recommendations, below). Our other approaches (nest counts, surface counts, and productivity estimates) although interesting, cannot directly address the measure of interest (breeding numbers) in a devegetation effort. For example, counts of unmarked birds arriving with food per hour doesn’t take into account individuals returning multiple times, and provisioning rate is extremely variable by time of day, among days and across the chick rearing period. Furthermore, the likely time-scale relevant to changes in auklet numbers is limited by features of their demography (long life span, delayed age at first breeding, delayed recruitment), suggesting that we might not be able to record changes in numbers in a short time span such as a few years. Nevertheless, our devegetation experiments are very encouraging in the sense that vegetation covered habitat is being exposed and birds are flocking to it. The challenge remaining is to derive a method of quantifying the positive effect of a large scale devegetation to restore Crested Auklet bird-years lost due to the Selendang Ayu oil spill.

Vegetation modification in the Aleutian Islands was originally suggested as an option for restoration because of the striking progress of overgrowth on auklet colonies due to plant succession on a decadal time scale (Jones 2009). We now suggest a related approach using modeling of the relationship between auklet nesting density and plant succession, to evaluate the effectiveness of a large scale vegetation modification. The approach of the new model assumes that to restore Crested Auklet bird-years, it is not necessary to 'make' any new birds. While this may seem counter-intuitive, the logic is based on the observation of the natural process of decline in all Aleutian auklet colony sites that is caused by vegetation overgrowth. If this decline is delayed by removing vegetation (in effect returning a site to an earlier plant successional stage) then extra 'bird-years' are created (the area between the two curves in Fig. 8). This modeling approach greatly simplifies the estimation of bird years because it is not necessary to measure or statistically confirm changes in auklet numbers at a particular plot or site (difficult, as our study has demonstrated). All that is necessary is an empirical estimate of mean Crested Auklet density in an area to be restored, an empirically derived estimate of the rate of decline of habitat, and a model to simulate bird-years (Fig. 8). We believe that future fieldwork efforts need to re-emphasize capture mark-recapture estimates of density and movement - a new approach to marking and 'resighting' Crested Auklets will be required (see Recommendations, below). Plant-ecology work at Gareloi and other sites to quantify the rate of plant overgrowth will also be required.

3.5 Recommendations for future research approaches

Due to the difficulty of re-sighting color-banded Crested Auklets at Gareloi, we believe a new field approach should utilize coded VHF radio tags (Lotek model # NTQB-4-2, 1 g) attached to leg bands, with individuals also marked with a single color band specific to capture location. With the coiled antenna option these tags have a detection range of < 100 m, ideal when combined with the Lotek SRX-DL-1 logging receiver. This system autonomously records (and logs for later analysis) individual identity, date, time, and signal strength for each coded tag detected, allowing for measurement of daily frequency and duration of plot attendance for tagged individuals. The tag data, combined with observer counts of banded to unbanded individuals at study plots, will allow estimates of auklet numbers with much higher precision, as the logging receivers will automatically provide an accurate record of the total number of tagged individuals present on each plot, freeing observers to conduct more reliable surveys without having to identify each individual from a hard to see combination of color bands. For example, with VHF tags marked birds will be identified individually even if they are only seen flying. Also, placement of additional receivers will allow for a similarly improved quantification of movement within the colony site.

To measure the rate of plant succession, we will need to visit and quantitatively measure vegetation and peat deposits on lava flows of known age at Aleutian auklet colony sites. ILJ proposes that the measure should be the mean depth of vegetation and peat, based on large samples of measurements taken at random locations. At Gareloi, the age of lava deposits (from 1938) at the southeast colony site is known and mean vegetation depth at this site should be measured. Also at Gareloi, mean vegetation depth at the *east* colony site should be measured and a geologist consulted to date the age of the flows there. Auklet crevices will begin to become unavailable when the depth of vegetation approaches the mean size of the openings in a lava flow. Further replication could be obtained by visiting and measuring vegetation and peat depth at two lava flows at Sirius Point, at the ‘new’ (1969) and ‘old’ (unknown age, perhaps c. 150 years) lava (Bob’s Plateau, where crevices disappeared between 1987 and 2001, Jones et al. 2001). These empirical data would provide the basis for a generalized decay curve for habitat suitability (e.g., Fig. 8).

Due to complexity and time requirements to successfully complete the field research protocol, it is recommended that measures be taken to ensure that the field crew is at Gareloi with the camp set up before June 1 in future years.

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Table 1. Capture-Mark-Recapture population estimates for Plots A-D. Mean ± standard deviation (percent change relative to 2009 estimates), at Gareloi Island, Alaska.

	2009		2010		2011	
Plot	**Nsurface**	**Nbreeders**	**Nsurface**	**Nbreeders**	**Nsurface**	**Nbreeders**
Am	2615 ± 1161	954±268	4440±3454 (+70)	560±242 (-41)	7954 ± 9666 (+204)	79 ± 47 (-92)
Au	1779 ± 1613	339±109	6568±4923 (+269)	346±318 (+2)	3246 ± 2208 (+82)	58 ± 59 (-83)
Bm	690 ± 450	441±187	2715±2674 (+293)	523±523 (+19)	3429 ± 6058 (+397)	66 ±59 (-85)
Bu	242	727±365	4269±5597 (+1664)	821±390 (+13)	1036 ± 977 (+328)	24 (-97)
Cm	892 ± 780	513±230	3445±5518 (+286)	286±171 (-44)	5117 ± 3994 (+474)	34 ± 31 (-93)
Cu	567 ± 464	268±86	3093±3755 (+446)	242±162 (-10)	2388 ±2159 (+321)	18 (-93)
Dm	1422	225±216	5025±3460 (+253)	452±246 (+101)	1841 ± 1394 (+29)	63 ± 16 (-72)
Du	1132 ± 1042	90±59	7063±7391 (+524)	1351±2024 (+1401)	4690 ± 5933 (+314)	124 ± 107 (+38)

Table 2. Feeders/hour at the four 2009 plots (mean ± s.d.), at Gareloi Island, Alaska.

Plot	2009	2010	2011
Am	85.96 ± 53.18	36.21 ± 33.23	14.25 ± 9.33
Au	45.04 ± 32.28	27.67 ± 13.66	9.25 ± 5/43
Bm	61.11 ± 40.8	25.32 ± 14.83	8.2 ± 6.8
Bu	41.32 ± 29.29	24.55 ± 15.71	7.5 ± 7.3
Cm	34.98 ± 31.31	21.12 ± 15.68	3.88 ± 3.82
Cu	31.14 ± 33.24	16.79 ± 8.53	5.62 ± 4.75
Dm	27.62 ± 28.37	19.73 ± 9.77	5.58 ± 4.42
Du	41.8 ± 36	34.5 ± 14.67	8.08 ± 7.65

Table 3. Movement of color-marked Crested Auklets relative to 2009 sightings and banding locations, and relative to 2010 sightings. Uses only individuals seen only on one subplot in 2011 and excludes individuals that couldn't be linked to a specific subplot in 2009 or 2010.

	Stayed in same plot		**Moved to different subplot**		**Moved to different plot**		**Excluded**
vs.2009	**control**	**devegetated**	**to control**	**to devegetated**	**to control**	**to devegetated**	
Number	35	40	4	11	10	17	36
Percent	22.9%	26.1%	2.6%	7.2%	6.5%	11.1%	23.5%
vs.2010							
Number	29	42	2	2	5	10	63
Percent	18.9%	27.5%	1.3%	1.3%	3.3%	6.5%	41.2%

Table 4. Comparison of nest counts and contents between 2009, 2010, and 2011 and among the eight subplots for the plots originally established in 2009 at the southeast colony, Gareloi Island, Alaska (Total column includes nests for which species could not be determined; differences between numbers of breeding crevices found may be due to observer effort and bias).

	CRAU			LEAU			Total		
Plot	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Am	66	33	23	20	9	9	92	61	32
Au	74	45	36	29	9	5	115	55	41
Bm	44	53	31	13	26	12	68	100	43
Bu	52	40	25	10	29	4	70	71	29
Cm	45	40	11	26	19	6	73	63	18
Cu	27	36	7	8	4	4	37	49	11
Dm	109	68	34	14	29	10	136	99	44
Du	106	43	28	28	23	15	143	81	43

Table 5. Comparison of the proportion of total crevices occupied by Crested and Least Auklet nests (e.g. Number CRAU nests / Number total nests) among subplots (manipulated subplot / control subplot) between 2009, 2010, and 2011 for the four original plots established in 2009 at the southeast colony, Gareloi Island, Alaska.

Plot	**CRAU**			**LEAU**		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
Am:Au	1.07	0.94	0.82	0.83	1.29	2.31
Bm:Bu	0.92	1.16	0.84	1.41	0.78	2.02
Cm:Cu	0.82	0.75	1.02	1.60	3.22	0.97
Dm:Du	1.12	1.08	1.19	0.54	0.86	0.65

Table 6. Summary of hatching success among the eight original subplots in 2010 and 2011, at Gareloi Island, Alaska.

Plot	**2010**				**2011**			
	Hatched	**Failed**	**Fate Unknown**	**Hatching Success**	**Hatched**	**Failed**	**Fate Unknown**	**Hatching Success**
Am	12	3	19	0.80	12	4	7	0.75
Au	31	3	11	0.91	13	9	14	0.59
Bm	24	9	20	0.91	11	6	14	0.65
Bu	24	4	10	0.86	13	1	11	0.93
Cm	22	14	4	0.61	4	2	5	0.67
Cu	6	1	29	0.86	3	0	4	1.00
Dm	51	15	2	0.77	19	3	12	0.86
Du	21	0	22	1.00	17	5	6	0.77
Total	191	49	117	0.84	92	30	73	0.78

Table 7. Summary of statistical differences in hatching success between 2010 and 2011 control and experimental subplots, at Gareloi Island, Alaska.

Plot	Chi-square	df	p-value
Am	0.54	1	0.46
Au	8.17	1	0.00
Bm	0.34	1	0.56
Bu	0.45	1	0.50
Cm	0.07	1	0.80
Cu	0.48	1	0.49
Dm	0.84	1	0.36
Du	5.40	1	0.02
2010			
m:u	11.27	1	0.00
2011			
m:u	0.03	1	0.87

Table 8. Reconyx surface counts for low density plots devegetated in 2010. Reports average daily maximum value of Crested Auklets (CRAU) and Least Auklets (LEAU) for each subplot, as well as the overall maximum value for that subplot.

Plot		**Avg daily max CRAU**	**Std Dev**	**Max CRAU**	**Avg daily max LEAU**	**Std Dev**	**Max LEAU**
Upper Colony Plots							
1U	Control	4.50	2.43	9	5.67	3.98	13
	Manipulated	4.83	1.17	6	6.17	2.71	11
2U	Control	5.17	5.12	14	5.17	6.85	17
	Manipulated	3.00	1.26	5	13.17	14.48	39
3U	Control	2.00	1.41	4	2.8	1.64	5
	Manipulated	6.20	6.06	17	11	6.28	18
4U	Control	n/a	n/a	n/a	n/a	n/a	n/a
	Manipulated	n/a	n/a	n/a	n/a	n/a	n/a
5U	Control	1.67	0.82	3	0.83	0.41	1
	Manipulated	1.33	0.82	2	0.67	0.52	1
6U	Control	0.67	0.82	2	0.50	0.55	1
	Manipulated	2.17	2.23	6	0.67	0.52	1
South Colony Plots							
1S	Control	1.67	1.53	3	2.00	1.73	4
	Manipulated	7.67	5.51	14	14.67	6.43	22
2S	Control	3.33	1.15	4	1.33	0.58	2
	Manipulated	6.33	4.51	11	8.33	5.03	13
3S	Control	2.17	0.41	3	2.17	1.47	4
	Manipulated	3.67	3.20	8	2.5	2.17	5

Plot		Avg daily max CRAU	Std Dev	Max CRAU	Avg daily max LEAU	Std Dev	Max LEAU
4S	Control	0.33	0.52	1	0.33	0.52	1
	Manipulated	3.67	2.16	7	5.67	5.28	13
North Colony Plots							
1N	Control	0	0	0	0	0	0
	Manipulated	1	1.26	3	0.17	0.41	1
2N	Control	0.6	0.55	1	0	0	0
	Manipulated	2	1.87	4	0.6	0.55	1
3N	Control	1	0	1	1	0	1
	Manipulated	1.67	0.58	2	1.33	0.58	2
4N	Control	2.33	0.58	3	1	0	1
	Manipulated	2.33	0.58	3	1.33	0.58	2
5N	Control	0.33	0.52	1	0.17	0.41	1
	Manipulated	3.5	1.05	5	3.83	2.23	7
6N	Control	0	0	0	0	0	0
	Manipulated	5.33	1.15	6	3	1.73	5
7N	Control	0.33	0.58	1	0.67	0.58	1
	Manipulated	1.33	0.58	2	0.67	0.58	1
8N	Control	2.5	2.74	5	0.83	0.98	2
	Manipulated	1.83	1.47	4	1	1.10	3

Plot		Avg daily max CRAU	Std Dev	Max CRAU	Avg daily max LEAU	Std Dev	Max LEAU
9N	Control	2.67	1.21	4	1	1.10	3
	Manipulated	4.5	2.17	8	6.17	5.56	13
10N	Control	1.83	0.75	3	2.83	2.14	6
	Manipulated	9.83	3.82	13	20.83	19.36	47
11N	Control	7.5	3.02	12	2.67	0.51639778	3
	Manipulated	5.67	3.08	9	3.17	2.04	6
12N	Control	1	0.89	2	0.5	0.55	1
	Manipulated	4.33	2.25	6	2.83	2.71	7
13N	Control	9.83	3.71	14	4.5	4.32	13
	Manipulated	6	3.69	13	8.83	4.45	14
14N	Control	0	0	0	0.17	0.41	1
	Manipulated	5.83	3.49	12	9.83	7.08	22
15N	Control	0.17	0.41	1	0.33	0.52	1
	Manipulated	14	5.10	21	15.5	9.31	27
16N	Control	0.17	0.41	1	0	0	0
	Manipulated	3.17	3.06	9	1.33	0.82	2
17N	Control	0.17	0.41	1	0	0	0
	Manipulated	2	1.67	5	1	0.89	2
18N	Control	0.17	0.41	1	0	0	0
	Manipulated	3	1.41	5	2	1.10	4

Plot		Avg daily max CRAU	Std Dev	Max CRAU	Avg daily max LEAU	Std Dev	Max LEAU
19N	Control	0	0	0	0	0	0
	Manipulated	7	3.74	13	8.5	3.51	14
20N	Control	0.83	0.75	2	0.17	0.41	1
	Manipulated	2.17	1.17	4	3.5	4.32	11

Table 9. Crested and Least Auklet nest counts on the 30 2010 plots in 2010 (pre-manipulation) and 2011 (post-manipulation). (Total includes nests for which species could not be determined)

Plot	CrAu		LeAu		Total	
	2010	2011	2010	2011	2010	2011
Upper Colony Plots						
1Um	2	-	4	-	7	-
1Uu	6	-	5	-	13	-
2Um	11	-	1	-	15	-
2Uu	5	-	4	-	9	-
3Um	6	-	1	-	7	-
3Uu	6	-	1	-	13	-
4Um	4	-	2	-	9	-
4Uu	2	-	4	-	7	-
5Um	3	3	0	2	5	5
5Uu	2	10	4	5	7	15
6Um	1	-	3	-	4	-
6Uu	0	-	1	-	2	-
North Colony Plots						
1m	1	3	3	1	4	4
1u	2	3	2	0	6	3
2m	4	0	4	3	8	3
2u	5	0	1	0	9	0
3m	17	6	6	1	23	7
3u	5	1	2	1	17	3
4m	12	5	5	2	17	7
4u	11	3	8	1	25	4
5m	17	5	13	3	30	8
5u	5	2	2	2	8	5
6m	11	7	7	4	22	11
6u	11	0	5	0	16	0
7m	2	7	3	2	6	9
7u	10	3	3	1	13	5
8m	8	0	0	0	11	0
8u	6	1	1	0	8	1
9m	4	11	0	7	5	18
9u	34	0	12	1	47	1
10m	3	5	3	2	6	7
10u	7	2	2	0	12	2
11m	4	12	0	4	5	16
11u	6	3	3	0	9	3
12m	5	-	2	-	7	-
12u	15	-	9	-	25	-
13m	5	5	2	7	12	12
13u	14	12	3	8	23	20
14m	7	4	4	3	12	7

Table 9. continued

Plot	CRAU		LEAU		Total	
	2010	2011	2010	2011	2010	2011
14u	14	2	5	2	20	4
15m	0	9	0	3	0	12
15u	3	6	2	4	5	10
16m	3	3	2	1	5	4
16u	0	4	1	0	2	4
17m	0	1	0	0	0	1
17u	0	1	0	0	0	1
18m	2	3	0	5	2	8
18u	16	3	1	1	17	4
19m	2	2	1	1	7	3
19u	2	3	1	5	3	8
20m	0	4	2	0	2	4
20u	0	5	0	0	0	5
South Colony Plots						
1Sm	14	13	1	5	31	18
1Su	16	17	4	1	22	18
2Sm	18	12	8	7	28	19
2Su	28	12	13	3	43	15
3Sm	2	2	6	3	10	5
3Su	5	11	4	9	10	20
4Sm	0	2	0	5	0	7
4Su	0	5	0	0	0	5

Table 10. Comparison of the proportion of total crevices occupied by Crested and Least Auklet nests (i.e. Number CRAU nests / Number total nests) among subplots, at the new plots pre-manipulation (2010) and post-manipulation (2011) at Gareloi Island, Alaska.

Plot	2010	2011
Upper Colony Plots		
1Um:1Uu	0.61	-
2Um:2Uu	1.65	-
3Um:3Uu	1.00	-
4Um:4Uu	2.00	-
5Um:5Uu	3.00	0.90
6Um:6Uu	Undefined	-
North Colony Plots		
1m:1u	0.50	0.75
2m:2u	0.60	Undefined
3m:3u	1.03	1.71
4m:4u	1.22	0.95
5m:5u	0.79	1.25
6m:6u	0.89	Undefined
7m:7u	0.52	1.04
8m:8u	1.17	0.00
9m:9u	1.35	Undefined
10m:10u	0.64	0.71
11m:11u	1.50	0.75
12m:12u	1.14	-
13m:13u	0.87	0.69
14m:14u	0.86	1.14
15m:15u	0.00	1.25
16m:16u	Undefined	0.75
17m:17u	Undefined	1.00
18m:18u	1.06	0.50
19m:19u	1.00	1.78
20m:20u	Undefined	1.00
South Colony Plots		
1Sm:1Su	1.17	0.76
2Sm:2Su	1.01	0.79
3Sm:3Su	0.45	0.73
4Sm:4Su	Undefined	0.29

Table 11. Summary of hatching success among the 60 plot halves in 2011, at Gareloi Island, Alaska.

Plot	Hatched	Failed	Fate Unknown	Hatching Success
1m	2	0	1	1.00
1u	2	0	1	1.00
2m	0	0	0	*[2]
2u	0	0	0	*[2]
3m	2	2	2	0.50
3u	1	0	0	1.00
4m	3	0	2	1.00
4u	3	0	0	1.00
5m	2	1	2	0.67
5u	2	0	0	1.00
6m	2	2	3	0.50
6u	0	0	0	*[2]
7m	6	1	0	0.86
7u	2	0	1	1.00
8m	0	0	0	*[2]
8u	1	0	0	1.00
9m	7	2	2	0.78
9u	0	0	0	*[2]
10m	1	2	2	0.33
10u	2	0	0	1.00
11m	6	1	5	0.86
11u	3	0	0	1.00
12m	*[1]	*[1]	*[1]	*[1]
12u	*[1]	*[1]	*[1]	*[1]
13m	3	1	1	0.75
13u	6	4	2	0.60
14m	1	2	1	0.33
14u	1	0	1	1.00
15m	4	3	2	0.57
15u	5	1	0	0.83
16m	3	0	0	1.00
16u	4	0	0	1.00
17m	1	0	0	1.00
17u	0	1	0	0.00
18m	2	1	0	0.67
18u	3	0	0	1.00
19m	2	0	0	1.00
19u	3	0	0	1.00
20m	2	1	1	0.67
20u	4	0	1	1.00

Table 11. continued

Plot	**Hatched**	**Failed**	**Fate Unknown**	**Hatching Success**
1Sm	5	5	3	0.50
1Su	11	5	1	0.69
2Sm	8	3	1	0.73
2Su	5	2	5	0.71
3Sm	1	1	0	0.50
3Su	5	4	2	0.56
4Sm	2	0	0	1.00
4Su	2	0	3	1.00
1Um	*[1]	*[1]	*[1]	*[1]
1Uu	*[1]	*[1]	*[1]	*[1]
2Um	*[1]	*[1]	*[1]	*[1]
2Uu	*[1]	*[1]	*[1]	*[1]
3Um	*[1]	*[1]	*[1]	*[1]
3Uu	*[1]	*[1]	*[1]	*[1]
4Um	*[1]	*[1]	*[1]	*[1]
4Uu	*[1]	*[1]	*[1]	*[1]
5Um	2	0	1	1.00
5Uu	5	2	3	0.71
6Um	*[1]	*[1]	*[1]	*[1]
6Uu	*[1]	*[1]	*[1]	*[1]
Total	137	47	49	0.8

*[1] No data available from 2011
*[2] No active breeding crevices were found

Table 12 Estimates of Crested Auklet breeding habitat exposed, overburden placement and vegetation regrowth (as of late July 2011) at the four 2009 10m x 10m plots and 30 2010 10m x 10m plots at Gareloi Island, Alaska.

Plot	Date visited	% suitable habitat present	Overburden issue (m^2 covered)	Vegetation regrowth (%), taxa
1 (2010)	July 21	20%	No	none
2 (2010)	July 21	35%	No	none
3 (2010)	July 21	50%	No	none
4 (2010)	July 21	50%	Yes, < 2 m^2	none
5 (2010)	July 21	60%	Yes, c. 5 m^2	none
6 (2010)	July 21	70%	Yes, < 1 m^2	none
7 (2010)	July 20	25% (from photo)	Yes, < 2 m^2	none
8 (2010)	July 20	1%	Yes, < 1 m^2	none
9 (2010)	July 20	75%	Yes, c. 5 m^2	none
10 (2010)	July 20	50%	Yes, c. 5 m^2	none
11 (2010)	July 20	50%	Yes, c. 5 m^2	none
12 (2010)	July 20	30%	No	none
13 (2010)	July 20	60%	No	none
14 (2010)	July 20	30%	Yes, c. 1 m^2	none
15 (2010)	July 20	65%	Yes, c. 5 m^2	none
16 (2010)	July 20	25%	Yes, c. 5 m^2	none
17 (2010)	July 20	2%	Yes, c. 5 m^2	none
18 (2010)	July 20	40%	Yes, c. 5 m^2	none
19 (2010)	July 20	50%	Yes, c. > 5 m^2	none
20 (2010)	July 20	10%	No	none
1U (2010)	July 25	80%	Yes, 10 m^2	none
2U (2010)	July 25	70%	Yes, c. 5 m^2	none
3U (2010)	July 25	60%	Yes, c. 5 m^2	none
4U (2010)	July 21	20%	Yes, c. > 5 m^2	none
5U (2010)	July 21	25%	No	none
6U (2010)	July 25	60%	Yes, c. 5 m^2	none
1S (2010)	July 26	60%	No	none
2S (2010)	July 26	100%	No	1%, grasses, chickweed
3S (2010)	July 29	60%	No	none
4S (2010)	July 26	25% (from photo)	Yes, c. 5 m^2	10%, grasses
A (2009)	July 29	>95%	No	<1%
B (2009)	July 29	>95%	No	<1%
C (2009)	July 29	>95%	No	<1%
D (2009)	July 29	>95%	No	<1%

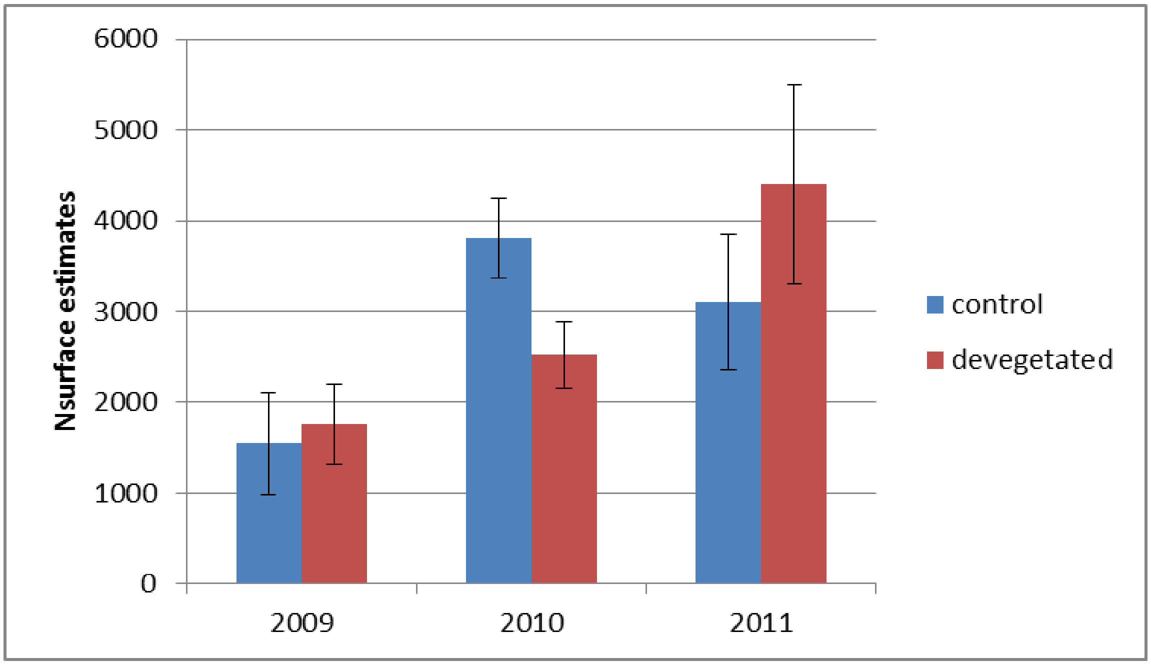

Figure 1. Capture-mark-recapture (CMR) estimates of the number of Crested Auklets on the surface ($N_{surface}$) of the four 2009 plots at Gareloi Island, Alaska.

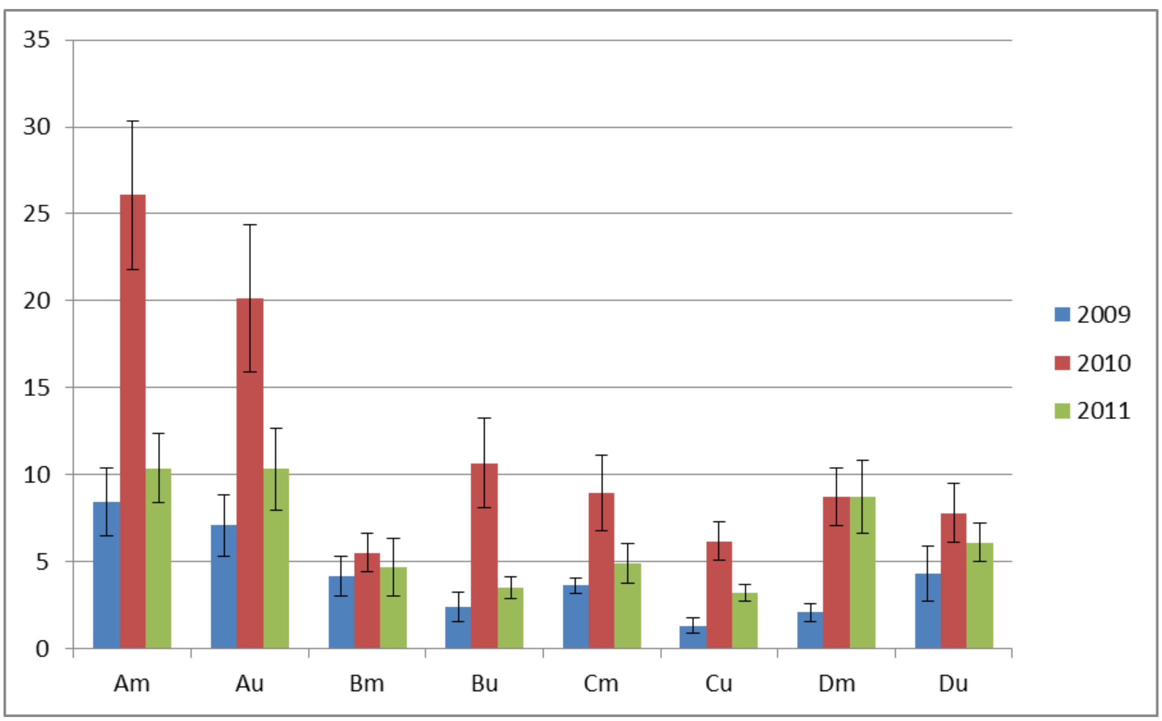

Figure 2. Daily average number of Crested Auklets observed during surface count surveys at 2009 plots.

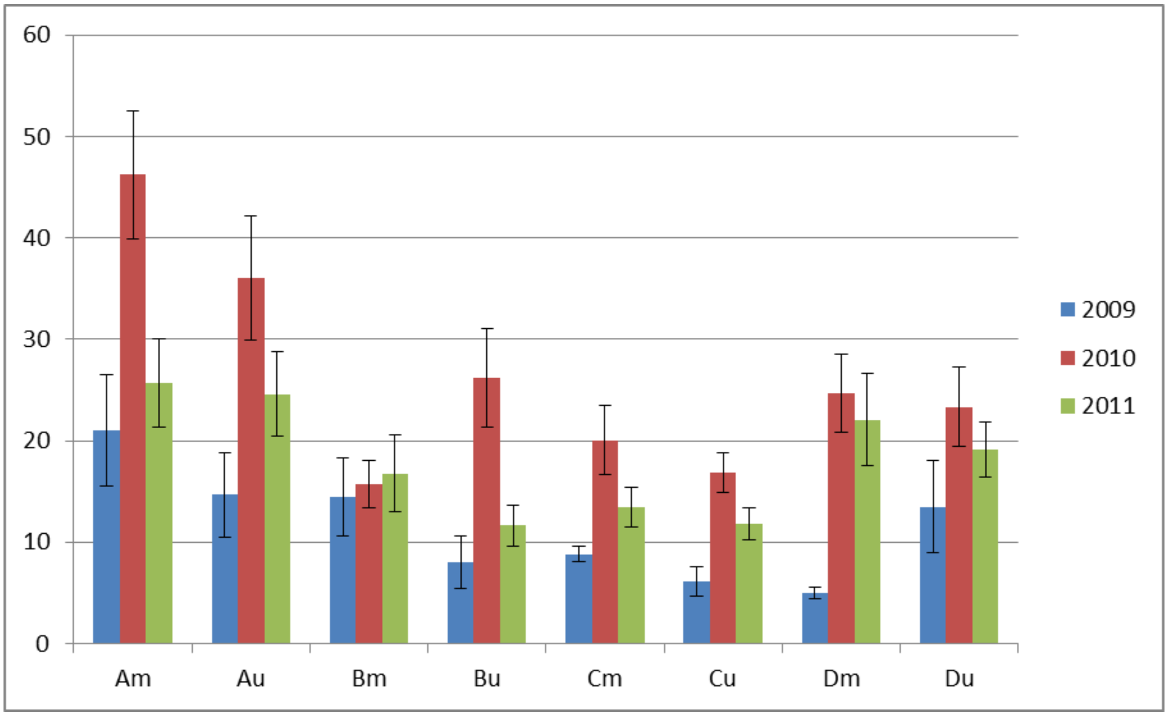

Figure 3. Daily maximum number of Crested Auklets observed during surface count surveys at 2009 plots.

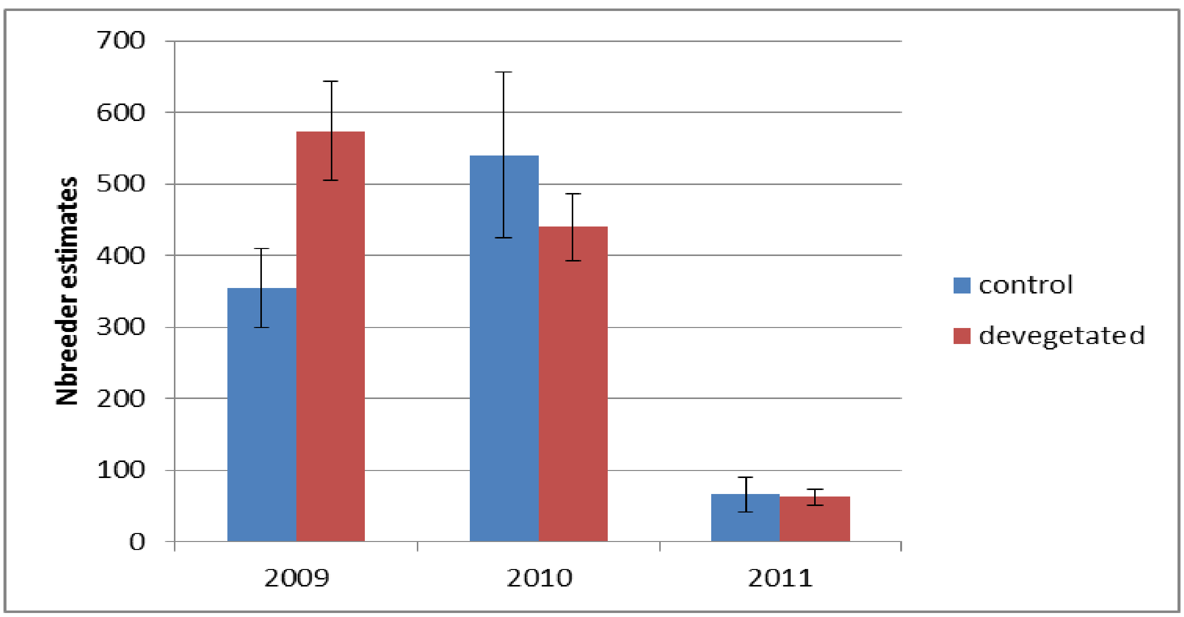

Figure 4. CMR estimates of the number of Crested Auklets breeding ($N_{breeder}$) on the four 2009 plots at Gareloi Island, Alaska.

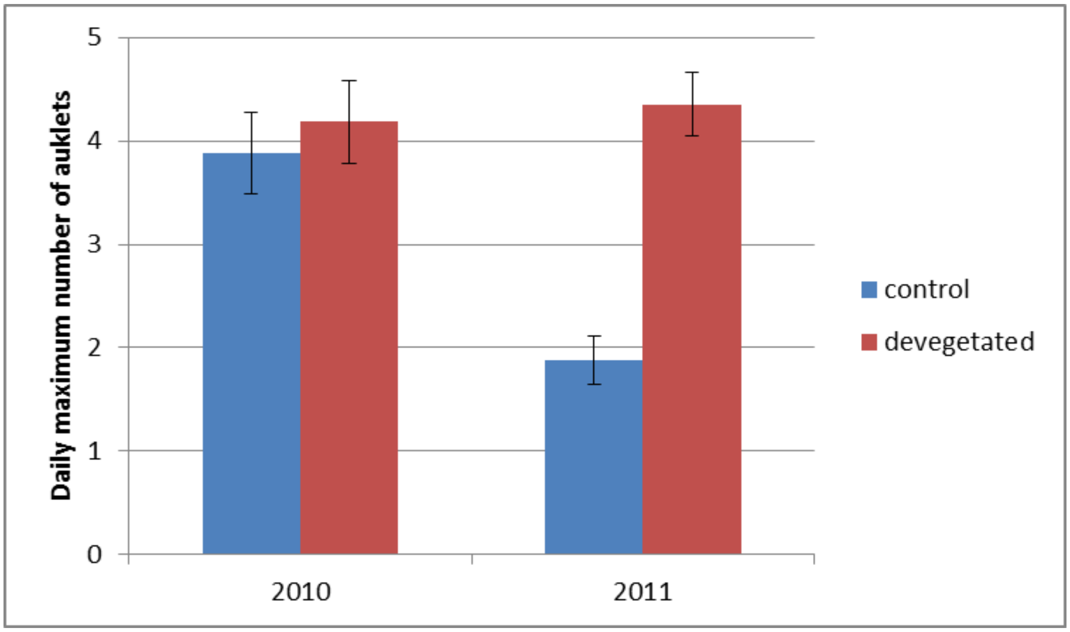

Figure 5. Daily maximum counts of Crested Auklets on the 30 2010 plots (Reconyx camera data), at Gareloi Island, Alaska.

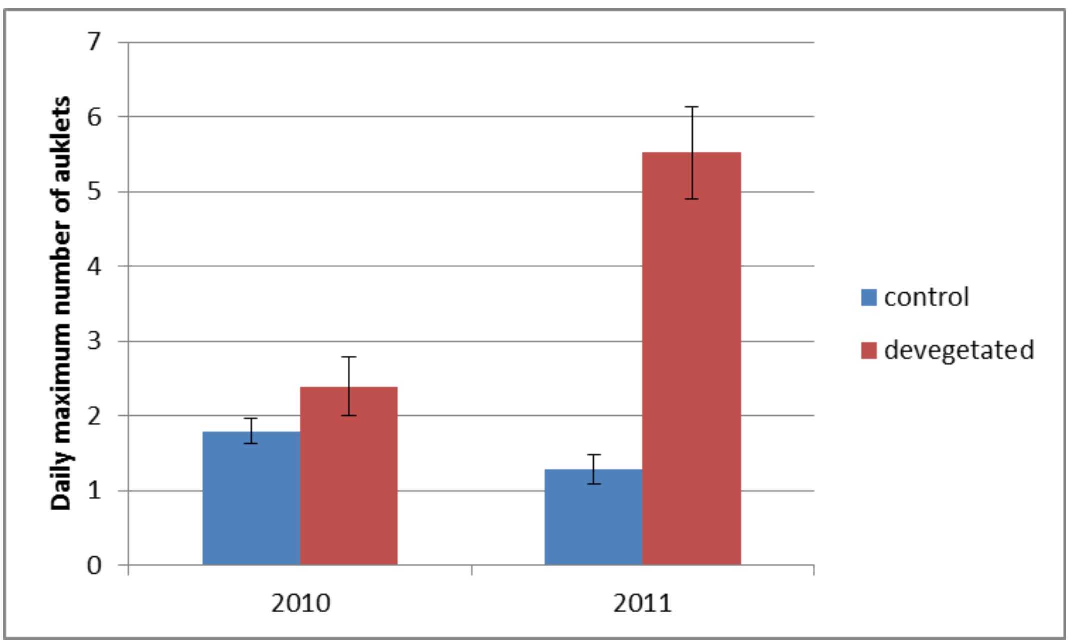

Figure 6. Daily maximum counts of Least Auklets on the 30 2010 plots (Reconyx camera data), at Gareloi Island, Alaska.

Figure 7. Lack of Crested Auklet breeding habitat revealed on new plot #17 (devegetated during August, 2010, date of photograph July 26, 2011) at Gareloi Island, Alaska.

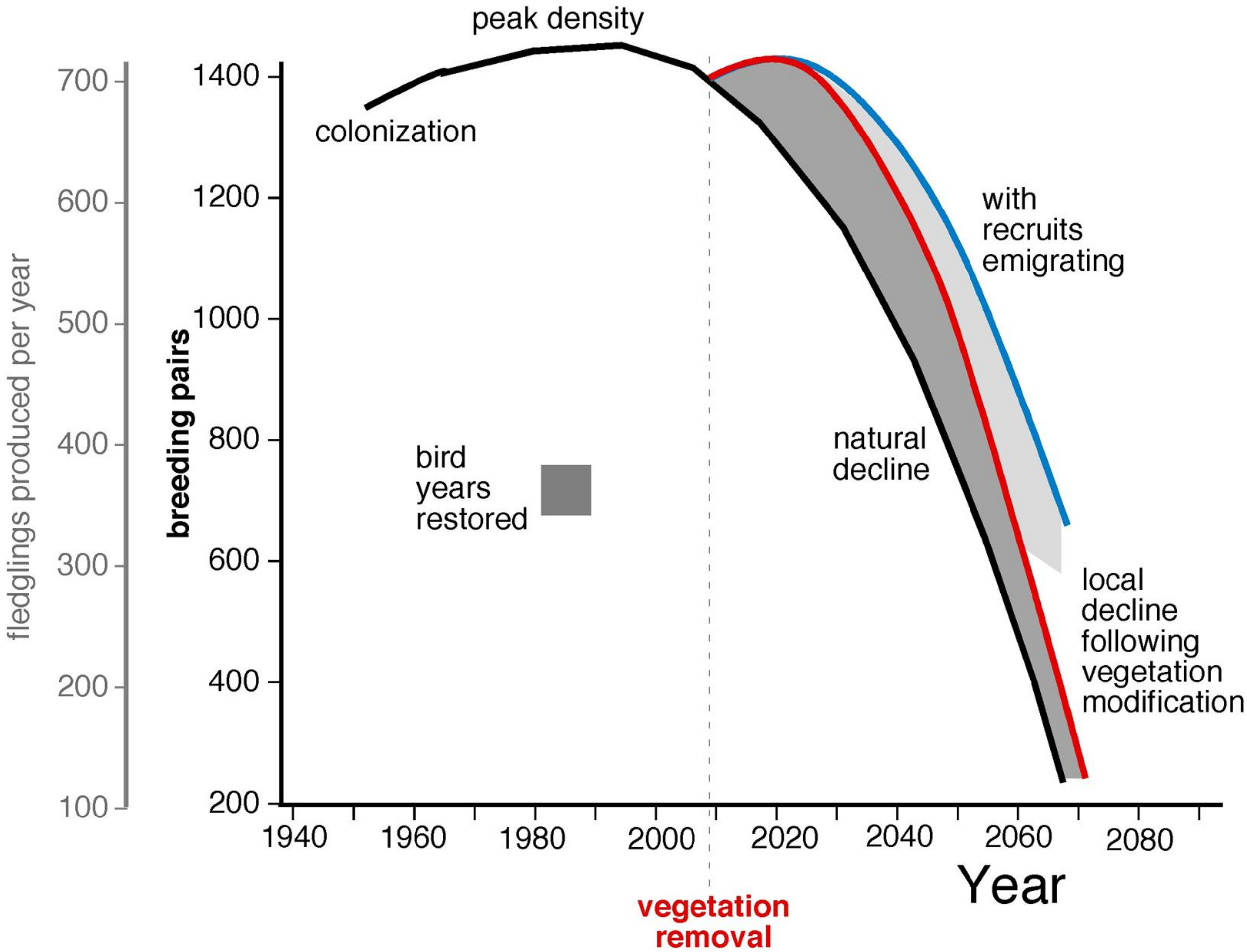

Fig 8. Graphic representation of a model to estimate ‘bird-years’ restored by the devegetation of plots ABCD at Gareloi Island in 2009 (using 0.5 fledglings produced per year as a mean level of Crested Auklet productivity).

Appendix I. Color-marked Crested Auklets seen on each of the four 2009 plots. Individuals in bold are known breeders.

Aa	Ab	Ba	Bb	Ca	Cb	Da	Db
DG/O-BK	**DB/LG-W**	DB/O-Y	W/R-BK	DB/DB-Y	BK/DB-Y	BK/DB-W	**BK/BK-DG**
DG/Y-Y	DG/Y-DB	DB/R-DB	DG/DG-DG	DB/GY-O	BK/DG-O	BK/O-Y	BK/LG-LG
GY/BK-O	**O/DG-O**	DG/O-R	O/DB-LG	DB/LG-R	BK/R-Y	BK/W-DG	DB/BK-W
GY/O-BK	O/DG-Y	DG/R-W	**Y/R-LG**	DB/O-R	BK/W-LG	DB/DB-R	DB/O-O
GY/R-O	R/BK-DG	DG/W-DG		DG/DB-LG	BK/Y-DB	DB/DG-R	DB/Y-BK
LG/LG-W	R/DG-BK	GY/R-W		DG/GY-LG	DB/DG-Y	DB/R-Y	DB/Y-O
LG/O-O	R/LG-LG	LG/W-R		DG/LG-R	DB/W-O	O/O-DB	DB/Y-R
O/R-R	R/Y-LG	O/O-GY		DG/O-DG	DG/GY-DG	R/DB-GY	DG/BK-R
O/W-DB	W/DB-R	O/O-W		DG/O-Y	LG/BK-LG	R/Y-DB	DG/DB-GY
R/O-DG	**W/DG-LG**	**O/O-Y**		DG/R-Y	LG/GY-DG	W/BK-O	DG/O-DB
W/BK-W	**W/DG-W**	O/W-R		DG/W-R	O/LG-BK	W/DB-O	DG/R-O
W/Y-DB	W/W-DG	R/DB-O		DG/W-W	O/Y-BK	W/DG-R	GY/DG-O
W/Y-GY	Y/R-DG	R/DG-Y		LG/GY-O	R/LG-DG	W/LG-R	LG/DG-DB
W/Y-O	**Y/Y-Y**	**R/LG-DB**		LG/GY-R	W/GY-Y	W/O-Y	O/GY-DG
W/Y-W		R/O-BK		**O/GY-R**	W/LG-O	Y/DB-R	O/LG-LG
W/Y-Y		**R/O-Y**		O/GY-W	Y/O-O	Y/R-O	O/W-LG
Y/DG-Y		R/R-Y		R/BK-Y	Y/W-Y	Y/Y-LG	R/O-O
		R/W-DB		R/GY-LG			R/W-DG
		W/BK-BK		R/GY-O			R/W-O
		W/LG-GY		**R/GY-W**			R/Y-Y
		W/R-LG		R/W-LG			W/O-LG
		W/W-LG		R/W-W			W/O-R
		W/W-W		R/Y-O			W/W-GY
		Y/DB-DG		Y/GY-BK			W/Y-R
		Y/DB-LG		Y/GY-LG			Y/LG-O
		Y/R-BK		Y/GY-W			Y/LG-R
		Y/W-O					Y/O-DB
		Y/Y-DB					**Y/R-Y**
		Y/Y-GY					
		Y/Y-R					

Appendix I. continued

A - Both halves	B - Both halves	C - Both halves	D - Both halves
O/DB-DG	**BK/O-BK**	W/GY-O	**R/DB-Y**
R/R-W	**R/DG-DB**	**Y/W-DB**	R/DG-O
			R/R-BK
			R/R-LG
			W/DB-DB
			W/O-W
			W/W-DB

Multiple plots

BK/DG-Y	DB/O-GY	O/LG-GY	R/Y-W	Y/O-R	Y/W-W
BK/O-W	DB/R-W	O/W-GY	W/DB-GY	Y/O-W	
DB/DB-DG	GY/DG-R	O/W-W	W/DG-Y	Y/R-GY	
DB/DB-GY	GY/GY-O	O/Y-DG	W/W-O	**Y/R-W**	
DB/DG-W	O/BK-W	R/Y-DG	W/Y-LG	Y/W-DG	