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EFFECTS OF EXTREME CLIMATE EVENTS ON ADULT SURVIVAL OF THREE PACIFIC AUKS

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A .„Climate change is predicted to increase the frequency and severity of extreme climate events, and it is important that we understand how this might a ect natural systems. We examined the e ects of extreme climate events on adult survival rates in three species of auks breeding on Triangle Island, British Columbia: Cassin•s Auklet (*Ptychoramphus aleuticus*), Rhinoceros Auklet (*Cerorhinca monocerata*), and Tufted Pu n (*Fratercula cirrhata*). Our -year study period (…) included two extreme climate events: a strong El Niño event in … and an atmospheric blocking event in . Neither event had any detectable e ect on the annual adult survival rate (± % con“dence interval) of either Tufted Pu ns (females: . ± . ; males: . ± .) or Rhinoceros Auklets (. ± . in both sexes). By contrast, the adult survival of female Cassin•s Auklets was halved during both extreme climate events (from a background rate of . ± . to . ± .), whereas survival of males was low, but constant through time (. ± .). Our results, combined with those of previous studies, suggest that the major ongoing decline in the Cassin•s Auklet population on Triangle Island is driven by negative e ects of climatic variation on both reproductive success and the survival of adult females. Climate change may result in continued Cassin•s Auklet population declines at this and more southerly colonies. By contrast, the relative stability of Rhinoceros Auklet and Tufted Pu n populations is likely attributable to the resiliency of adult survival rates to climatic conditions. .

Key words: Cassin•s Auklet, *Cerorhinca monocerata*, climate change, El Niño, *Fratercula cirrhata*, *Ptychoramphus aleuticus*, Rhinoceros Auklet, seabird, sex di erence, Tufted Pu n.

examine how extreme climate events in”uence adult survival of the two pu n species; previous research demonstrated that the … El Niño event reduced adult survival in Cassin•s Auklet (Bertram et al. , Lee et al.).

METHODS

Study site and species„Triangle Island (° N, ° W) supports the world•s largest Cassin•s Auklet colony (~ , pairs in ; Rodway), the largest Tufted Pu n colony in the Northeast Paci“c outside Alaska (~ , pairs in ; Rodway), and a large colony of Rhinoceros Auklets (~ , pairs in ; Rodway). e Tufted Pu n and Rhinoceros Auklet populations at Triangle Island remained relatively stable between and . By contrast, the Cassin•s Auklet population declined by an estimated % between and (M. S. Rodway and M. J. F. Lemon unpubl. data), and declines of a similar or greater magnitude have occurred on the other large colony in the Scott Islands archipelago (Hipfner et al. a), and at the Farallon Islands, California, well to the south (! %, … ; Lee et al.). Population modeling indicates low reproductive success and adult survival related to warm SSTs are the primary drivers of the Cassin•s Auklet population decline on the Farallon Islands (Wolf et al.). e same variables are likely important contributors to the population decline on Triangle Island because reproductive success at Triangle Island and the Farallon Islands covaries and is signi“cantly related to local oceanographic conditions (Wolf et al.), and extreme

TABLE 1. Model rankings and ranking criteria from Program MARK (White and Burnham 1999) for the predominant hypotheses to explain adult Tufted Puf“n survival during 2002…2007 on Triangle Island, British Columbia. " $_i$ is the difference in $QAIC_c$ value from that of the top-ranked model, $QAIC_c$ is Akaike•s information criterion adjusted for small sample size and corrected for , QDeviance is the model deviance after correcting for , and w_i is the Akaike weight. Models with " $_i$ > 10 are not shown because they lack meaningful support (Burnham and Anderson 2002). See online Supplementary Material for the full set of models (Appendix 1) and corresponding hypotheses (Appendix 2).

Model rank	Model[a]	" $_i$	K	QDeviance	w_i
1	$_{(sex)}p_{(sex)}$	0.00	4	25.95	0.35
2	$_{(.)}p_{(sex)}$	0.23	3	28.22	0.32
3	$_{(climate)}p_{(sex)}$	2.17	4	28.12	0.12
4	$_{(sex, climate)}p_{(sex)}$	2.75	5	26.65	0.09
5	$_{(M2\text{-}sex/sex)}p_{(sex)}$	3.61	6	25.45	0.06
6	$_{(sex, sex*climate)}p_{(sex)}$	3.87	6	25.70	0.05
7	$_{(t)}p_{(sex)}$	7.24	7	27.00	0.01

[a]Model notation follows Lebreton et al. (1992) and Cooch and White (2010): = survival probability, p = recapture probability, sex = sex effect, t = differs through time, (.) = constant through time, climate = extreme-climate-year effect, M2 = inclusion of a time-since-marking effect (comprising two time-since-marking periods; effects on the “rst year after initial marking [includes •transientŽ and •residentŽ individuals] precede the •/Ž and effects on any subsequent year [includes only •residentŽ individuals] follow the •/Ž), and asterisk indicates interaction between factors.

rate in males and females (. ± .). e model-averaged survival rate of females was . ± . in all years except the extreme-climate year (…), when it was . ± . . e model-averaged survival rate of males was . ± . in all years. e best-supported structure of resighting rate varied only by sex, being . ± . in females and . ± . in males.

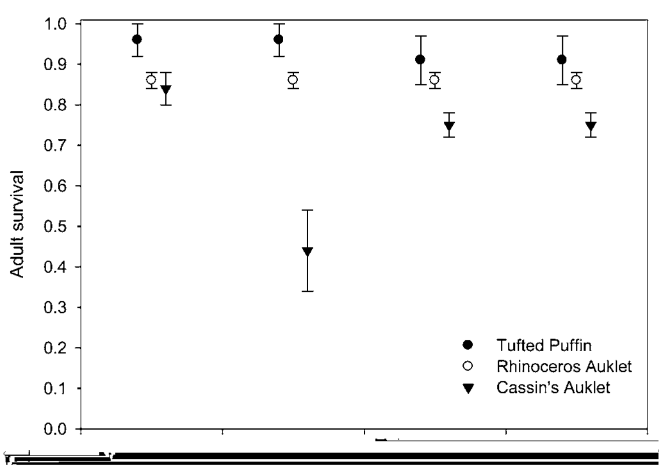

FIG. 1. Adult survival estimates of female and male Tufted Puf“ns, Rhinoceros Auklets, and Cassin•s Auklets on Triangle Island, British Columbia, from 1995…1996 to 2007…2008. •Non-climate yearsŽ include all years, excepting the •climate yearsŽ of 1997…1998 and 2005…2006 that are de“ned by extreme climate events. The Tufted Puf“n data set includes only the period from 2002…2003 to 2006…2007. The survival estimates presented are from the best-supported model from each analysis with 95% con“dence intervals.

Rhinoceros Auklets.—e survival analysis included , individuals (females and males). ree hundred and seventy-one individuals (%) were encountered in multiple years (females and males), giving an e ective sample size of , . e global model explained the data well (= .). e best-supported model in the candidate set included constant adult survival that was equal between the sexes (Table). is model received about . × the support of both the second-ranked model, which allowed survival to di er in extreme-climate years, and the third-ranked model, which allowed survival to di er in the year following each extreme-climate year (-year time lag). However, the maximized log likelihood values of the second- and third-ranked models were essentially the same as that of the top-ranked model (both … , . , vs. … , .), which indicates that both additional terms were unimportant •pretending variablesŽ (Burnham and Anderson , Anderson).

e best-supported model estimated the survival rate of adult Rhinoceros Auklets to be . ± . (Fig.). Model-averaged survival estimates were very similar to those from the best-supported model and were the same between the sexes. Survival in both extreme-climate years was . ± . , whereas survival in the year following and in all other years was . ± . and . ± . , respectively.

e best-supported structure of recapture rate varied through time without transient or sex e ects and produced estimates from . ± . to . ± . (but . ± . in , when sampling e ort was reduced). e average recapture rate was . ± . . e support for a recapture rate that varied through time was not a result of the low sampling e ort in , because a model that allowed recapture rate in to be estimated separately from all other years received less support than models in which recapture rate varied through time (ranked th; online Appendix).

Cassin•s Auklets.—e survival analysis included , individuals (females and males). We encountered individuals (%) in multiple years (females and males), resulting in an e ective sample size of , . e global model explained the

TABLE 2. Model rankings and ranking criteria from Program MARK (White and Burnham 1999) for the predominant hypotheses to explain adult

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