

Short visits reveal consistent patterns of interyear and intercolony variation in seabird nestling diet and performance

D.F. Bertram, T. Golumbia, G.K. Davoren, A. Harfenist, and J. Brown

Abstract: To investigate the utility of short visits to seabird colonies to gauge nestling growth performance and diet, in 4 consecutive years (1995–1998) we measured nestling development and diet of Rhinoceros Auklets (*Cerorhinca monocerata*) at three colonies in British Columbia: Seabird Rocks, Triangle Island, and SGaang Gwaii (Anthony Island). In all years, nestlings of a given wing length on Triangle Island were significantly smaller than those on Seabird Rocks or SGaang Gwaii. Meals were also significantly lighter on Triangle Island than on Seabird Rocks or SGaang Gwaii; meals on the latter two islands were indistinguishable in mass. Results suggest the influence of large-scale ocean climate phenomena on our entire study region and beyond. We did not, however, observe noticeable effects of the 1997–1998 El Niño Southern Oscillation event on nestling growth performance or diet. We discuss the utility of our short-visit techniques for seabird-monitoring programs.

Résumé : Nous avons évalué l'efficacité de courtes visites à une colonie d'oiseaux marins pour mesurer la performance de croissance et le régime alimentaire d'oisillons au nid. Durant 4 années consécutives (1995–1998), nous avons mesuré le développement et le régime alimentaire de petits macareux rhinocéros (*Cerorhinca monocerata*) au nid dans trois colonies de Colombie-Britannique : Seabird Rocks, Triangle Island et SG

aang Gwaii. Tous les ans, les petits macareux d'une longueur d'aile donnée sont significativement plus petits sur Triangle Island que sur Seabird Rocks ou SGaang Gwaii et la masse de leurs repas y est aussi plus faible que sur les deux autres îles où les masses alimentaires sont semblables. Le développement retardé des oisillons au nid à Triangle Island et leurs repas réduits reflètent sans doute l'importante proportion de sébastes (*Sebastes* spp.) à l'alimentation des petits macareux, ce qui ne se produit pas dans les autres colonies. Les différences de performance des oisillons au nid dans les différentes colonies semblent être le reflet de l'influence des populations locales de poissons proies. Néanmoins, un déclin de la performance s'est produit dans toutes les colonies en 1996, suivi d'un regain général; cela laisse croire à l'influence d'un phénomène climatique océanique à grande échelle qui a affecté toute la région de l'étude et au-delà. Nous n'avons cependant pas observé d'effets mesurables du phénomène d'El Niño de 1997–1998 sur la performance de croissance ou sur le régime alimentaire des petits macareux au nid. L'utilité de notre technique de visites courtes dans le cadre de programmes de surveillance des oiseaux marins fait l'objet d'une discussion.

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Introduction

In investigations of marine ecosystems, seabirds can be used to provide unique samples from the environment that

supply information on both seabirds and prey populations. Measurements of seabird nestlings coupled with samples of nestling diet can provide general insight into relationships between developmental performance and local marine prey

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D.F. Bertram.^{1,2} Centre for Wildlife Ecology, Department of Biological Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6, Canada, and Canadian Wildlife Service, Environment Canada, 5421 Robertson Road, Delta, BC V4K 3N2, Canada.

T. Golumbia and J. Brown. Parks Canada Agency, Box 37, Queen Charlotte City, BC V0T 1S0, Canada.

G.K. Davoren.³ Department of Biology, University of Victoria, P.O. Box 3020, Victoria, BC V8W 3N5, Canada.

A. Harfenist.⁴ Canadian Wildlife Service, Environment Canada, 5421 Robertson Road, Delta, BC V4K 3N2, Canada.

¹Corresponding author (e-mail: bertramd@pac.dfo-mpo.gc.ca).

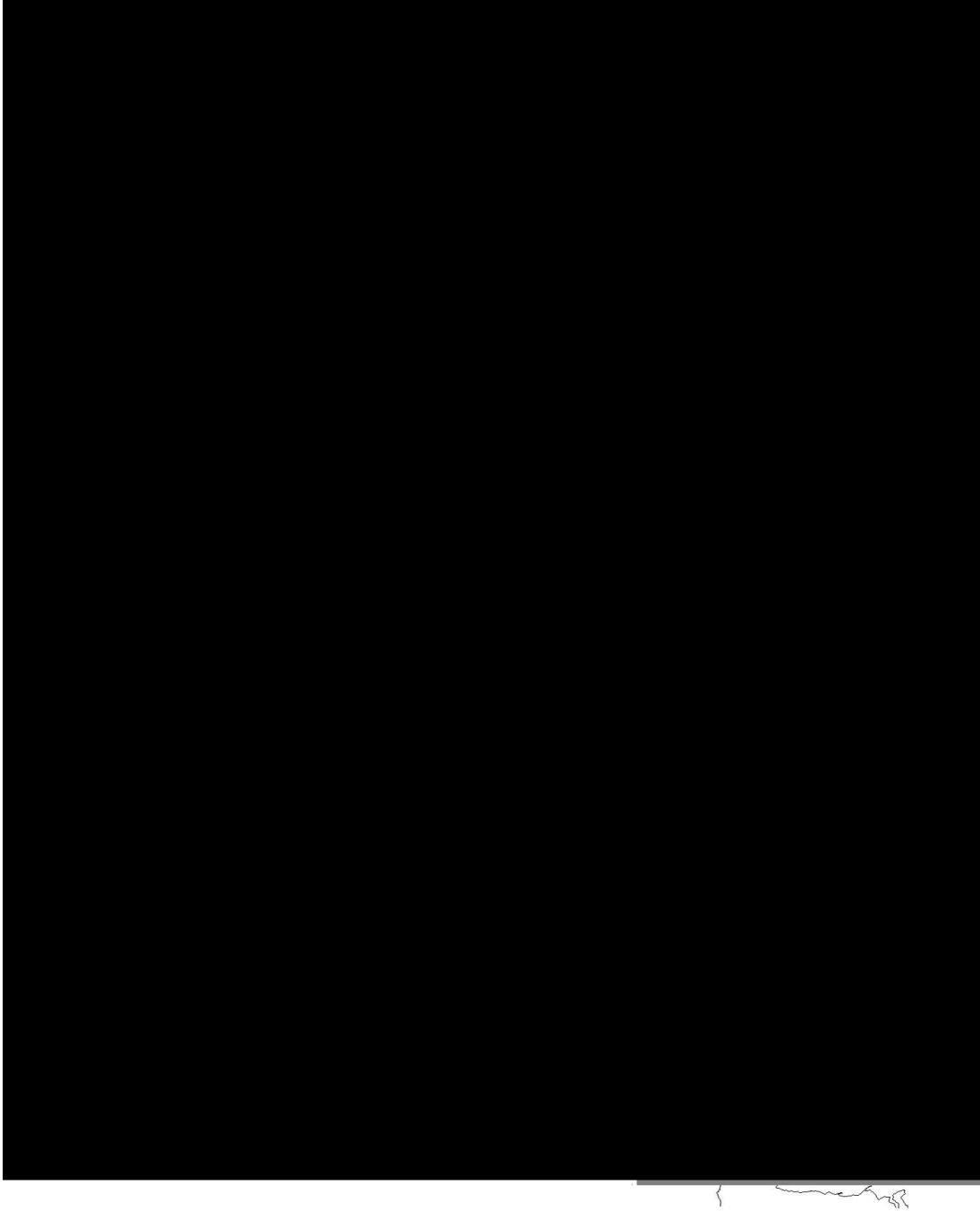
²Present address: Canadian Wildlife Service, Environment Canada, c/o Institute of Ocean Sciences, 9860 West Saanich Road, P.O. Box 6000, Sidney, BC V8L 4B2, Canada.

³Present address: Departments of Biology and Psychology, Memorial University of Newfoundland, St. John's, NF A1B 3X9, Canada.

⁴Present address: Harfenist Environmental Consulting, P.O. Box 2498, Smithers, BC V0J 2N0, Canada.

species composition. At larger spatial scales, intercolony time-series comparisons can also provide insight into recruit-

Fig. 1. Locations of the Rhinoceros Auklet (*Cerorhinca monocerata*) colonies in the study. Note that SGaang Gwaii is also known as Anthony Island.



cant differences were found, multiple paired tests of colony or year were conducted to identify the steepest and shallowest slopes. We tested for differences in the elevation of the mass versus wing length relationship using the same model with retention of the interaction term in all cases. The ANCOVA adjusts the mean masses to compare them at the same wing length. Post-hoc contrasts were performed on the adjusted mean masses and significance was based on Bonferroni-adjusted probabilities.

Nestling diet

We compared the species composition of fishes in the

nestling diet by pooling the bill loads collected within each year on each colony to obtain the percentage of mass composed of sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea pallasii*), rockfishes (*Sebastes* spp.), salmon (*Salmonid* spp.), surf smelt (*Hypomesus pretiosus*), Pacific saury (*Cololabis saira*), and Pacific hake (*Merluccius productus*). The percentages were arcsine and square-root transformed to investigate the differences between colonies for each species using a univariate ANOVA followed by post-hoc contrasts with Bonferroni-adjusted probabilities. The masses of food loads were compared between colonies by pooling all the loads collected within each year in a one-way ANOVA

followed by post-hoc contrasts with Bonferroni-adjusted probabilities.

Results

Nestling growth and developmental patterns

Intercolony comparisons

There were significant differences between colonies that persisted in all years of the study. Nestlings on Triangle Island had a significantly smaller mass for a given wing length than birds on either Seabird Rocks or SGaang Gwaa*i* (Fig. 2, Table 1). In contrast, nestling development on Seabird Rocks and SGaang Gwaa*i* was very similar except in 1998, when nestlings on SGaang Gwaa*i* were significantly heavier than

values (Vermeer and Devito 1986). In the present study, bill loads were again lighter on Triangle Island. We consider the lighter loads on Triangle Island to reflect the dominant rock-

fish composition and suggest that the bill-load size is constrained by the squat body morphology of the rockfish prey. Nestling age has been shown to affect the amount of food

Colony	Year	<i>n</i> ^a	Slope ^b of mass versus wing length bivariate relationship (g·mm ⁻¹)	Elevation (ALS mean mass versus wing length) ^c
SBR	1995	11	1.88 _a	305 _a
	1996	12	2.18 _a	267 _b
	1997	12	1.94 _a	271 _a
	1998	16	2.05 _a	275 _a
	All	4	2.01	279.5
TRI	1995	33	1.62 _a	209 _a
	1996	24	1.53 _a	187 _b
	1997	37	1.43 _a	202 _a
	1998	39	1.73 _a	212 _a
	All	4	1.58	202.5
SG	1995	43	2.35 _a	282 _a
	1996	44	2.18 _{ab}	249 _b
	1997	43	1.79 _b	249 _b
	1998	58	2.41 _a	296 _a
	All	4	2.18	269

Note: For names of colonies and sampling dates see Table 1.

^aNumber of nestlings measured.

^bIf differences were detected, post-hoc contrasts on slopes were based on multiple paired comparisons.

^cAdjusted least square (ALS) means based upon the ANCOVA including the interaction term. Tests of mean elevations of mass versus wing length were conducted using Bonferroni-adjusted probabilities of post-hoc contrasts.

delivered to the burrow (e.g., Bertram et al. 1991), but there was considerable overlap in nestling-developmental stages between colonies.

Sand lance consistently composed most of the nestling diet on SGAang Gwaii, where nestling growth performance was strong. Rapid nestling development (e.g., measured in grams per day) has been associated with high proportions of sand lance in the diet (Wilson and Manuwal 1986; Bertram and Kaiser 1993). The present study also demonstrates strong nestling performance on diets that were not exclusively dominated by sand lance. Nestlings on Seabird Rocks performed as well as those on SGAang Gwaii on varied diets composed of surf smelt, herring, and salmon in addition to sand lance. Bill-load masses were similarly large on Seabird Rocks and SGAang Gwaii and the diet on Seabird Rocks routinely included surf smelt and herring, which have a similar energy density to sand lance (e.g., for data from Alaska see Anthony et al. 2000). On Teuri Island in Japan (44°25'N, 141°19'E), Rhinoceros Auklet nestlings grew most rapidly and fledged at heavier masses when provisioned primarily with anchovy (*Engraulis japonicus*) because bill loads were heavier and energy densities were higher than those reported for 0+ sand lance (Takahashi et al. 2001). Clearly, regional differences in nestling performance will depend on the regional availability of alternative prey species and the age classes present within the breeding season.

Ocean temperatures on the British Columbia coast dropped significantly in 1999 to levels that were observed in the 1970s and have remained low, in contrast to those reported for most of the 1990s. On Triangle Island, sand lance abundance in the diets of Rhinoceros Auklet nestlings increased, to exceed 50% by mass in 1999, and nestling growth rates also exhibited a marked increase in that year compared with those found in this study (1995–1998), when rockfish and other species were dominant (Bertram et al. 2001; Department of Fisheries and Oceans 2001). It is plausible that re-

cruitment to sand lance populations around Triangle Island increases in cool years (Bertram et al. 2001) such as 1999, but independent data on prey abundance are needed to test this hypothesis. Our results herein (1995–1998) demonstrate that when sand lance did not dominate nestling diets on Triangle Island, growth rates on the alternative prey species were relatively poor.

Interyear variation

Between years, colonies generally tended to show similar rankings in nestling performance, rising and falling in unison. Most notably, nestlings on all colonies tended to perform poorest in 1996. The interyear similarity in performance on the widely separated colonies suggests the presence of oceanographic influences that operate at a larger spatial scale than in our study area. In a recent study, Whitney et al. (1998) argued that “there are interannual changes in seawater properties in the NE Pacific Ocean which affect nutrient supply and primary production, and by inference, higher trophic level productivity”. Estimates of nitrate depletion in a 290 000-km² patch off the west coast of Vancouver Island from 1989 to 1996 were lowest in 1996, consequently new production was reduced by 40% through spring and summer. Whitney et al. (1998) argued that observed variability in mixed-layer water properties (such as nitrate) in the northeast Pacific Ocean is not regional but results from changes in atmospheric forcing that likely affect the entire North Pacific Ocean. The mechanisms leading to a reduction in seabird performance at basin-level scales are presently unclear and are likely to affect different species in different ways. During the study period the water temperatures in British Columbia were among the highest of the century, and spring was early, particularly in 1996 and 1998. In those early, warm spring years, production of Cassin’s Auklet nestlings on Triangle Island was exceedingly poor, likely because of a mismatch in timing between the availability of the principal copepod prey (*Neocalanus cristatus*)

and seabird breeding (Bertram et al. 2001). The copepod prey disappeared early from surface waters (and hence from nestling diets) in 1996 and 1998, and as a consequence the Cassin's Auklet (*Ptychoramphus aleuticus*) nestlings grew slowly and many starved. We expect that because zooplankton prey populations have annual life cycles and can exhibit massive community species reorganization from one year to the next (see Mackas et al. 2001), variation in reproductive performance of the largely planktivorous Cassin's Auklet should closely track variability in zooplankton prey populations. For the largely piscivorous Rhinoceros Auklet, however, we expect that because of the addition of another trophic level that consists of age-structured prey populations, the connection between ocean forcing and seabird reproductive performance will be-

come less direct and thus more complicated. Nonetheless, it is striking that despite differences in trophic level between species, 1996 was uniformly the poorest year for nestling performance during the 1990s for Rhinoceros Auklet, Tufted Puffin (*Fratercula cirrhata*), and Cassin's Auklet populations on Triangle Island (Bertram et al. 2001). The trophic connectivity between zooplankton prey populations, pelagic fish preda-

tors (including seabird prey such as sand lance, herring, salmon, and rockfish), and breeding piscivorous seabirds such as the Rhinoceros Auklet is an open research topic that requires an integrated, ecosystem-based investigative approach.

It is important to point out that our study did not detect any major influences on nestling performance or diet in 1998, when a very large ENSO event was observed (PICES 1999). In 1998, values for nestling performance on all colonies ranked among the highest observed. (Note that the highest values observed on Triangle Island were still lower than all of those measured on the other colonies.) We do not suggest, however, that the ENSO event had no effect on seabirds in British Columbia. The number of birds attempting to breed (based upon burrow occupancy) was significantly reduced for the Cassin's Auklets on both Triangle Island and Frederick Island (53°56'N, 133°11'W), although poor nestling performance was only observed on Triangle Island (Bertram et al. 2001; A. Harfenist, personal observation). Time-series information (1983–1999) for Ancient Murrelets (*Synthliboramphus antiquus*) from the Queen Charlotte Islands indicate that the 1998 ENSO event significantly reduced breeding success, resulting in an average of <1 chick reared per breeding pair compared with average values of >1.4 chicks per pair (Gaston and Smith 2001).

The present study reports only on nestling development and diet and does not offer information on parental foraging effort such as regularity of feeding or distance traveled to the feeding areas from the colony. It is known that breeding Rhinoceros Auklets (Bertram et al. 1996), like many other seabirds (Ydenberg and Bertram 1989; Burger and Piatt 1990; Monaghan et al. 1994; Shaffer et al. 2001; Hedd et al. 2002), can adjust parental provisioning effort. Consequently, within certain levels of prey availability, seabirds have a buffering capacity and may mask the effects of poor ocean foraging conditions on nestling growth by increasing their provisioning effort. Nonetheless, because the Rhinoceros Auklet is a nocturnal single-load-provisioning species, its potential to buffer environmental vagaries may be constrained (Takahashi et al. 1999) compared with other, multiload-provisioning species. We were not able to evaluate the effects of population and colony size (e.g., Hunt et al. 1986) on performance, owing to the lack of replicate colonies.

Utility of methods for marine-ecosystem monitoring

Our monitoring technique, based on short visits to seabird colonies, is attractive to marine management and conservation programs because it provides valuable insight into both seabird and prey fish populations at a low cost and with minimal disturbance. To be most effective, future visits to colonies should be timed so that nestlings are at comparable stages of development, prior to the onset of pre fledging mass loss. Because of constraints on the timing of our visits to SGaang Gwaii and Seabird Rocks, nestlings on different colonies were at different stages of development. (Note that our

1998, respectively. Fledging masses were 299, 229, 224, and 255 g in 1995, 1996, 1997, and 1998, respectively. Fledging success (fledged/hatched) was 81, 53, 70, and 82% in 1995, 1996, 1997 and 1998, respectively. Most notably, the rankings of the growth-rate estimates and the mass versus wing length comparisons between years are the same for both methods, with 1996 falling below the other years. In general, 1996 stands out as the poorest year for performance, based upon both the longitudinal datasets and the cross-sectional data analyses of mass versus wing length. The cross-sectional data and the longitudinal growth data, however, cannot capture events that take place following the sampling periods, as

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