NUMBERS AND HABITAT SELECTION OF CASSIN'S AUKLET BREEDING ON TRIANGLE ISLAND, BRITISH COLUMBIA

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ABSTRACT.—Triangle Island, with approximately 360,000 breeding pairs, constitutes the largest Cassin's Auklet (*Ptycoramphus aleuticus*) colony in the world and contains 40% of the total breeding population of that species. Nesting habitat preferences were determined by stepwise multiple regression analyses. Cassin's Auklets preferred nesting in sparse shrubbery and short herbaceous vegetation on slopes and in the interior of the island. Their nesting densities ranged from 0.1 to 1.1 pairs per m^2 with an overall density of 0.37 pairs per m^2. Highest densities occurred on the open summit, around the edge of the plateau, on the southeast plateau, and on the southwest slope. They nested least densely on the central plateau of the island, where dense, tall salmonberry was the dominant vegetation, as well as on slopes where other burrowing alcids, Rhinoceros Auklets and Tufted Puffins, were present in large numbers. The latter two alcids were restricted to certain slopes and cliff tops while Cassin's Auklets nested on all slopes and on relatively flat areas of the island. Differences in nesting distribution between the three alcids may partly be explained by the lower wing-loading of Cassin's Auklets. *Received 1 March 1978, accepted 26 November 1978.*

CASSIN'S Auklets (*Ptychoramphus aleuticus*) nest on treed as well as treeless islands in British Columbia (Drent and Guiget 1961). On treed islands they nest predominantly at the edge of forests with little or no understory and burrow in bare or moss- and grass-covered ground. They nest on low islands as well as above cliff edges up to 100 m high. They are the most abundant nesting seabirds on Triangle Island, British Columbia (Vermeer et al. 1976). It was not until the summer of 1977 that a survey was conducted on the island to determine the total breeding population, thought to be the largest for the species in the world. Another large colony of 52,500 pairs occupies Southeast Farallon Island, California (Manuwal 1974a) where Thoresen (1964), Manuwal (1974a, b) and Speich and Manuwal (1974) studied its natural history and population structure. The objectives in this study were to document the breeding population of Cassin's Auklets on Triangle Island and its importance in relation to other known populations, to determine breeding densities of Cassin's Auklets among broad habitat units, and to identify the factors influencing those densities by means of regression analyses. The 1977 survey on Triangle Island and present inventories in British Columbia by the British Columbia Provincial Museum and the Canadian Wildlife Service, in Alaska by the Outer Continental Shelf Environment Assessment Program, and in California by S. M. Speich, made it possible to compare the Triangle Island population with the known population of Cassin's Auklets.

STUDY AREA AND METHODS

Triangle Island (50°52'N, 129°05'W), the outermost of the Scott Islands, is situated 46 km northwest of Cape Scott, at the northern end of Vancouver Island, British Columbia (see Fig. 3). Triangle Island is approximately 1.5 km long on its greatest dimension and is roughly triangular in shape. The perimeter is generally steeply sloped while the upper regions are more level, rising to a maximum elevation of approximately 200 m. The island was the site of an active light station from 1909–1919. Now only the

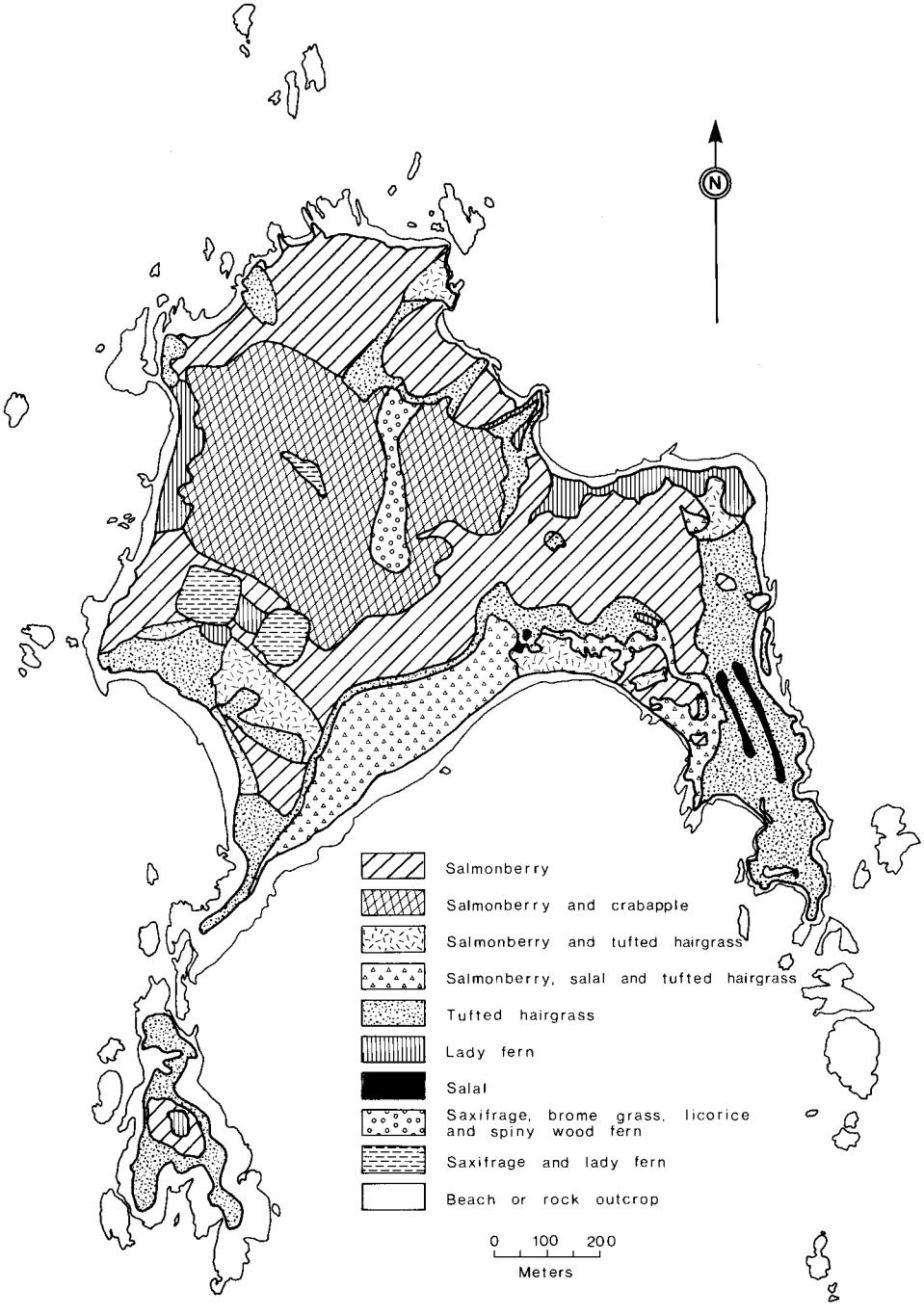

Fig. 1. Distribution of dominant vegetation on Triangle Island in 1977.

concrete shell, building foundations, and rusted train track remain. The climate is very humid and promotes a dense cover of vegetation over most of the island although strong winds prune larger shrubs to a continuously low and even height. There are no trees, and much of the island is covered by salmonberry (*Rubus spectabilis*) (Fig. 1). Lady ferns (*Athyrium filix-femina*) form large patches among the salmonberries. Tufted hairgrass (*Deschampsia caespitosa*) covers most wind-exposed ridges and slopes. Salal (*Caultheria shallon*) is abundant near rocky promontories. A more detailed description of the climate, flora, and fauna of Triangle Island has been given by Carl et al. (1951), while its bird fauna has been described in more detail by Vermeer et al. (1976).

Triangle Island was divided into 11 broad habitat units on the basis of their physical characteristics (Fig. 2). Those units were censused from 20 June to 31 July 1977, with the exception of the eastern portion of the south slope where 38 quadrats were censused in the summer of 1976. Quadrats of 5 m × 5 m were set out systematically 40 m apart on transects running up the slope from the beach. Transects were 50 m apart. On the edges around the island plateau, quadrats were established 70 m apart on a continuous transect that circled about two-thirds of the island. The plateau was sampled from quadrats 40 m inland of each plateau edge quadrat. One transect with quadrats spaced at 50-m intervals was run along the summit of the plateau. The number of alcid burrow entrances, major vegetation types, percentage plant cover, slope angles, and elevation were determined for each quadrat. Not all burrows were occupied, and some had more than one entrance. Therefore, in order to be able to estimate numbers of breeding pairs from the number of entrances the number of occupied burrows was determined in eight of the 25 m^2 quadrats mentioned earlier. Those eight quadrats represented a variety of exposures, vegetation types, and topographic situations in different parts of the island. Occupancy was determined by noting the presence of copious quantities of fresh feces at burrow entrances, and in the absence of the feces, by excavating the burrows to determine whether eggs or chicks were present. The substrate composition was determined at 26 different locations representing various vegetation types on the island. Nesting habitat areas were measured in different regions of the island. Areas of rock bluffs that were unsuitable for burrowing were excluded from those measurements. A report by the third author, providing detailed calculations of Cassin's Auklet breeding density, population, and nesting habitat, and showing 10 maps with transects and quadrats in 11 habitat units on Triangle Island, is on file in the Canadian Wildlife Service library at Delta, British Columbia.

The burrow density of Cassin's Auklets was multiplied by a factor of 25, the quadrat size, and was regressed by stepwise multiple regression on the amount of major vegetation types, amount of bare ground, slope angle, and elevation to determine if the birds preferred certain habitats for burrowing. Density of Cassin's Auklets burrow entrances was also regressed on that of Rhinoceros Auklets where the two species nested together on the eastern portion of the south slope. The stepwise procedure involved the reexamination at every stage of the regression for all variables incorporated into the model in previous stages (Draper and Smith 1966). The partial F-statistic for each variable in the regression at any stage was evaluated to check for the significance of each variable in the presence of others in the regression. This procedure evaluated the contribution made by each variable as though it had been the most recent variable entered. The SPSS stepwise regression program was used in the analyses. Any variables with $F \leq 0.01$ or tolerance level ≤ 0.001 were not admitted into the regression equation. A tolerance level of 0.001 implied that a variable may be entered if the proportion of its variance not explained by other independent variables exceeded 0.1%. The model was considered defined at the stage when the latest variable entered had a significant partial F-statistic at the 5% level or when an important variable became significant in the presence of other variables in the regression. The partial F-statistic is the ratio of the sum of squares contributed by a variable to the residual mean square of the regression. All variables in the reported equations were significant except for one. The F-statistic for the coefficient of determination (R^2) is the ratio of the total mean square of regression to the residual mean square. The R^2 values for all models were significant at the 1% level. Of many linear regression analyses made, only five equations are shown as they are thought to be representative of the nesting preference of Cassin's Auklets on Triangle Island. The nesting distribution of Cassin's Auklets, Rhinoceros Auklets (*Cerorhinca monocerata*), and Tufted Puffins (*Lunda cirrhata*), on the island were compared as the latter two species are also burrowing alcids that may compete with the Cassin's Auklets for nesting habitat.

Results and Discussion

Breeding densities and populations.—In eight quadrats examined the number of occupied burrows was 36–58% of the number of burrow entrances, with a mean of

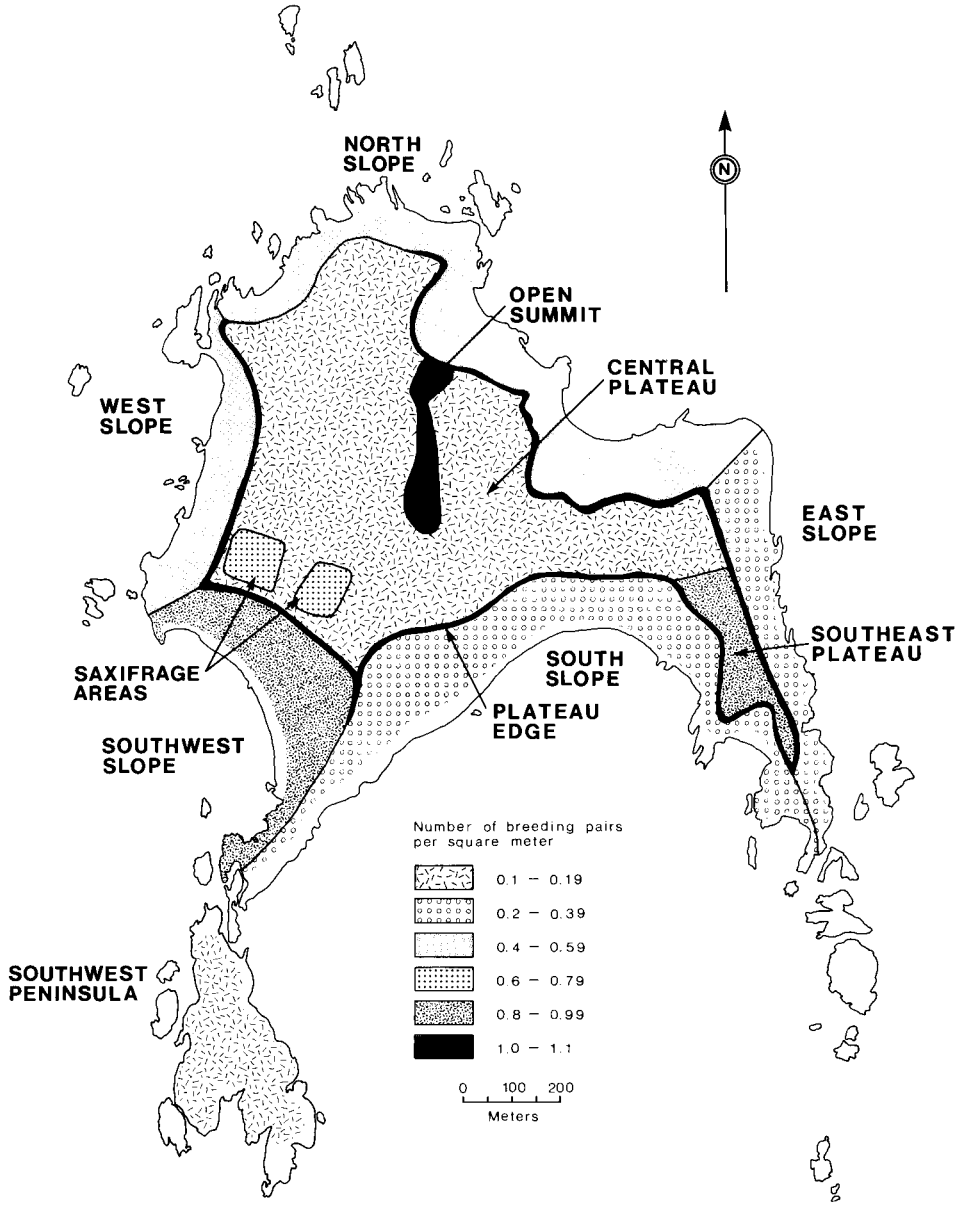

Fig. 2. Breeding densities of Cassin's Auklets according to broad habitat units on Triangle Island in 1977.

48%. Based on this average and 7,631 burrow entrances in 288 quadrats representing a total of 970,000 m^2 of nesting habitat, we calculated breeding densities of Cassin's Auklets on Triangle Island in 11 habitat units (Fig. 2). The densities varied from one habitat to another with an overall density of 0.37 pairs of Cassin's Auklets per m^2. Nesting was densest in areas with short herbaceous vegetation or sparse shrubbery such as the southwest slope with tufted hairgrass and low wind-pruned salmonberry interspersed with bare ground, the southeast plateau with tufted hairgrass

and Alaska brome grass (*Bromus sitchensis aleutensis*), the open summit with Newcombe's saxifrage (*Saxifraga newcombeii*) and licorice fern (*Polypodium vulgara*) and spiny wood fern (*Dryopteris austriaca*), the saxifrage areas with Newcombe's saxifrage and lady fern, and the plateau edge around the island interior with a frequent and abrupt gradient between short vegetation such as tufted hairgrass and dense, tall salmonberry. Breeding densities were low in the central plateau of the island where 0.5–2.0-m tall, dense salmonberry with some Pacific crabapple (*Malus fusca*) and salal were dominant. Cassin's Auklets also nested in lower numbers on the southwest peninsula, where tufted hairgrass was dominant and where about 16,500 pairs of Tufted Puffins used most of the nesting habitat.

The total breeding population of Cassin's Auklets on Triangle Island was calculated to be 359,000 breeding pairs in 1977. The total breeding population in British Columbia outside Triangle Island consists of approximately 200,000 pairs (R. W. Campbell pers. comm.). About 250,000 pairs are found in Alaska (A. Sowls pers. comm.) and approximately 100,000 pairs breed south of British Columbia along the west coast of the United States and Baja California in Mexico (S. M. Speich and A. Thoresen pers. comm.). The known population of Cassin's Auklets, all situated along the North American west coast, therefore consists of approximately 900,000 pairs. British Columbia appears to contain approximately 60% of the known population of Cassin's Auklets, of which about 40% are found on Triangle Island. The next largest colonies are on Frederick Island on the west coast of the Queen Charlotte Island with approximately 65,000 pairs (R. W. Campbell pers. comm.); at Forrester Island, southeastern Alaska with 54,000 pairs (A. J. De Gange pers. comm.); and on Southeast Farallon Island with 52,500 pairs (Manuwal 1974b). The breeding center of Cassin's Auklets, with approximately 65% of the world's known population, ranges from Triangle Island to Forrester Island on the Alaska–British Columbia boundary (Fig. 3).

Habitat selection.—The burrow densities in the habitat units reflect the Cassin's Auklet preferences for certain habitat variables such as type of vegetation, slope angle, and elevation, and the inhibiting effects of unsuitable vegetation and other burrowing alcids competing for nesting space. The relationship between the Cassin's Auklet burrow density and the various habitat variables may be formally described by linear analyses. The south slope is ideally suited for regression analysis as it contains most of the variables that were expected to affect burrow density. Most of the vegetation types are found on the south slope, and Rhinoceros Auklets are present on the eastern portion of that slope. The estimated regression equation for Cassin's Auklets on the south slope is shown in Table 1.

Of the independent variables, slope angle, percent tufted hairgrass, density of Rhinoceros Auklet burrow entrances, and altitude were significant. Thus it appears that Cassin's Auklets prefer nesting in short hairgrass and away from Rhinoceros Auklets and steep slopes. Cassin's Auklets nests were most dense on a relatively flat area of the eastern part of the south slope, just below the plateau edge, where few Rhinoceros Auklets nested. In this case the significant negative partial regression coefficient for slope angle and positive regression coefficient for altitude may be attributed to the preference of this species to nest away from Rhinoceros Auklets, as Cassin's Auklets were observed to nest commonly on relatively steep slopes and low altitudes elsewhere on the island.

The significant explanatory variables on the southwest slope were bare ground

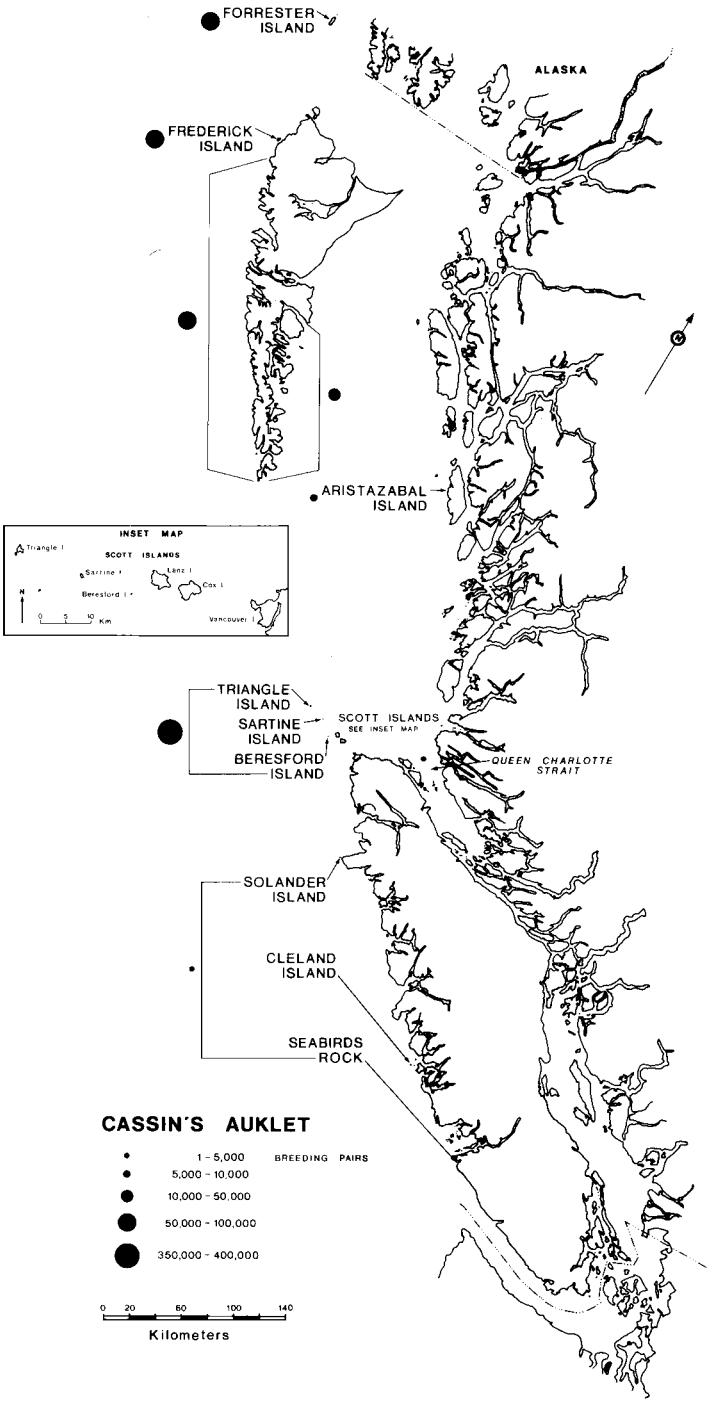

Fig. 3. Breeding populations of Cassin's Auklets in British Columbia and on adjacent Forrester Island, Alaska. Inset shows Triangle Island in the Scott Island Group.

TABLE 1. Linear regression equations for Cassin's Auklet burrow densities in different locations on Triangle Island, where D = density of Cassin's Auklet burrow entrances, SLO = slope angle, GRA = % tufted hairgrass cover, R = density of Rhinoceros Auklet burrow entrances, ALT = altitude, BG = % bare ground, SB = % salmonberry cover, F = % fern cover, and BGS = bare ground and saxifrage cover.

Location	Regression equations	Coefficient of determination	Degrees of freedom (residual)
South slope	$D = 37.67 - 0.92\ SLO + 0.24\ GRA - 0.58\ R + 0.13\ ALT$ ($F = 35.9$) ($F = 17.8$) ($F = 11.1$) ($F = 4.1$)	$R^2 = 0.745$ ($F = 24.1$)	33
Southwest slope	$D = 16.97 + 0.75\ BG + 0.28\ ALT$ ($F = 13.7$) ($F = 8.6$)	$R^2 = 0.463$ ($F = 12.5$)	29
Plateau edge	$D = 28.84 + 0.38\ GRA - 0.18\ SB + 0.09\ ALT$ ($F = 9.8$) ($F = 4.0$) ($F = 2.0$)*	$R^2 = 0.473$ ($F = 13.4$)	45
Central plateau	$D = 31.84 - 0.26\ SB + 1.15\ BG$ ($F = 20.8$) ($F = 4.1$)	$R^2 = 0.511$ ($F = 24.0$)	36
Open summit	$D = 68.32 - 0.64\ SB - 0.72\ F + 0.32\ BGS$ ($F = 25.4$) ($F = 8.3$) ($F = 4.9$)	$R^2 = 0.875$ ($F = 25.6$)	11

* Not significant, but included as the SB variable is significant in the presence of the ALT variable.

and altitude (Table 1). Cassin's Auklets appeared to prefer open habitat there as at the eastern part of the south slope. Therefore the significant coefficient for altitude for the southwest slope may be related to the predominance of bare areas that occurred at higher altitudes. Although salmonberry was a major vegetation type, it had no significant inhibiting effect, perhaps because it was less dense and was short compared to elsewhere on the island.

At the plateau edge, tufted hairgrass and salmonberry were significant (Table 1). Salmonberry was tall and dense at the edge, hence the preference of the Cassin's Auklets to nest away from the salmonberry.

At the central plateau, salmonberry and bare ground were significant (Table 1). Salmonberry was most dense and tall and the highly significant negative correlation with salmonberry indicates avoidance of it by Cassin's Auklets. No burrow entrances were observed in quadrats completely covered with dense salmonberry. Neither were there any burrows on a trail cut through the salmonberry in 1975. However, in 1976 and 1977, fresh Cassin's Auklet burrows were common on the trail.

The burrow density of Cassin's Auklets on the partly open summit was also regressed on major vegetation types, amount of bare ground, altitude, and slope angle. As saxifrage, a short herbaceous plant, was sparsely distributed in bare areas it was combined with bare ground under one variable, BGS. Cassin's Auklets preferred bare ground and saxifrage away from dense salmonberry and ferns (Table 1). Cassin's Auklets therefore preferred nesting in open and short vegetation on all slopes and at all elevations of the island.

The slope substrate of Triangle Island is high in rock content, much more so than the less steeply undulating top of the island. The 25-cm top layer composition for 16 slope substrate samples averaged 44% rock, 33% soil, and 23% vegetation, while that of 10 plateau samples contained 3% rock, 60% soil, and 37% vegetation. Most of the rock material in the substrate consisted of pieces less than 3 cm long. The

substrate generally did not appear to be a limiting factor to nesting as some of the highest Cassin's Auklet breeding densities were found in the soil containing most rock. No correlation was observed between the dominant vegetation types and their substrates. Therefore correlations observed between breeding densities of Cassin's Auklets and vegetation did not appear to be affected by their substrates.

Interaction and nesting differences between burrowing alcids.—Cassin's Auklet burrow entrances occurred in the same quadrats with those of Rhinoceros Auklets and Tufted Puffins on the eastern portion of the south slope and on the southwest peninsula. Cassin's Auklets, however, generally avoided high breeding densities of Rhinoceros Auklets. There were not sufficient quadrats on the southwest peninsula to determine whether there was a correlation between puffins and Cassin's Auklets, but Cassin's Auklet breeding densities there were among the lowest on the island. Cassin's Auklets burrows were commonly observed to be cut off by those of puffins and Rhinoceros Auklets. Perhaps Cassin's Auklets became displaced from the dense nesting areas of puffins and Rhinoceros Auklets by the extensive burrowing activities of those two species.

Cassin's Auklets were the most diversified nesters of the three burrowing alcids on Triangle Island. Rhinoceros Auklets nested in various types of vegetation on the eastern portion of the south slope and on the northeast slope, while the two main breeding concentrations of Tufted Puffins were located mainly in tufted hairgrass on steep slopes and cliff tops on the southwest peninsula and the east slope. Small groups of puffins also nested dispersed in tufted hairgrass on other slopes. The nesting pattern of Tufted Puffins suggested that they preferred steep slopes or cliff tops free of tall vegetation for flight departure from their burrows. Rhinoceros Auklets nested on gradual slopes and were not chiefly restricted to tufted hairgrass as were puffins. The Cassin's Auklet was the only species to nest on relatively flat areas in the island interior. Their initial flight when taking off was in a more horizontal plane than that of puffins and Rhinoceros Auklets, which dropped considerably in their initial flight along the nesting slopes. Cassin's Auklets have significantly lower wing-loading ($P < 0.01$) than Rhinoceros Auklets and Tufted Puffins (0.94 g/cm^2 vs. 1.46 and 1.49 g/cm^2, respectively). Lower wing-loading facilitates horizontal takeoff. The ability of the Cassin's Auklet to nest in relatively flat areas may be a consequence of its lower wing-loading.

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