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LASKEEK BAY RESEARCH

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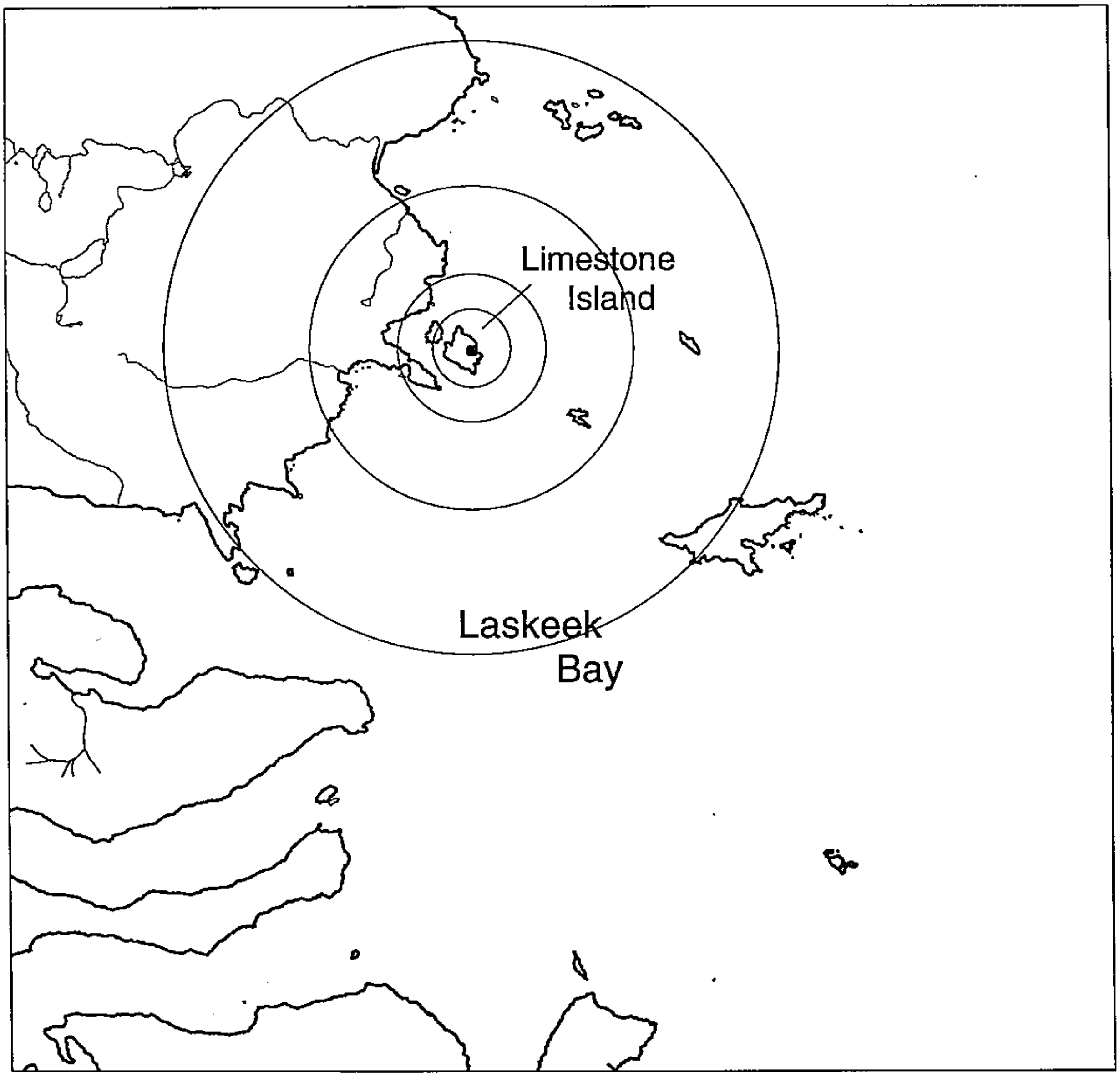
LASKEEK BAY CONSERVATION SOCIETY
ANNUAL SCIENTIFIC REPORT, 1996



October 1997

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7

LASKEEK BAY CONSERVATION SOCIETY
ANNUAL SCIENTIFIC REPORT, 1996

Edited by

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October 1997

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Suggested citation: Gaston, A.J. 1997. Laskeek Bay Research 7. Laskeek Bay Conservation Society, Queen Charlotte City, B.C.

LASKEEK BAY CONSERVATION SOCIETY

The Laskeek Bay Conservation Society is a volunteer group based in the Queen Charlotte Islands. The society is committed to increasing the appreciation and understanding of the natural environment through:

sensitive biological research that is not harmful to wildlife or its natural habitat

interpretation and educational opportunities for residents of and visitors to the Queen Charlotte Islands

Since 1990, the Society has operated a field research station at East Limestone Island and is carrying out a diverse long-term monitoring, research and interpretation programme in the surrounding islands and waters of Laskeek Bay. We actively involve volunteers from our island communities, many other locations in British Columbia, as well as from overseas. For further information contact:

Laskeek Bay Conservation Society
Box 867, Queen Charlotte City, British Columbia, Canada V0T 1S0
Phone/fax (250) 559-2345; E-mail <laskeek@island.net>

BACKGROUND

The goals and objectives of the Society are:

1. *To undertake and support research and long term monitoring of wildlife populations, including nesting seabirds and other marine birds, forest birds, marine mammals and introduced species of the Laskeek Bay area (roughly coastal waters of Hecate Strait from Cumshewa Inlet to Lyell Island) of Haida Gwaii, the Queen Charlotte islands.*

2. *To provide information on all aspects of the biology of the Laskeek Bay area for residents of Haida Gwaii, the Queen Charlotte islands, and visitors to the area.*

3. *To encourage students and residents of the area to participate in field programs and to undertake and assist in presentations and other activities that promote better understanding and improved conservation of marine birds and forested and marine ecosystems throughout Haida Gwaii, the Queen Charlotte Islands.*

INTRODUCTION

The Laskeek Bay Conservation Society organizes a volunteer programme each summer to carry out biological monitoring and research, to provide interpretation for visitors, and learning opportunities for students and volunteers. During the past seven years, a camp at East Limestone Island has been operated during the spring and early summer. In 1996 it was run from mid-March to mid-July.

The scientific work of the Society is carried out in collaboration with several researchers who have ongoing interests in the ecology of Haida Gwaii, especially the islands of the Laskeek Bay area. The research programme is directed by a Scientific Advisory Committee that works closely with the Society's board of directors to develop research that is relevant to the conservation needs of Haida Gwaii and consistent with the goals of the Society. Beginning with a programme of marine bird monitoring (an extension to a programme that was initiated by the Canadian Wildlife Service in 1984) the research activities have now been expanded to include marine mammals, intertidal invertebrates, plants, forest birds, and issues relating to the impact of introduced mammals, including the impacts of deer, raccoons and squirrels on island ecosystems. The aim of the work is to provide long term information on the biology and ecology of Laskeek Bay ecosystems. Ongoing monitoring, using simple standardized techniques that allow year-to-year comparisons to be made, and allowing the direct participation of volunteers, is the cornerstone of the Society's activities. By monitoring a variety of indicator species in ocean, intertidal and terrestrial ecosystems, we can obtain an overall measure of their health. Because marine waters may be subject to cyclical or directional changes operating at the scale of decades, such observations become most valuable when they are tracked consistently over many years.

About the 1996 report

The preparation of this report has fallen behind schedule, so that the 1997 field season has already come and gone. Consequently, this report deals only with three major topics: preliminary work on the impact of deer on vegetation among the Laskeek Bay islands (Daufresne and Martin), monitoring of seabirds at George Island (Lemon), and the mass at departure of Ancient Murrelet chicks hatched on East Limestone island (Gaston). Summary information on standard monitoring carried out in 1996 will be incorporated in the 1997 report, which should be published before the start of the 1998 field season.

ACKNOWLEDGEMENTS

The Laskeek Bay Conservation Society is a non-profit volunteer-run organization, and could not operate without the generous support from a wide variety of groups and individuals. We gratefully acknowledge the contributions of all our supporters and apologize to any we may have inadvertently omitted from this list:

The **National Wildlife Research Centre** of the **Canadian Wildlife Service**, for financial support and equipment loans;

The **Canadian Wildlife Service, Pacific and Yukon Region**, and especially **Gary Kaiser**, for equipment loans;

The **Ministry of Environment, Lands, and Parks, Wildlife Branch**, for permission to conduct our programs in the Skedans, Limestone, and Reef Islands Wildlife Management Area;

W. Alton Jones Foundation for generous financial assistance towards our administration and educational programmes;

The **Gwaii Trust** for supporting "Project Limestone", our programme for students of Haida Gwaii schools.

The **Gwaii Haanas Archipelago Management Board** for permission to conduct surveys in the southern Laskeek Bay area;

Marvin Boyd, Dan Pick and **Mark Batten** of **South Moresby Air Charters**, for safe and efficient weekly transport of volunteers, gear, and groceries;

Rick Nickerson on Clipper II and Western Flyer for bringing in and taking out the East Limestone Island camp;

Terry Husband on Kingii for bringing gasoline when we reached the bottom of the barrel ;

Nathalie Macfarlane and the **Queen Charlotte Islands Museum Society**, for continuing to provide us with meeting space and storage space for all our gear;

All of the in-town support people who bought groceries, met volunteers, and picked up the garbage;

The many people who gave donations or bought LBCS t-shirts at Limestone Island;

And finally an enormous appreciation of each volunteer who came to East Limestone Island to discover and to help. We hope to see you again!

SCIENCE ADVISORY COMMITTEE, 1996

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CHANGES IN VEGETATION STRUCTURE AND DIVERSITY IN RELATION TO THE PRESENCE OF A LARGE HERBIVORE: THE IMPACT OF INTRODUCED BLACK-TAILED DEER ON OLD-GROWTH FORESTS IN HAIDA GWAII (QUEEN CHARLOTTE ISLANDS)

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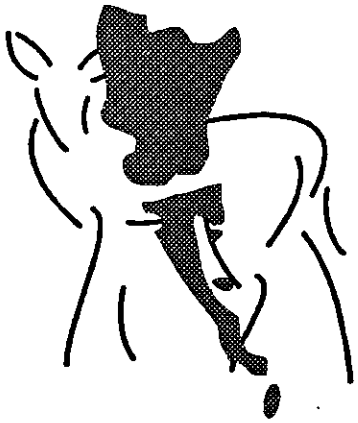


ABSTRACT

We studied the understory vegetation of five islands in the Haida Gwaii archipelago, of which two were inhabited by Black-tailed Deer (*Odocoileus hemionus sitkensis*), and three were without large herbivores. Comparison of islands with and without deer enabled us to describe the impact of deer browsing on the understory vegetation. We concluded that browsing resulted in:

- a decrease in understory vegetation;
- a reduction in the diversity of plant communities in the understory;
- a reduction in the species diversity of the understory;
- a replacement of the original understory species by saplings of the dominant canopy trees.

A census of deer on the occupied islands estimated a density of 33 deer/km^2. A brief analysis of deer diets suggested that the deer feed principally on the foliage of tree saplings.

Introduction

Deer are relics of the once abundant fauna of large mammals that have survived recent man-made changes in the Northern Hemisphere. They exist today mostly in the context of agricultural and managed forest landscapes and they are important elements in the ecology of these recent ecosystems. At present, as forests are being replanted in Europe and utilized with increasing intensity in North America, and as deer populations increase on both continents, it seems increasingly important to understand the role of deer in vegetation dynamics. This explains the numerous studies that have been ongoing for many years in Europe and North America.

Rich in endemics, the flora and fauna of Haida Gwaii has undergone great changes since the arrival of Europeans at the end of the 18th century: especially the destruction of primary forest by commercial logging (Hall 1937) and the introduction of non-indigenous plants (Taylor 1989) and animals (McTaggart-Cowan 1989, Martin et al. 1994, Martin 1995). The archipelago is an ideal area in which to study the relationship between deer and forests. This group of forested islands, offshore of the Pacific coast of Canada, despite extensive clearcutting, retains substantial areas of old-growth forest. Free of large forest herbivores when first visited by Europeans, the islands' forests have been rapidly colonized by Black-tailed Deer which were introduced in the early 20th century. Their increase, and impact on the native vegetation, was noted in the early 1980s (Pojar et al. 1980, Pojar and Banner 1984, Coates et al. 1985), and probably has no parallel in the Northern Hemisphere.

This work is designed as a contribution to understanding the dynamics of interactions between deer and forests. It is a preliminary study and part of a larger, co-operative Franco-Canadian project. We chose to examine only a small part of the archipelago to develop provisional answers to the following questions:

- what is the impact of deer browsing on the species diversity of the forest understory?
- how do deer modify the dynamics of understory vegetation, especially the age structure of shrubs?
- in what way do deer exploit the understory?
- what is the density of deer on the study islands?

The study provides material towards a general model of deer-vegetation dynamics in Haida Gwaii. In addition, it contributes evidence on the general role of large ungulates in the process of forest regeneration and the biodiversity of North American forests.

Material and methods

I. Black-tailed Deer

The genus *Odocoileus*, to which the Black-tailed or Mule Deer (*O. hemionus*) belongs comprises two species in North America, the other being the White-tailed Deer (*O. virginianus*). The range of the Black-tailed Deer covers all of western North America, from northern Mexico to southern Alaska. The great variety of habitats within this range accounts for the variability of the species, for which 11 races have been described. Races in the eastern portion of the range are generally known as Mule Deer, while those on the Pacific coastal fringe are known as Black-tailed Deer: both names refer to the same species. The subspecies of interest in this case (*O. h. sitkensis*, Merriam) occupies the Pacific coast of northern British Columbia and southern Alaska. It is adapted to rainforest, being essentially a browser (McTaggart-Cowan 1956). In 1910, about 20 deer from Porcher island, SE Alaska, were introduced to Graham Island (Dalzell 1968). Adept at swimming, the species rapidly colonized all but the most isolated islands.

II. Study area

To study the impact of deer on understory vegetation in Haida Gwaii requires comparison among areas affected to a greater and lesser extent by deer. Two approaches are possible:

- compare the understory vegetation, at the scale of the entire archipelago with that of adjacent mainland areas where pressure from deer browsing is less (e.g. Pojar et al. 1980, Pojar and Banner 1984).
- compare understory vegetation within Haida Gwaii on islands with and without deer. Because only small, isolated islands are without deer at present, this necessitates research on a relatively local scale.

We chose the latter option by selecting a group of islands close to one another, forming part of the same biogeographic zone, and supporting a similar type of forest, some of which supported deer while others did not.

The area selected, Laskeek Bay, is on the eastern side of the archipelago. We concentrated on 5 islands, all within 10 km of one another:

- Reef Island (249 ha, deer present)
- East Limestone Island (48 ha, deer present)
- Lost, Low and South Low islands, all less than 10 ha and without resident deer.

III. Description of vegetation

1. Sampling methods

We adopted the classification proposed by Aldous and used in diet studies of Roe Deer (*Capreolus capreolus*) by the Office National de la Chasse (Carnac 1978). We used study plots of 40 m2 (circles of radius 3.6 m). On the two large islands (Reef, East Limestone) they were spaced at 150 m intervals along pre-existing transects established for studies of birds and squirrels (Martin 1995) and passing through representative areas of different vegetation types.

We used 117 plots on Reef Island, representing approximately 0.2% of total island area, and 33 plots on East Limestone Island, approximately 0.25% of area. For the remaining islands without deer, we distributed vegetation plots randomly, using a total of 16 plots for the three islands combined, representing approximately 0.2% of area. We believe that these samples adequately reflect the vegetation of the study islands. All observations were made in May 1996.

In all study plots the vegetation was divided into 3 strata (Figure 1):

- ground layer, less than 1.5 m high (1.5 m is the browse limit for Black-tailed Deer);
- shrub layer, >1.5 m, <8 m;
- canopy layer, >8 m.
- The ground and shrub layers together constitute the understory, a term used extensively below. Study plots on Reef and East Limestone islands were combined to create a sample of 151 plots representing "deer affected islands" (DAI), while the other three islands combined created a sample of 16 plots representing "deer-free islands" (DFI).

2. Measurements taken

Proportion of cover

The proportion of cover provided by each plant species (% plot surface covered) was estimated for each of the three vegetation layers defined above.

Degree of stress on the woody vegetation (DAI)

For each woody species in the ground layer we measured the degree of browsing impact. For the two other layers, the degree of impact was measured only for vegetation accessible to deer. Browsing impact was measured as the proportion (%) of shoots showing evidence of browsing (twigs bitten, dwarfed shoots, etc.). This measure of browse impact integrates the effects of browsing over the entire period of the plant's growth.

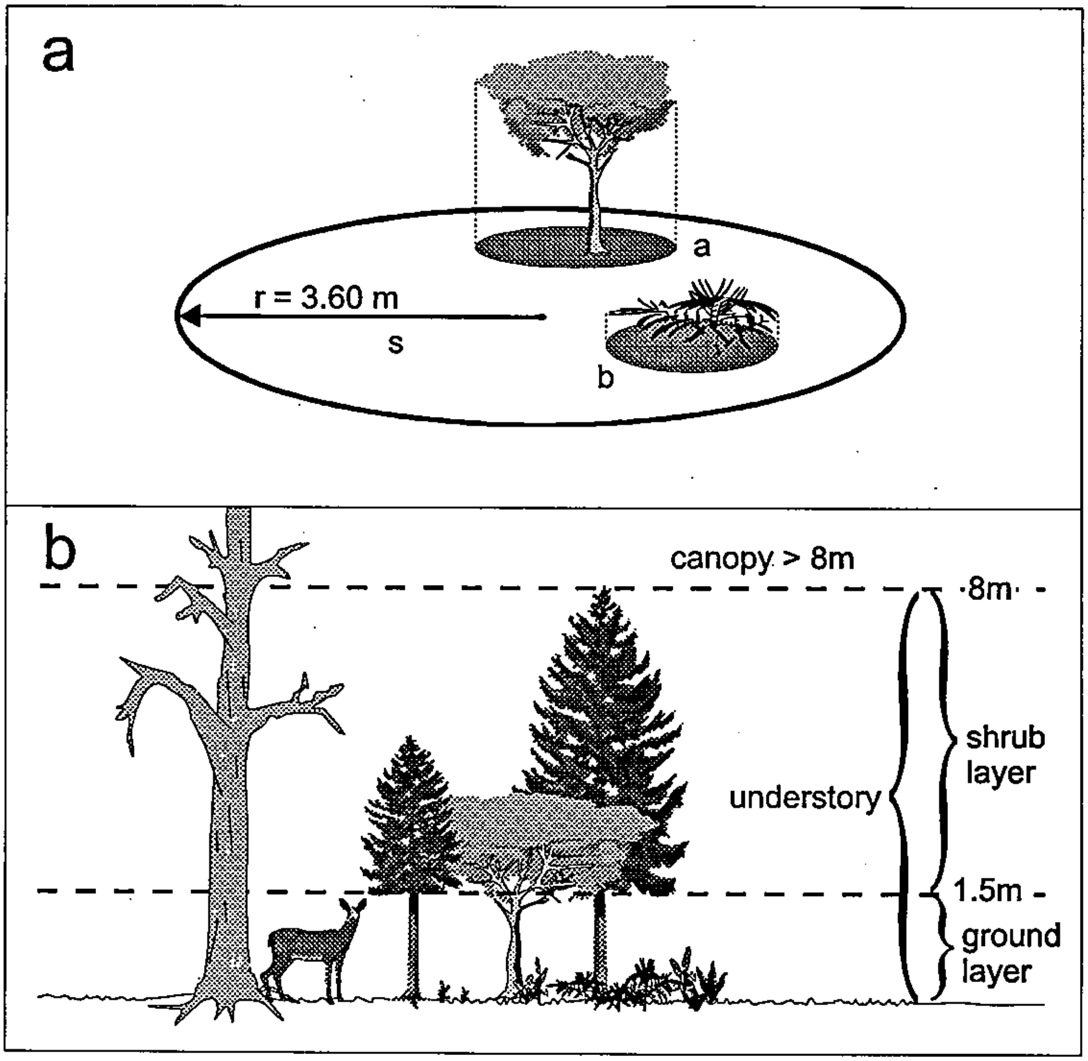


Figure 1. Definition of vegetation layers: (a) circular plots, showing the way in which cover values were estimated for ground and shrub layers; shaded areas a and b represent the projection on the ground surface of all vegetation in the layer concerned; (b) the three vegetation layers; 1.5 m is used as the upper boundary of the ground layer as this represents the upper limit of deer browsing on flat ground.

Species composition of the understory (DAI, DFI)

The frequency of a species was estimated as the occurrence as a proportion (%) of the total plots examined. Median cover proportions were calculated for understory species, but only species having 0.5% or greater cover in a minimum of 2 plots per treatment (DAI, DFI) were analysed.

Species diversity of the understory

The total number of species present was calculated for each plot and median calculated separately for DAI and DFI. The number of woody species (saplings and shrubs) in the ground and shrub layers was also calculated for each plot and medians calculated for each layer, as indicators of species diversity in the two layers.

Diversity of the understory and spatial structure

We estimated an index of understory density for each plot by summing the ground cover estimates for all species in the ground and shrub layers. Median were calculated separately for DAI and DFI. We also examined the distribution of this variable by calculating κ^2, the sample variance/median. If $\kappa^2 > 1$ the distribution is clumped; if $\kappa^2 < 1$ the distribution is over-dispersed. Where $\kappa^2 = 1$, the distribution is random.

3. Generality of observations

Principal components analysis (PCA) was carried out for plots on islands with and without deer, using all understory variables (proportion of cover for each species in ground and shrub layers). The interpretation of these analyses allowed us to identify the major differences between understory vegetation on islands with and without deer.

Our choice of study sites precluded the separation of deer effects from those of island size, because all islands without deer were much smaller than those with deer. Before assuming that differences between DAI and DFI were caused by browsing and not by island size, we carried out a PCA of the same type on islands of uniform size, using data collected previously by J-LM (cf. Martin et al. 1995). The results of these two analyses are compared.

IV. Studies of deer

1. Diet preference of deer

Pellet counts - The method of counting deer pellets to obtain information on herbivore density and distribution has been used for a long time and such studies have been numerous in North America (Bennet et al. 1940, Rogers et al. 1958, Smith 1964), both on a large scale (Neff 1968) and on a local scale, assuming that the distribution of pellets reflects the intensity with which an individual uses different parts of its home range (Pellerin 1977). We have assumed that, on our study islands, the deer have no natural predators, and hence their distribution is determined chiefly by their choice of areas in which to forage.

For each vegetation plot, we counted the number of deer defecations (groups of pellets), making separate counts of fresh and old defecations. These data were analysed separately and combined (fresh + old = total defecations). We analysed the relationship between defecation density and vegetation characteristics using linear correlation (Pearson coefficient).

Direct observations - We observed the behaviour of deer while feeding and timed the duration of feeding on different understory species. These observations were greatly facilitated by the lack of fear of humans exhibited by the deer.

2. Estimation of deer densities

Estimation by line transects - Line transects have been used frequently to estimate deer populations and densities: they can be carried out by a single observer with little preparation. In addition, the recent use of this method for censusing Barking Deer (*Muntiacus muntjak*) by the CNRS (Gaillard et al. 1992) in conditions similar to those in Haida Gwaii (small deer, forest habitat, high density of animals) encouraged us to select this method.

In line transects the observer walks a fixed route of pre-defined length (L), watching on either side for animals (Figure 2). When a deer is seen, three measures are recorded:

- distance from observer to animal (r);
- perpendicular distance from animal to line of transect (x);
- angle between transect line and direction of animal (t).

As the three measures are related ($x = r.\sin(t)$), the estimation of r and t allows us to check estimates of x, the statistic of interest, which provides an estimate of the distribution of sightings in relation to distance from the transect, and hence the effective transect width. Another method by which we can measure effective transect width is to measure the distance at which an object resembling a deer disappears from view when moved away from the observer on the transect line. This provides an estimate of transect width independent of sightings of deer (Cumming 1975).

Estimation by total count - The relatively small area of East Limestone Island (48 ha) allowed us to attempt a population census by counting all the deer present. On 31 May a total count was made using a line of 10 observers, of whom 1/3 were equipped with walkie-talkies, plus one "sweeper" and one person in a boat close to shore, also equipped with a radio.

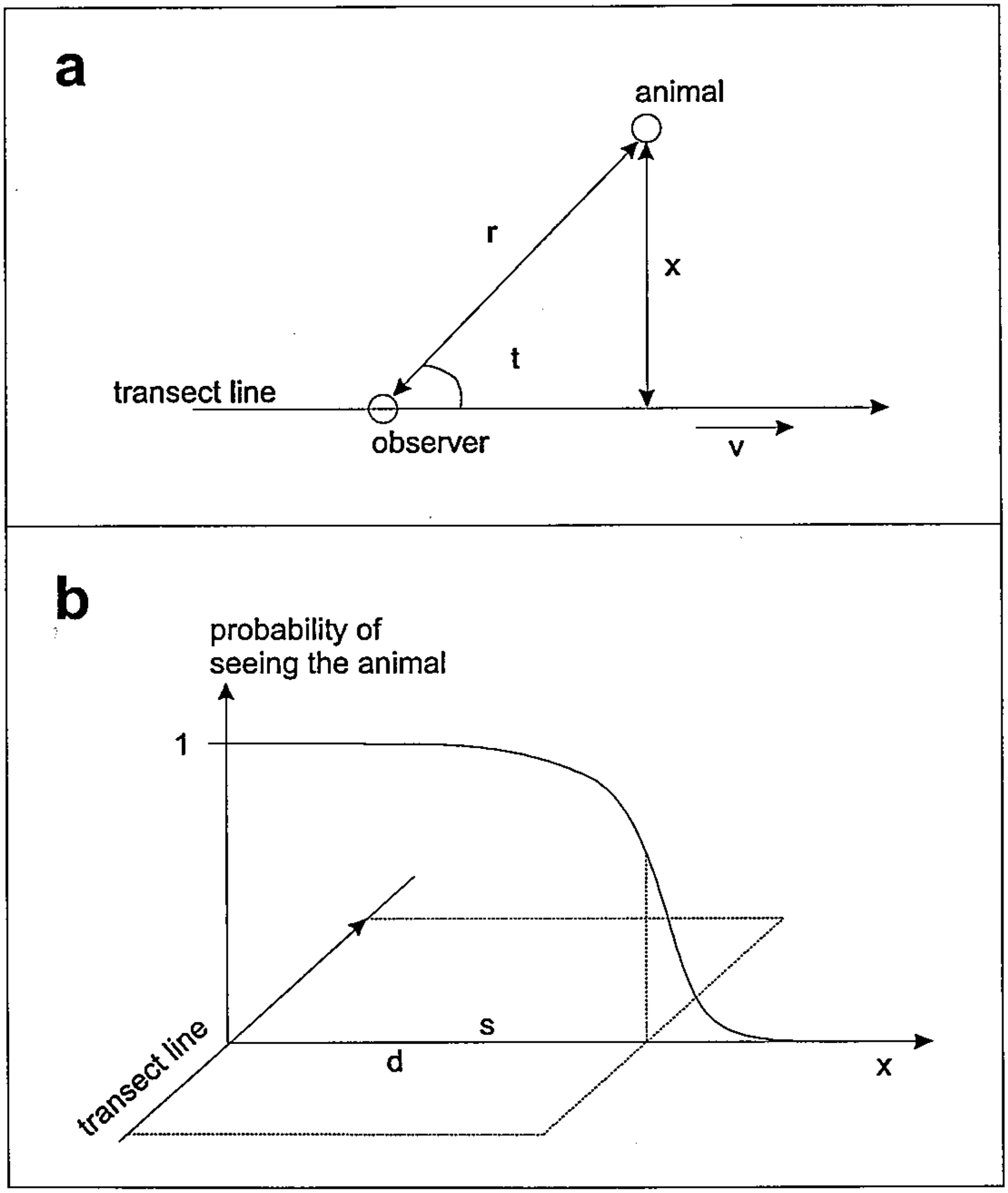


Figure 2. Line transects: (a) the observer walks in direction v, r is the distance from the observer to the animal when seen, and x is the distance from the animal to the transect line; t is the angle between the transect line and the direction of the animal from the observer. (b) The probability of seeing an animal in relation to its distance from the transect line: on the line itself the probability is 1 and it decreases the further the animal is from the nearest transect route. The effective area covered by the observer is the product of the transect length and the 'disappearance distance' (d).

Results

I. Vegetation

1. Impact of deer on the understory

The results of the principal components analysis (PCA) showed that the first two principal components explained 26.7% of the variance (PC1, 14.6%; PC2, 12.1%, Fig. 3A). Further principal components yielded no additional explanatory power. The PCA provides evidence of segregation between vegetation on islands with and without deer which we enlarge on below. The contribution of different plant species to segregation along PCs 1 and 2 is illustrated..

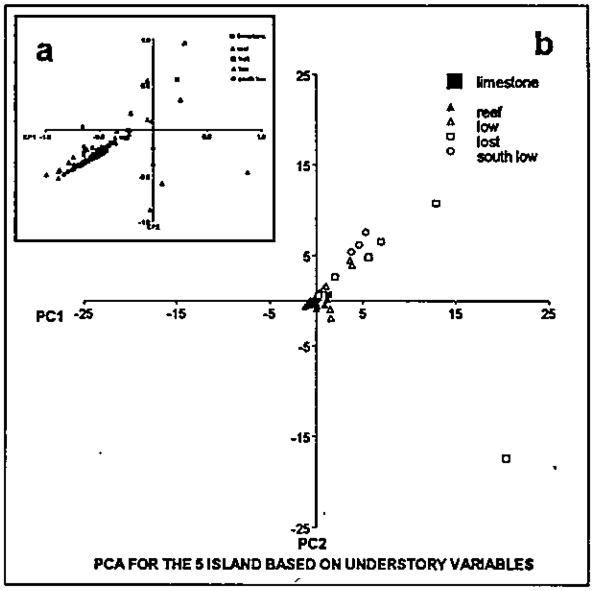
Species of groups 1,2 and 4 make large positive contributions to both PCs. They are made up mainly of shrubs in a gradient running from Red Elder (*Sambucus racemosa*) to Snowberry (*Symphoricarpos albus*). Associated with these were certain ferns (*Polypodium glycyrrhiza*, *Polystichum munitum*) and False Lily-of-the-valley (*Maianthemum dilatatum*).

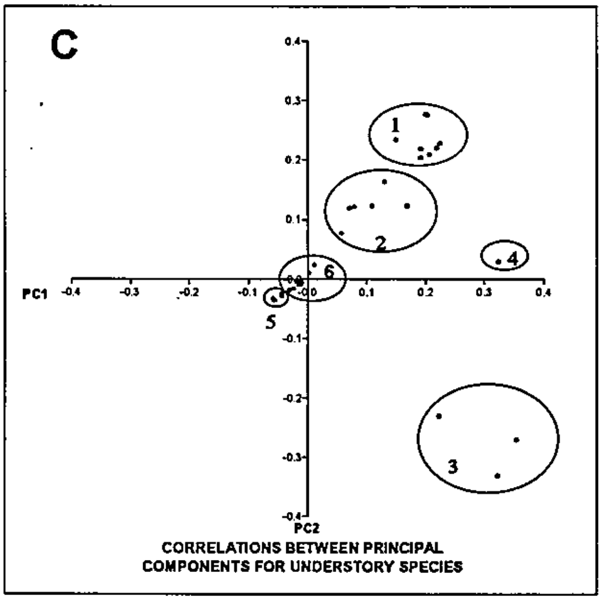
Group 3 contributes positively to PC 1 and negatively to PC2. It comprises species that grow especially in open canopy stands and blow-downs. It includes Salal (*Gaultheria shallon*) in the shrub layer and Bracken (*Pteridium aquilinum*) and vetch (*Vicia* sp.) in the ground layer. Group 5 contributes slightly negatively to both axes and comprises saplings of the main canopy tree, Western Hemlock (*Tsuga hetrophylla*) and Sitka Spruce (*Picea sitkensis*), grasses and Wood Fern (*Dryopteris expansa*).

Species in group 6 make little contribution to either axis. They include several ferns (*Athyrium felix-femina, Asplenium viride* and *Adiantum pedatum*), saplings of less-common trees (Red Cedar *Thuja plicata*, Alders *Alnus* spp.), sedges and two shrubs (*Amelanchier alnifolia, Mensiezia ferruginea*).

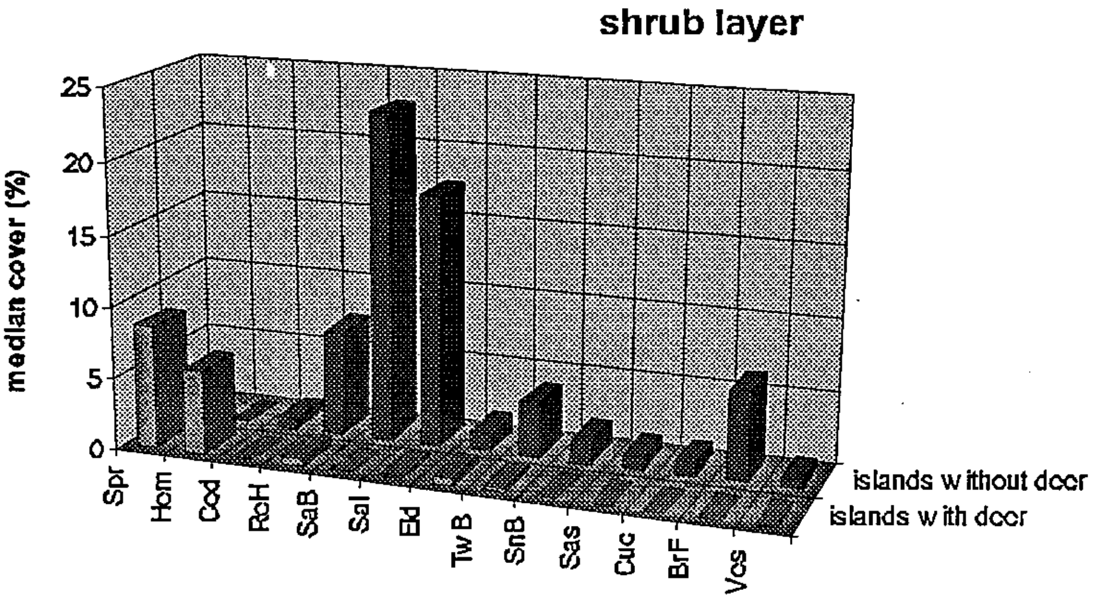
On the basis of this analysis, we propose the following interpretation:

PC1 represents a gradient of composition and species richness from a low diversity and an abundance of canopy tree saplings towards a greater diversity and a stronger representation of understory shrubs. PC2 represents a gradient in structure of the understory, the most important effect being change in the cover of the shrub layer, possibly in combination with other variables that our data do not permit us to detect. The analysis based on data from Martin et al. (1995) gives a similar segregation.





Figures 3a and 3b. Results of the Principle Components Analysis carried out on understory variables for the five islands examined: each point represents one sample plot. Above, islands with deer (East Limestone, Reef) are shown by black symbols, those without (Lost, Low and South Low), white. The smaller graph (a) is an enlargement of the central portion of the larger graph. Figure 3c shows the correlation between PC1 and PC2 for each understory species. The circles (grouped by eye) define groups as follows: **1, 2 and 4**, *Ribes* sp., *Sambucus racemosa, Vaccinium parvifolium, Rubus spectabilis, Gaultheria shallon* in ground layer, *Symphoricarpos albus, Lonicera involucrata, Polypodium glycyrrhiza, Polysticum munitum, Maianthemum dilatatum*; **3**, *Gaultheria shallon* in shrub layer, *Pteridium aquilinum, Vicia* sp.; **5**, *Tsuga heterophylla, Picea sitkensis, Poa* sp., *Dryopteris expansa*; **6**, *Athyrium felix-femina, Asplenium viride, Adiantum pedatum, Thuja plicata, Alnus* sp., *Carex* sp., *Amelanchier alnifolia, Menziesia ferruginea.*



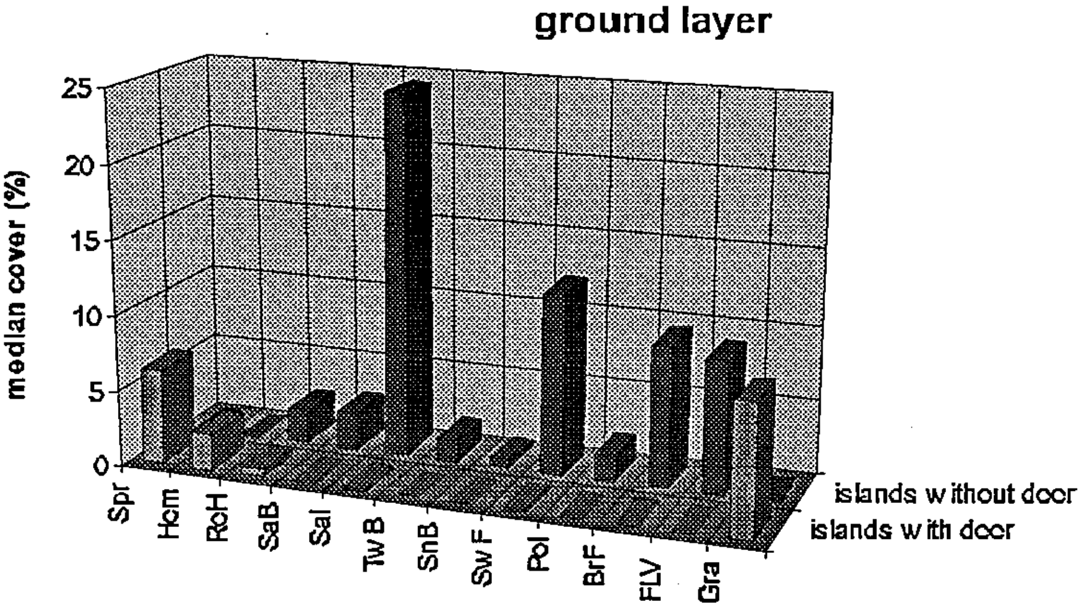


Figure 4. Median cover values for understory plants (ground and shrub layers) on islands with and without deer. Only species with median cover >0.5% are shown: BrF = Bracken, Cuc = currant, Eld = Elder, FLV = False Lily-of-the-valley, Gra = grass, Hem = Hemlock, Pol = Liquorice Fern, ReH = Red Huckleberry, SaB = Salmonberry, Sal = Salal, Sas = Saskatoon, SnB = Snowberry, Spr = Spruce, SwF = Sword Fern, TwB = Twinberry, Ves = Vetch.

2. Measures of deer impact

Species richness of the understory - Figure 4 ranks the frequency of understory species on islands with and without deer. Fifteen species were recorded on DFI and 16 species on DAI. The difference in total numbers is attributable to the much larger sample size on DAI (149 vs 16 plots).

Proportion of cover for different understory species - Maximum cover on DAI was provided by saplings of Sitka Spruce and Western Hemlock, whereas on DFI the greatest cover was provided by Sword Fern (*Polysticum munitum*) and Red Huckleberry (*Vaccinium parvifolium*) (Figure 5).

Intensity of browsing - On DAI, all plants of Red Elder, Twinberry (Lonicera involucrata) and Salmonberry (Rubus spectabilis) showed signs of browsing, and more than half of all Red Huckleberry, and Salal bushes, and Western Cedar and Spruce saplings (Table 1).

Table 1. The average proportion of shoots showing signs of browsing for individual shrubs in the understory vegetation. Figures for Elder, Twinberry, Western Red Cedar and False Azalea need to be treated with caution, because none of these species was recorded in more than five plots.

Species	Proportion showing signs (%)
Elder	100
Twinberry	100
Salmonberry	100
Red Huckleberry	89
Salal	83
Western Red Cedar	75
Sitka Spruce	61
Western Hemlock	44
False Azalea	42

Species diversity of the understory - The mean number of species observed per plot on DAIs was 2.4 ± 2.1 and on DFIs was 5.0 ± 2.5, the difference being significant ($P < 0.01$). When we compared the diversity of woody species in the shrub layer and ground layer separately, the DAI had a mean of 0.81 + 0.56 woody species per plot in the shrub layer, while DFIs had 2.56 + 1.25 species. Similarly, in the ground layer, DAIs had 1.44 + 1.69 species/plot, whereas DFIs had 2.06 + 2.31 species/plot. Islands without deer had similar species diversity in both ground and shrub layers, whereas islands with deer had a significantly lower diversity in the shrub layer than in the ground layer.

Density and distribution of the vegetation - The sum of all cover values for understory species was greater on DFIs than DAIs, with mean values of 128.5 (variance 506.2) and 36.9 (variance 462.2) respectively; a significant difference ($P < 0.01$). The fact that variances were much larger than means in both cases demonstrates that cover tended to be clumped, rather than randomly dispersed.

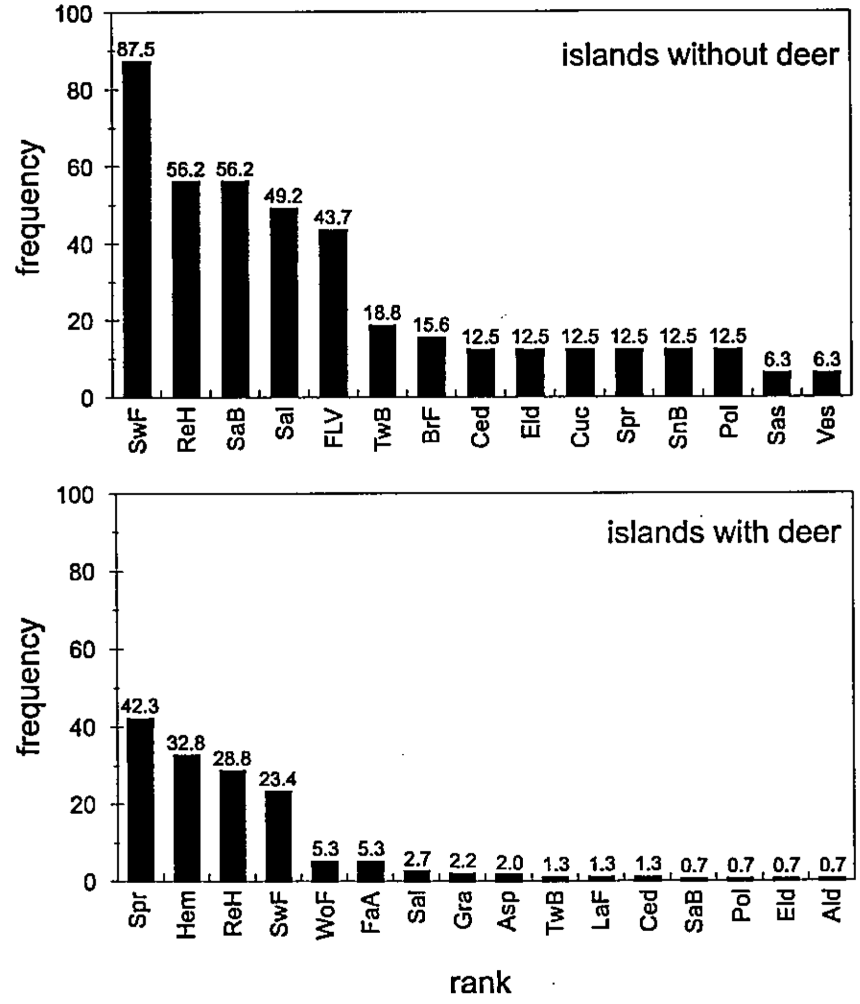


Figure 5. Rank frequency diagrams of understory species for islands with and without deer. Only species occurring at more than 0.5% of sites were included. Ald = Alder, Asp = Green Spleenwort, BrF = Bracken, Ced = Red Cedar, Cuc = currant, Eld = Elder, FaA = False Azalea, FLV = False Lily-of-the-valley, Gra = grass, Hem = Hemlock, LaF = Lady Fern, Pol = Liquorice Fern, ReH = Red Huckleberry, SaB = Salmonberry, Sal = Salal, Sas = Saskatoon, SnB = Snowberry, Spr = Spruce, SwF = Sword Fern, TwB = Twinberry, Ves = Vetch, WoF = Spiny Wood-Fern.

II. Studies of deer

1. Feeding behaviour

Density of defecations - We found significant correlations between total numbers of defecations and the proportion of spruce in the ground layer ($r = 0.25$, $n = 149$, $P < 0.01$), and between old defecations and the proportion of Salal in the shrub layer ($r = 0.38$, , $P < 0.001$). Deer appear to favour areas where Salal is dominant in the understory and where there is an abundance of regenerating spruce. A correlation between numbers of old and fresh defecations ($r = 0.32$, $P < 0.001$) suggested that the preference for such areas had persisted for some time. Numbers of old defecations were also correlated with the occurrence of browse damage to spruce ($r = 0.23$, $n = 76$, $P = 0.04$), hemlock ($r = 0.36$, $n = 52$, $P < 0.01$) and grasses ($r = 0.44$, $n = 48$, $P < 0.01$)

Direct observations - Six deer were observed feeding for a total of 109 min between 2 - 20 May. The proportion of time spent feeding on different plant species was as follows: spruce 50%, ground (herbs and ferns 30%, Red Huckleberry 10%, dried kelp and lichen fallen from trees 1% each.

2. Density of deer

Line transects - On Reef Island, 16 deer were observed on 38.5 km of transects. The effective transect width was estimated at 20 m, hence the area surveyed was 154 ha, giving a density of 0.104 deer/ha, or one deer for every 9.6 ha. On East Limestone Island, 3 deer were seen on 8.5 km of transects and the effective transect width was estimated at 16 m, giving a density of 0.107 deer/ha (1 deer to 9.6 ha)(Table 2). Unfortunately, the sample sizes obtained are probably inadequate for accurate estimation of the numbers of deer present (Burnham et al. 1980).

Total counts - We counted 16 deer during the survey of East Limestone Island, of which 7 were females, 8 males and 1 was a juvenile (sex ratio 47 : 53). As the island is 48 ha in area, this gives a minimum density of 33.3 deer/km^2, about 3 times that obtained by the line transect method. If we assume that the difference between the two methods would have been the same at Reef Island, this suggests a density there of 32.4 deer/km^2.

Table 2. Results of line transect surveys for deer

Measure	East Limestone I.	Reef I.
Females	3	8
Males	0	3
Sex ratio (f : m)	100 : 0	70 : 30
Juveniles	0	3
Indeterminate	0	2
Totals	3	16
Area surveyed (ha)	28	154
Density of deer (/km^2)	10.7	10.4

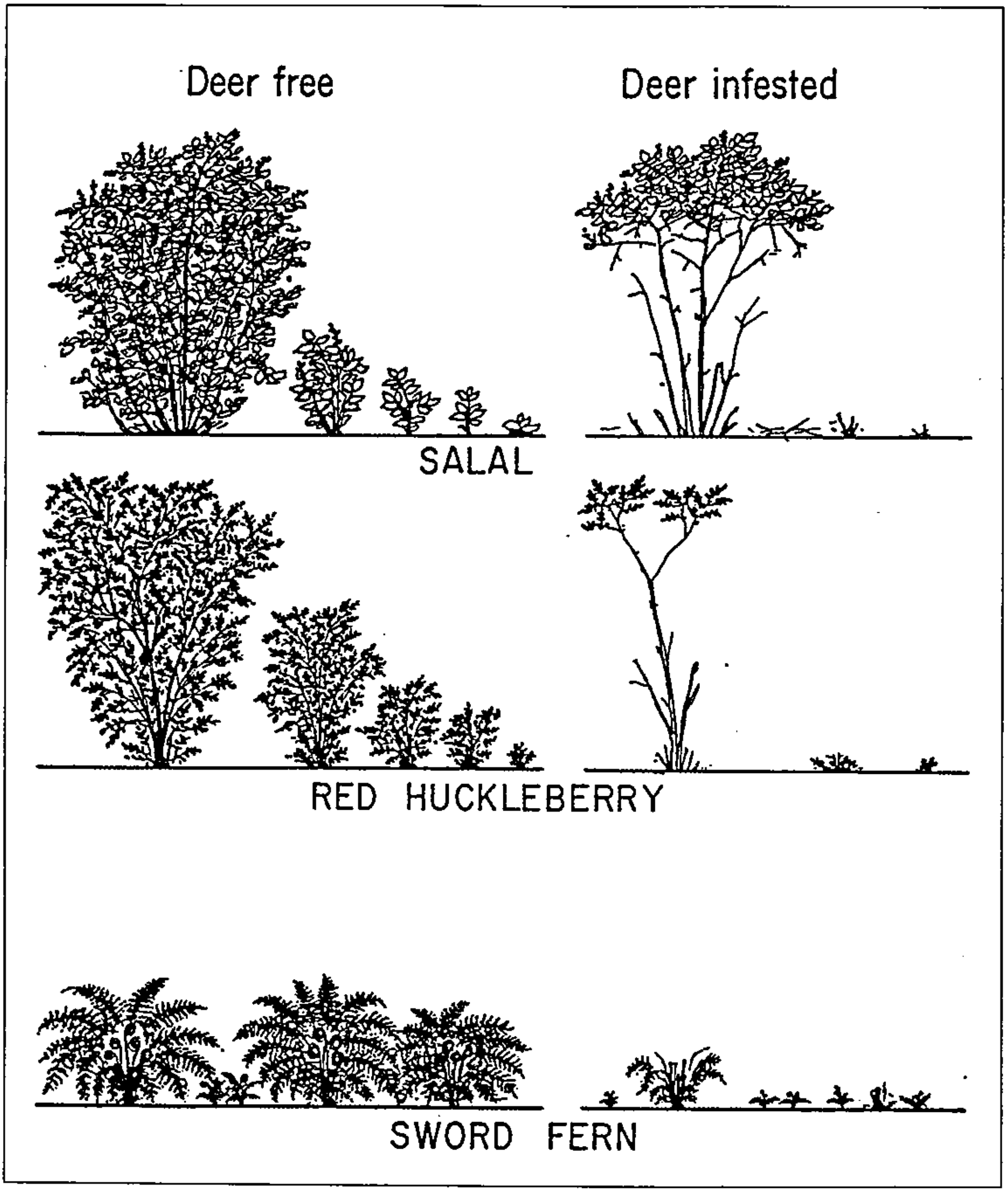


Figure 6. Schematic diagrams showing the growth forms of Salal, Red Huckleberry and Sword Fern observed on islands with and without deer.

Discussion

I. Vegetation

1. Evidence of deer impact and the general characteristics of affected vegetation

The principal components analysis allowed us to distinguish marked differences between the vegetation of islands with and without deer and these differences appear to be independent of island size. Such differences are probably the direct result of deer browsing and they can be summarised as follows:

On islands without deer, we notice a strong trend in Figure 3 with the majority of values positive along axis PC1. This demonstrates considerable variation in the understory, with a diversity of species and a substantial component of shrubs in the understory. In contrast, for islands with deer, most observations are clustered close to the origins of the axes, suggesting a homogenous and well-spaced understory, with a low species diversity, the understory being composed mainly of canopy tree saplings. Hence, deer have two major effects on the understory of islands that they colonize: a decrease in plant species diversity and decrease in structural diversity.

2. Quantification and interpretation of deer impact

Understory composition and diversity
The composition of the understory not affected by deer, as measured by us, is similar to that described for mainland areas by Pojar and Banner (1984), although because of our limited study area and the timing of our surveys, we did not find all the species reported by those authors. A full list of species recorded is given in Appendix 1. As on the mainland, we found the understory to be dominated by deciduous shrubs (*Vaccinium* and *Rubus* spp. and salal), with a strong presence of ferns (*Polystichum munitum*, *Pteridium aquilinum*). The diversity of different understory types found on our deer-free islands was also noted by Pojar and Banner (1984). Deer browsing seems to cause the disappearance of numerous species, while favouring the development of others. Among the species most affected are deciduous shrubs, Salal, ferns and broad-leaved herbs: we describe further the effects on species dominant in the understory of islands without deer.

Salmonberry (*Rubus spectabilis*), the dominant deciduous shrub in the understory of deer-free islands is almost entirely absent from those with deer. Those few individuals that are found on deer-affected islands are usually young plants situated close to mature specimens growing out of reach of deer (e.g. on stumps or cliffs). All show signs of heavy browsing. Pojar et al. (1980) considered this species to be among those most favoured by deer in Haida Gwaii.

Salal (*Gaultheria shallon*), a very robust shrub, is also very susceptible to browsing, as it goes from being dominant, in terms of cover, in unaffected understory, to almost disappearing on islands with deer. According to Pojar et al. (1980) it is less favoured by deer than deciduous shrubs, but it is an important source of deer browse during winter (Douglas et al. 1989-94). Where deer are absent, salal may form dense thickets, unmixed with other shrubs, and extremely difficult to penetrate. Where deer are present, salal occurs in clumps that are gradually eroded from the periphery by deer browsing, diminishing year by year. We believe that these clumps are the remnants of previously extensive thickets gradually broken up by the browsing of the deer.

Bracken (*Pteridium aquilinum*) is the commonest fern, apart from sword fern, on islands without deer. It is completely absent where deer are present. Although it occurs in the diet of Black-tailed Deer (Pierce 1981, in Hanley 1984) it does not seem to be especially favoured, because McTaggart-Cowan (1956) considered it only 12th in their diet preferences and Pojar et al. (1980) did not mention it.

False Lily-of-the-valley (*Maianthemum dilatatum*) is common in the ground layer where deer are absent but is never found where they are present. It is a less widespread species than those mentioned above and has received little mention from other authors dealing with deer and vegetation in Haida Gwaii. It is a regular component of the diet of Black-tailed Deer (Merriam 1965, 1967, Reynolds 1979).

Western Red Cedar (*Thuja plicata*) is a less common canopy tree than either spruce or hemlock and unlike those species does not appear to be favoured by the presence of deer. Saplings are almost completely absent from areas with deer. This finding confirms those of foresters who consider the future regeneration of this tree in Haida Gwaii to be threatened by the presence of deer.

A dramatic reduction in cover seems to affect most species eaten by deer, not just those most favoured. Where species continue to be represented in the understory of deer-affected islands, they tend to be either very young individuals, or older plants situated out of reach of deer. Few young plants reach an age of more than 1-2 years where growing within reach of deer. The persistence of species is dependent on the existence of refuges out of reach of deer, such as ledges on cliffs, or sites created by the forest itself: elevated stumps, the tops of overturned root systems, or even old eagle nests. Two species appear to contradict this generalization:

Red Huckleberry (*Vaccinium parvifolium*), although a deciduous shrub, manages to persist, albeit with much decreased foliage. It is considered the fourth most important shrub in the diet of Black-tailed Deer in British Columbia (McTaggart-Cowan 1956) and in Haida Gwaii (Pojar et al. 1980).

Klein (1965) also considered it heavily browsed by these deer. We found that the browsing pressure was similar to that sustained by other deciduous shrubs (Fig. 6) in the understory of deer-affected islands. Hence, the huckleberry appears to sustain just as much browsing pressure as other species, but appears better able to survive under these conditions. Plants found in the understory are of two types:

a) old bushes, comparable in size with those found on unaffected islands and tall enough that the highest shoots are out of reach of deer: these bushes fruit successfully (J-LM pers. obs.). All shoots at ground level are strongly browsed. We speculate that these bushes were already tall enough for their top shoots to be beyond the reach of deer at the time of the original colonization by deer. This idea could be tested by determining their age.
b) young shoots or older individuals that are heavily browsed: these rarely exceed 10 cm in height. It appears that huckleberry can sustain heavy browsing and still persist in a dwarfed form.

The present abundance of Red Huckleberry, compared to other shrubs, on islands with deer appears to depend on the existence of a small number of successfully reproducing adults and the ability of young plants to resist heavy browsing. Their persistence may diminish with time, given the absence of plants intermediate in age between the old "survivors" and the young dwarfs. There appears to be no way for the breeding stock to recruit new plants under the current regime.

Sword Fern (*Polystichum munitum*), the only fern to persist in the understory, although diminished in size and degree of cover. This persistence is noted by Pojar and Banner (1984) for the *Picea sitchensis-Tsuga heterophylla-Polystichum munitum* association, but without special comment. It is not classed by McTaggart-Cowan (1956) as an important component of Black-tailed deer diet. Klein (1965) considers it to be a low-quality food browsed only when food is sparse. On the other hand, Pojar et al. (1980) consider Sword Fern third in order of importance in deer diets in Haida Gwaii. It was clear from our observations that Sword Fern, although affected less than most plants, was nevertheless browsed heavily. As for Red Huckleberry, plants tend to be either old perennial rosettes, or very young plants. We could not tell whether recruitment to the adult population was taking place, and hence whether the current configuration is likely to be stable.

The diminution or disappearance of the majority of understory plants creates the lower species diversity observed on islands with deer. Our results agree with those of Klein (1965), who studied the impact of Black-tailed deer on two islands in Southeast Alaska. They also agree with Decalesta and Redding (in press), who studied White-tailed Deer in forested enclosures and found a threshold density of deer (3.7 deer/km^2) above which there is a decline in the diversity of shrubs.

Along with a decrease in the diversity of the understory, there is a change in the relative diversity of woody plants in the ground and shrub layers. Where deer are absent, the two layers tend to have similar diversity. However, where deer are present, the number of species in the shrub layer tends to be less than that in the ground layer, because many species never manage to reach maturity, being represented only by young plants not contributing to the shrub layer

Species favoured by the presence of deer. Another important result of deer browsing is the proliferation of saplings of Western Hemlock and Sitka Spruce, the dominant canopy trees. Their regeneration is relatively sparse on islands without deer, but they form the majority of the understory on islands where deer are present.

Decalesta and Redding (in press), working on White-tailed Deer in Pennsylvania, found that above a certain density of deer a new equilibrium became established in the understory, with ferns and herbaceous plants replacing shrubs. Hanley (1984) suggested that the regeneration of conifers may be augmented by moderate browsing, through a decrease in competition with shrubs. The appearance of a similar trend in our study shows that coniferous regeneration may be favoured even by intense browsing. The proportion of young spruce and hemlocks browsed (61% and 44% respectively) was high, but not as high as for the deciduous shrubs. In addition, the proportion of young conifers showing signs of browsing was variable, with some heavily browsed while others showed little sign: this was not the case for shrubs, all of which showed signs of heavy browsing. As a result, we see a continuous age structure among conifers, from young shoots to young trees, without the missing cohorts evident among shrubs, showing that conifers continue to recruit. Deer do not appear to prevent their development, although they may slow it. The reduction in growth caused by the browsing of the apical shoot, leads to an accumulation of young conifers in the ground layer. Rather than a change in equilibrium between young conifers and the original shrubs of the understory, as suggested by Hanley (1984), we should rather talk of a replacement of the shrubs, with the exception of Red Huckleberry.

A strong representation of grasses in the understory of islands with deer is difficult to interpret. The grasses occur mainly in a zone just inland of the shore, and we could not determine whether the presence of the grasses is due to soil factors, or to the activities of the deer. Grasses occur in the diet of the Black-Tailed Deer, but do not predominate, except in the study of McTaggart-Cowan (1956). Our observations also suggested that grasses were unimportant in the diet in our study area.

Density and structure of the understory. The decrease in density of the understory on islands with deer is due to the decrease in the proportion of original understory species. The vacuum thus created is only partially filled by young canopy trees, which tend to regenerate in dense patches, causing an increased clumping in the understory vegetation. The spacing out of the understory is one of the most dramatic effects of deer browsing and has been previously noted by Pojar and Banner (1984) for Haida Gwaii and by Klein (1965) for southern Alaska. Plates 1 and 2 illustrate the impact of deer on the understory.

II The Deer

1. Diet

Previous information on deer diet in the Queen Charlotte islands is given in Appendix 2. Our results suggest that deer prefer to use certain parts of the understory. The correlation between defecation densities and the presence of spruce, hemlock and grasses in the understory suggests the existence of well-defined feeding areas. An abundance of defecations in regular feeding areas was demonstrated by Pellerin (1977) for the muntjac in France, in forest habitat. The young conifers, along with the grasses, appear to play a major role in the diet of the island deer, which is hardly surprising, considering that these plants make up the bulk of available forage.

Apart from salal, we found no correlation between the abundance of droppings and the occurrence of the original understory shrubs. This is probably because most of the species, although heavily browsed, are extremely rare at present. Their scarcity and small size means that they do not form sufficient concentrations to be of any significance. Salal is an exception, being found in dense patches. These patches are the site of intensive foraging, as demonstrated by the strong correlation with dropping densities. However, the clumps are small and sparsely distributed, and no longer form an important resource for deer on the affected islands.

Our observations suggested that, during May, 50% of deer feeding was on young spruce, especially the young shoots, that are browsed preferentially. It appears that the deer may switch to hemlock later in the summer. The consumption of kelp was noted by McTaggart-Cowan (1956) and it would be interesting to know what contribution it makes to the diet of deer on small islands such as those that we studied.

2. Density of deer

The underestimation of density by the line transect method was probably the result of insufficient sample sizes. However, our observations also suggested that the number of deer seen tended to be less than the number actually present in the zone of visibility. On Reef and East Limestone islands, the deer appeared to be well camouflaged and deer that did not move were very hard to detect in the heavily-shaded understory. Males appeared to be more difficult to detect than females, based on the difference in sex ratio between the transect and whole island counts at East Limestone Island.

The "total count" method used at East Limestone Island appears to be better adapted to the situation than the line transect method, permitting the detection of animals that might be passed over by the solitary observer, and a proper estimation of the sex ratio. For a larger island, such as Reef Island, it might be possible to apply the total count method to selected parts of the island to provide an estimate of overall density.

Our estimates of deer densities for the two islands (33 deer/km ^{2}) is relatively high. Estimates of densities in this range are regarded as important in the literature on deer in North America. Anderson and Loucks (1979) mention 37/km ^{2}, with a peak of 50-100/km ^{2} for White-tailed Deer in coniferous forests in Wisconsin. Densities of Black-Tailed deer in the forests on the Northwest include 21-24/km ^{2} for Admiralty Island (Barrett 1979 in Pojar et al. 1980), and 30-60/km ^{2} for northern Vancouver island in winter (Smith and Davis 1975 in Pojar et al. 1980).

We should view current deer populations in their demographic context. The population in Haida Gwaii is the result of a recent introduction to a previously unbrowsed habitat where predators of adults are absent. According to Klein (1965), where deer populations are without predators, their populations are determined by the quality and quantity of available forage. A decrease in the availability of forage leads, through complex processes, to:

- an increase in the age of the population;
- a bias in the sex ratio towards greater numbers of females;
- a decrease in the size and weight of individual animals;
- a decline in the overall population.

Our study of the Laskeek Bay islands suggest that the presence of deer has decreased the availability of forage. However, we do not have information on how these changes may have affected the deer populations. We can only make the following inferences:

- small size of deer observed. This was already mentioned by Pojar et al. (1980); the small antlers of males were also striking, although we could obtain no quantitative information;
- the sex ratio at East Limestone Island seems to be more-or-less equal.

A study of inter-island movements within the archipelago, as part of an overall demographic study, would be essential to a proper understanding of deer-vegetation interactions in the islands.

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APPENDIX 1

LIST OF PLANT SPECIES RECORDED ON THE 5 ISLANDS (mosses and lichens excluded)

Adiantum pedatum (Maidenhair Fern)
Alnus rubra and *Alnus crispa* (Alder)
Amelanchier alnifolia (Saskatoon)
Asplenium viride (Green Spleenwort)
Athyrium filix-femina (Lady Fern)
Carex sp. (Sedge)
Dryopteris expansa (Spiny Wood Fern)
Maianthemum dilatatum (False Lily-of-the-Valley)
Gaultheria shallon (Salal)
Lonicera involucrata (Black Twinberry)
Menziesia ferruginea (False Azalea)
Picea sitkensis (Sitka Spruce)
Poaceae (Grasses)
Polypodium glycyrrhiza (Licorice Fern)
Polysticum munitum (Sword Fern)
Pteridium aquilinum (Bracken)
Ribes sp. (Currant)
Rubus spectabilis (Salmonberry)
Sambucus racemosa (Red Elder))
Symphoricarpos albus (Snowberry)
Thuja plicata (Western Red Cedar)
Tsuga heterophylla (Western Hemlock)
Vaccinium parvifolium (Red Huckleberry)
Vicia sp.

APPENDIX 2

Diet:

McTaggart Cowan (1956), describes the diet of the Black-tailed Deer as catholic, but dependent mainly on shrubs and saplings. For British Columbia, the main components of the diet are:

Thuja plicata (Western cedar)
Pseudotsuga taxifolia (Douglas fir)
Usnea barbata (Beard moss)
Vaccinium parvifolium (Red huckleberry)
Arbutus menziesii (Madrone)
Gaultheria shallon (Salal)
Salix sitchensis (Sitka willow)
Alnus rubra (Oregon alder)
Spiraea discolor (Ocean spray)
Symphoricarpos racemosa (Snowberry)
Hypochaeris radicata (False dandelion)
Pteridium aquilinum (Bracken fern)

In the case of the Queen Charlotte Islands, diet has been reported by Pojar et al. (1980, 1984), and Coates et al. (1985). According to Pojar et al., the diet preference of the Black-tailed Deer in the islands is as follows:

1. *Lysichiton americanum* (Skunk cabbage)
2. *Rubus spectabilis* (Salmonberry), *Oplopanax horridus* (Devil's club), *Thuja plicata* (Red cedar)
3. *Athyrium filix-femina*(Lady fern), *Dryopteris assimilis* (Spiny wood fern), *Polystichum munitum* (Sword fern)
4. *Vaccinium parviflorum* (Red huckleberry), *V. ovalifolium* (Oval-leaved blueberry), *V. alaskaense* (Alaskan blueberry), *Blechnum spicant* (Deer fern), *Gymnocarpium dryopteris* (Oak fern)
5. *Menziesia ferruginia* (False Azalea), *Gaultheria shallon* (Salal), *Chamaecyparis nootkatensis* (Yellow cedar)
6. *Picea sitchensis* (Sitka spruce)
7. *Tsuga heterophylla* (Western hemlock)

SEABIRD COLONY
MONITORING ON GEORGE ISLAND, 1996

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ABSTRACT

The seabirds breeding at George Island, Gwaii Haanas, were censused by the Canadian Wildlife Service in 1985, when eight permanent monitoring plots were designated. A return visit was made in 1991, when counts of the permanent plots suggested that a substantial increase had taken place in the population of Ancient Murrelets. In 1996, a joint CWS-Laskeek Bay Conservation Society team visited George Island from 18-28 June to revisit the permanent plots and carry out another colony-wide census to assess whether the trends suggested by the permanent plots were representative of the whole colony. Between 1985-96, numbers of Ancient Murrelet burrows in the permanent plots rose from 258 to 367 (+40%). The census, based on counts in 86 7 x 7 m quadrats, gave a population estimate of 21,509 burrows. With an occupancy of 80.8%, based on examination of 125 burrows, the number of breeding pairs was estimated at 17,384 ± 1,835, an increase of 50% over the 1985 estimate of 11,614 pairs. Numbers of Cassin's Auklets, estimated at 4,326 breeding pairs were not significantly different from the 1985 estimate of 5,933 pairs. The lower numbers recorded in 1996 were thought to be due to a change in the protocol for quadrat selection, leading to a more realistic estimate. In addition, 309 pairs of Leach's Storm-Petrels were estimated to breed on the island.

Introduction

In 1985, the Canadian Wildlife Service (C.W.S.) surveyed the nesting colonies of seabirds on George Island in Skincuttle Inlet, Gwaii Haanas, as part of a program to inventory all seabird colonies along the British Columbia coast (Rodway et al. 1988). In addition, George Island was selected as a long-term monitoring site for Ancient Murrelets. Eight permanent monitoring plots were set up within the colony to provide early detection of trends in the population. The results of a repeat survey of these permanent plots in 1991 suggested that the Ancient Murrelet population on the island had increased since 1985 (Lemon 1992). The purpose of the present study is to repeat the census of the island using the same technique as in 1985 and to once again resurvey the permanent plots to compare the results derived from the permanent plots with those from the more labour intensive transect method.

Study site

George Island, largest in the Copper Islands chain in Skincuttle Inlet, has a total area of 42 hectares, of which 32.7 ha is vegetated. The island is forested predominantly by Sitka Spruce near the shore, and Western Hemlock and Western Red Cedar in the interior. There are scattered areas of windfall on the east and southeast shores. An area of recent windfall in 1985, just west of the north bay, now has a dense understorey of regenerating sitka spruce. A more detailed description of the island is given in Rodway et al. (1988).

Methods

From a camp on George Island, we carried out the census of the seabird colony and resurveyed the permanent plots between 18 - 28 June, 1996. As one of the original 1985 field crew, I was able to ensure that the methods used were similar to those used earlier. The survey method and analysis is described in Rodway et al. (1988).

1. Transects

We repeated the colony census from June 23 - 27, 1996 using methods similar to those employed in the original CWS survey in 1985. The 1996 census consisted of counts of burrows in 86 quadrats (7m x 7m) spaced at 30m intervals along six parallel transects set roughly perpendicular to the shore at a bearing of 215° and spaced 110m apart. Initially, the route of these transects was laid out on an airphoto of the island, and the beginning points identified by landscape features, or measurements from obvious landmarks. A slight error in the compass bearing caused the transects to deviate from their intended route. This combined with beginning adjacent transects from alternate shores amplified the error and the transects converged slightly and were not evenly spaced. At the extreme, the closest approach was 80m and the furthest distance apart was 165m (Fig 1). In the 1985 survey, there were 67 quadrats surveyed along only four transects. Those transects were spaced 150 m apart, and all were begun on the same shore.

In 1985, the first quadrat was always laid out at the edge of the vegetation and "burrowable" habitat at the shore. In 1996, in order to reduce a possible bias resulting from always sampling the edge of the colony, we began the first quadrat at a randomly

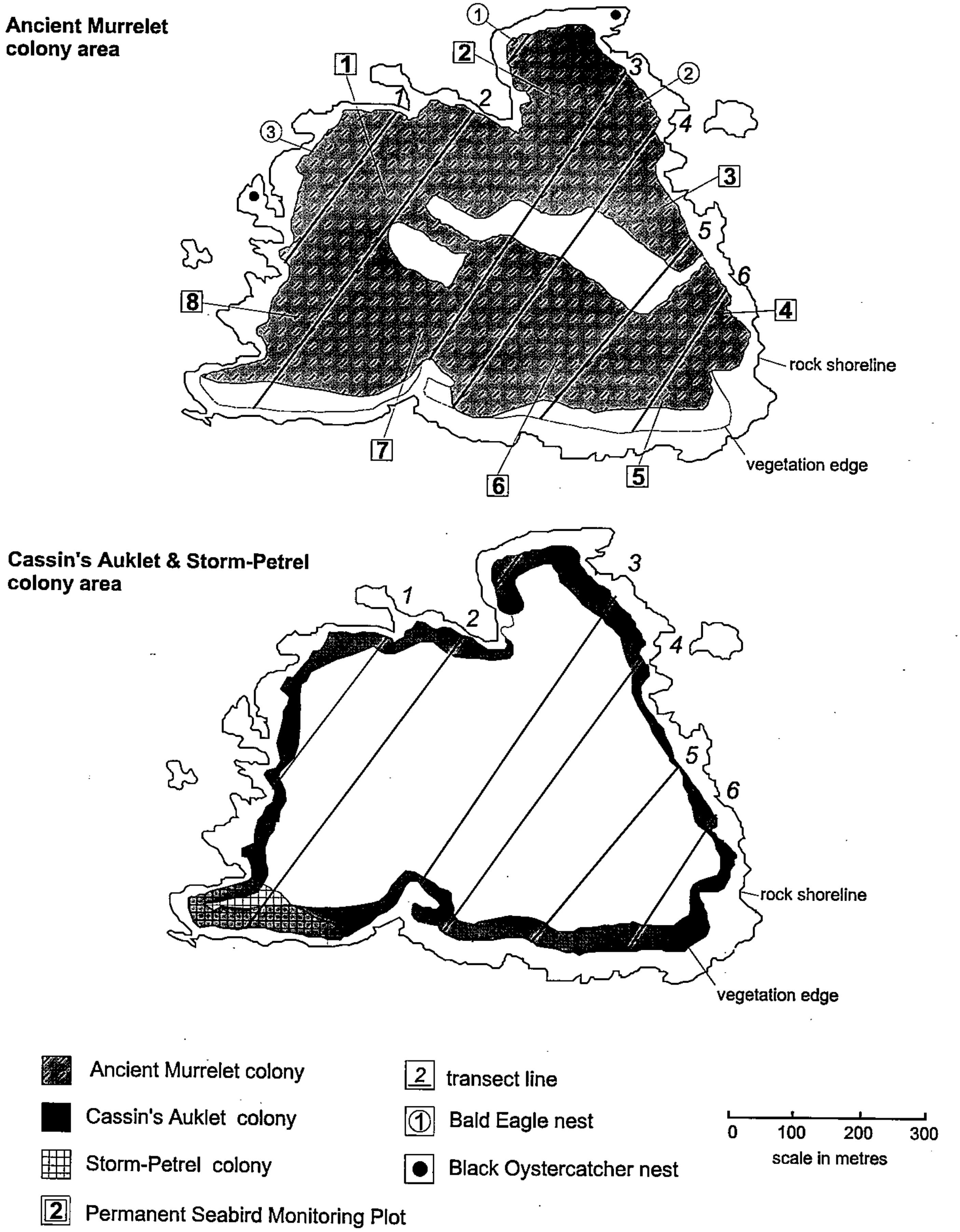

Fig. 1. **Seabird colony areas and transect locations on George Island in 1996**

chosen distance from the edge of the vegetation. To ensure that at least one quadrat would fall within the narrow strip of Cassin's Auklet colony along the shore edge, the random number selection was limited to one meter intervals between 0m and 13m. (The previous survey determined that the minimum width of Cassin's Auklet colony was about 20m.)

As in 1985, the colony areas were defined as including all areas with burrows. If there were no burrows within a quadrat, the surrounding area was searched to determine if the quadrat fell within the colony boundaries. If burrows or signs of activity were found within a distance halfway to adjacent quadrats along the transects or half the distance laterally to adjacent transects, the area was considered part of the colony and the data obtained from the quadrat was included in calculations of burrow density. If no burrows were found within this range, the area was not considered to be part of the colony and the quadrat data was not used in density calculations.

The mean density of burrows and its standard error for the colony was calculated as the mean of the burrow densities found within each quadrat within the colony boundaries.

We attempted to determine occupancy (breeding effort in the current year) of all burrows that fell within the quadrats. Exploring burrows longer than an arm's reach required digging one or more small access holes until the end was encountered. Excavated holes were immediately patched with portions of cedar shakes and soil. However, many burrows were inaccessible under tree bases and roots, and we were only able to gain full access to a portion of the burrows. Adult birds with eggs or chicks, and cold eggs in burrows are evidence of occupied burrows. Since we conducted our survey at the end of the Ancient Murrelet breeding season, freshly hatched egg membranes were the main evidence of occupied burrows. If no evidence was found in burrows that were completely explored, then these were designated as empty (no nesting effort in 1996). In addition, for Cassin's Auklets whose burrows are generally much longer and more complex, burrows were recorded as occupied if a latrine or regurgitated food (indications of the presence of a chick) was encountered while exploring the burrow. Occupancy rate was calculated as the number of occupied burrows/total burrows of known status for each quadrat. Thus the mean occupancy rate and standard error for the colony is determined from the rates for each quadrat.

In addition to the census of burrows, we recorded evidence of predation (number of depredated eggshells, feather piles, wings and carcasses) within the quadrats and as a continuous 7m strip along the transect. We also checked for dug-up burrows and checked eggshells for tooth marks (for signs of raccoons or rats within the colony).

2. Permanent plots

In 1985, the Canadian Wildlife Service established eight 20m x 20m plots within the Ancient Murrelet colony on George Island (Fig.1). Along each of the four colony census transects set up in 1985, two plots were located at randomly chosen distances. A description of the methods of marking the plots is given in Rodway et al. (1988).

The location of burrows in relation to the positions of trees, stumps, logs and other features were mapped for each plot. Burrows were examined by feeling through the entrance as far as an arm could reach; no excavations were performed. All signs of occupation by birds (egg shells and membranes, feathers etc.) were recorded.

The plots were resurveyed by a team of observers in June 1991 (Lemon 1992). From June 20 - 22, 1996, we relocated and examined all plots using the same methods as in 1985 and 1991. The status of previously mapped burrows and burrow "starts" was recorded and the positions of new burrows were added to copies of the original maps. Burrows less than 30cm long and without nest chambers which were apparently in the process of construction, were recorded as "starts"; these were mapped, but not counted in the total number of burrows.

Results

1. Colony census

Ancient Murrelets

The Ancient Murrelet colony on George Island covered almost the entire island except for the low wetland area in the centre (Fig. 1). The colony extended inland from the vegetation edge at the shore except along most of the south coast of the island, where it began approximately 30m inland (Table 1). The total area of the Ancient Murrelet colony in 1996 was virtually the same as in 1985 (27.47 hectares compared to 27.1 hectares). The estimate of colony area is slightly larger in 1996 than in 1985 mainly as a result of finer definition of the interior wetland area, where no burrowing occurs. The delineation of colony boundaries along the shore varied slightly between years, due mainly to the sparse nature of the Ancient Murrelet burrows at the periphery of the colony, which makes it difficult to identify the colony boundary with precision.

Of the 86 quadrats surveyed along the 6 transects, 74 fell within the Ancient Murrelet colony boundaries (Table 2). The lowest burrow densities occurred around the interior wetland area. The mean burrow density determined was substantially higher in 1996 (783 +/- 74 burrows/ha) than in 1985 (558 +/- 74 burrows/ha; $P = 0.03$)

We were able to determine the occupancy status of 125 of the burrows found within the census quadrats (Table 3).

The majority of the 101 burrows which contained evidence of breeding effort in the current year, held the thickened white membranes of hatched eggs in the burrow's tunnel or within the nest bowl. A few contained either one or two cold eggs, indicating a failed breeding attempt in 1996. Mean burrow occupancy rate in the Ancient Murrelet colony was 80.8 +/- 3.9 %, higher than the rate determined during the 1985 survey, but not significantly different. Hence, the 1996 nesting population of Ancient Murrelets on George Island was 17,384 +/- 1, 835 pairs of birds, an increase from the 1985 population estimate of 11,614 +/- 1751 pairs ($P = 0.028$).

Although the estimate of the colony area is slightly larger in 1996 than in 1985, this is due to a more exact resolution of the interior wetland, and is not a consequence of expansion into some potential habitat previously unoccupied. The 1996 census showed the interior wetland area to be smaller than we had determined in 1985, but the resultant increase in colony area only adds slightly less than 2% to the estimate of the total number of Ancient Murrelet burrows on the island. The estimate of the occupancy rate of burrows was slightly higher in 1996 than in 1985, but only contributes 7% to the increase in the estimate of the breeding population of Ancient Murrelets on George Island in 1996. By far, the greatest contribution (40%) to the increased population estimate can be attributed to the substantial increase in burrow density.

Evidence of predation on Ancient Murrelets was found on the surface throughout the colony (Table 5). The mean density of depredated eggshells within all the census quadrats along the transects was 28 +/- 8 depredated eggshells/hectare, while the density derived from the 7m wide strip along the length of the transect was 15 +/- 3 eggshells/ha.. This is considerably lower than the estimated mean of 67 +/- 18 eggshells/ha in census quadrats in 1985 (Rodway et al. 1988). Using feather piles as an indicator of depredation on adult birds, I calculated a mean density of 85 +/- 13 feather piles/ha from data collected within all the census quadrats along the transects in 1996, but only 45 +/- 6 feather piles/ha derived from the number of remains found along the 7m wide strip along the 6 transects. In 1985, the density of depredated adult birds was estimated to be 68 +/- 16 per hectare based on feather piles found within census quadrats (Rodway et al 1988).

We didn't find any carcasses of Ancient Murrelets, only feather piles and occasionally either single or paired wings. Although we found a few burrows that had been excavated by a predator, we did not find any evidence of raccoons either at the site of these burrows or on the island during the course of our work, and concluded that river otters were most likely responsible for digging up the burrows. The remaining depredation is more consistent with avian predators.

In addition to finding Bald Eagle pellets containing Ancient Murrelet feathers scattered about the island, in an area of open spruce and hemlock forest and thickets of regenerating Sitka Spruce at the northeastern end of transect 4, under a raised root bowl of a tree, we found many Northwestern Crow and Common Raven sized pellets containing feathers.

Although we did not do regular sea-watches, on several evenings we scanned with a spotting scope from the northeast point of the island near camp. Looking northwards from George Island, we counted a minimum of 3000 Ancient Murrelets on the water between the east end of Burnaby Island and the coast of East Copper Island on June 21. It appeared that there were many more birds beyond our viewing range. In the forest, Ancient Murrelets were still regularly visiting the island during the nights, and departing chicks were heard leaving the colony past our camp on the night of June 20 -21.

Cassin's Auklets

The Cassin's Auklet colony extended in a nearly continuous band around the perimeter of the island, averaging 30 m in width (Table 1). The maximum width was 54 m along the southwest shoreline. The colony area of 7.17 hectares was essentially the same as that measured in 1985. Burrow density was greatest around the southwest and northeast points of the island and sparser along the southeast shore (Table 6). In most shoreline areas, Cassin's Auklet burrows were interspersed with those of Ancient Murrelets. Mean burrow density determined from the 13 quadrats which fell within the Cassin's Auklet colony boundaries was 644 +/- 225 burrows/ha, substantially lower than the density estimated in 1985 (Table 4). The difference in our estimate of density may be at least partially attributed to differences in methodologies between years. Cassin's Auklet colonies generally follow a density gradient, with the densest part of the colony along the edge of the shore (Rodway et al 1988, 1990, 1994). By placing the first quadrat at the shore edge in the 1985 survey (rather than at a random distance from shore as in 1996), we may have biased our burrow density estimate in 1985 by a non-random sampling of the denser part of the colony.

We were able to determine the contents of 16 of the 41 burrows in the survey quadrats (Table 7). The occupancy rate was estimated to be 93.8 +/- 6 %. Most of the occupied burrows contained chicks, although we assumed the presence of a chick in most cases from the presence of fresh latrines and regurgitated food, and located chicks in only two of the burrows. Five of the 15 occupied burrows contained either dead chicks or cold eggs. This 33% failure rate may be indicative of a poor season for Cassin's Auklets. In contrast, the Ancient Murrelet colony experienced an 8% failure rate, based on the number of cold eggs and dead chicks found in the burrows at the end of the breeding season (Table 3 and 7). The 1985 survey, carried out at the end of April, occurred earlier in the breeding season of Cassin's Auklets. None of the occupied burrows in the small sample used to determine an occupancy rate had experienced a nesting failure.

Although the occupancy rate was higher in 1996 than in 1985, the estimate of the 1996 nesting population of 4,326 +/- 1,534 pairs of Cassin's Auklets is lower than in 1985 (Table 4), mainly as a result of the lower burrow density estimate. Neither burrow density, not occupancy, differed significantly from 1985 and overall it seems that the population of Cassin's Auklets is stable.

Leach's Storm-Petrels

Leach's Storm-Petrel burrows were interspersed among those of Cassin's Auklets in the open moss and grass understorey of the Sitka Spruce shoreline fringe forest on the southwest point of the island (Fig. 1). Storm-Petrel burrows extended approximately 80 m inland in this area along transect 2 (Table 1), to where Western Hemlock begins to dominate the forest and the ground cover is devoid of vegetation, where they were mixed with Ancient Murrelet burrows. We attempted to delineate the boundaries of the colony and roughly estimated an area of 1.26 hectares. Storm-petrel burrows occurred in the vicinity of the first three quadrats along the south end of transect 2, with 4, 0, 1 burrows in those quadrats, respectively. We found a Leach's Storm-Petrel sitting on an egg in two of these burrows, confirming this species presence and breeding efforts on the island for the first time. Although the sample size for burrow density is small, I estimated a mean density of 340 +/- 245 burrows/ha., and a nesting population of 429 +/- 309 pairs (Table 4).

We didn't find any evidence of nesting Fork-tailed Storm-Petrels, although both Fork-tailed and Leach's Storm-Petrels flew and called each night around our camp in the bay on northeast end of the island. Both of these species nest in large numbers on Skincuttle Island and Rock Islets, the two closest islands to the west. We did not find any storm-petrels nesting on George Island during the 1985 survey, but we may have been too early that year, as that survey was conducted in late April, before the breeding season of Leach's Storm-Petrels. A.J. Gaston (pers. comm) reported hearing Fork-tailed Storm-Petrels calling and flying at night on the island during several nights in June 1992. Although we did not encounter any of their burrows within our sample quadrats, it is likely that there is a small number of these birds nesting on the island.

Black Oystercatcher

Two pairs of Black Oystercatchers were nesting on the rocky shoreline of George Island. (Fig.1). One nest containing two eggs was spotted on June 21, on the high rocky northeast point of the island. By June 27, when we revisited that nest site, the two adults were in attendance, and were brooding one chick. The other egg had not yet hatched. A second nest constructed of shell chips on the limestone pocketed rock on the mid-western shore, contained three eggs on June 22. The two adults were present in the vicinity of the nest. It was located on a portion of the rock shelf that became detached from the rest of the main shore of the island during high tide.

2. Permanent plots

The increase in the total number of Ancient Murrelet burrows on all 8 plots from 1985 to 1996 is 42% - (258 burrows in 1985 to 367 burrows in 1996) (Table 8). The total number of burrows on all 8 plots rose from 323 burrows in 1991 to 367 burrows in 1996, an increase of 14%. This is smaller than the 29% increase in the total number of burrows during the 6 year period between 1985 and 1991 (after a recalculation, the percentage increase in 1991 differs slightly from that reported in Lemon 1992). Between 1991 and 1996, the numbers of Ancient Murrelet burrows increased in 7 of the 8 plots, with increases ranging from 8 - 44 % over the number of burrows recorded in the 1991 survey. Two of the plots which had the smallest increase in burrow numbers from 1985 to 1991, showed a greater increase in the second time period between 1991 and 1996, while the other 6 plots all had a smaller percentage increase in the second time interval (Tables 8 and 9). A small number of burrows that were present in 1991 were filled in and no longer present in 1996 (Table 9). Several of the "starts" (burrows in the process of construction) that were present in 1991 had become burrows that showed signs of current breeding efforts in 1996, or held bits of shell or shell membrane from nesting activity in the intervening years. Some of the "starts" had completely disappeared, while others appeared to be in the same condition as when we found them in 1991. New burrow "starts" as well as new complete burrows had been created in all 8 plots since the survey in 1991. The details and history of the burrows in each plot is presented in Table 9.

In the 8 plots we were able to determine the contents of 154 burrows, and 128 of these had been occupied in the current season (Table 10). This occupancy rate of 83.1 +/- 2.3%, was similar to the estimate of occupancy rate along the transects (Table 4 and 10). In 1991, 74 out of 93 burrows in the plots were occupied that season (79.6 +/- 5 %), while in 1985 we were able to determine the contents of 51 burrows, 38 of which were occupied (74.5

+/- 9.4 %). The 1985 occupancy estimate derived from the permanent plots was similar to the rate determined in the quadrats along the transects in that year.

Discussion

The estimates of Ancient Murrelet burrow density on George Island increased by 40.3% from 1985 to 1996 as determined from the transect survey. This increase in burrow density is mirrored almost exactly by the observed 42 % increase in total burrow numbers in the 8 permanent plots between 1985 and 1996. Although an estimate of the nesting population cannot be derived directly from the data obtained in the permanent plots, the plots reflect the percentage change in burrow density between survey years. The trend in burrow density in the permanent plots showed that increases in burrow numbers and density were greater in the interval between 1985 and 1991, than between 1991 and 1996.

The transect method and permanent plot method for investigating the status of the breeding population of seabirds suggested the same percentage increase in the breeding population of Ancient Murrelets on George Island between 1985 and 1996. While this is very encouraging, for a population monitoring program we also need to know that a declining trend in a breeding population of seabirds can be demonstrated, and whether the results will be similar for other species of burrow-nesting seabirds. It will be useful to see also if the results are similar on other Ancient Murrelet colony islands where permanent plots were set up and transects have been surveyed in previous years.

Increasing the number of transects and therefore sample quadrats in 1996 from the number surveyed in 1985 did not change the confidence limit of the final estimate of burrow density (Table 4). However, increasing the number of burrows sampled for the current years occupancy status did reduce the standard error of the estimate of burrow occupancy.

Censusing the Ancient Murrelet colony after the breeding season increases our ability to determine the contents of burrows, as hatched eggshell membranes are often dragged from the nest bowl into the burrow's tunnel closer to the entrance. It also prevents disturbance to nesting birds that could occur earlier in the season. It may, however, skew the estimate of occupancy rate in favor of burrows with current breeding effort, but if done consistently at the same time of year, should be comparable between years.

Although we attempted to determine the contents of all burrows encountered within the quadrats along the transects, excavating Ancient Murrelet burrows did not add a great deal more to the information we could obtain from merely reaching into the burrows. In total we were able to determine the occupancy status of 125 (44%) of 284 burrows encountered in the quadrats. We were able to reach to the nest chamber of 88 (31%) of these burrows, and in addition were able to determine the status of a further 30 burrows (11%) despite being unable to reach as far as the nest chamber (in these burrows, the hatched egg membrane was found in the tunnel forward of where the nesting chamber would be). Only 11 of the remaining 166 burrows were in locations where we were able to excavate small access tunnels and we were only able to determine the current years' nesting status of 7 of these 11. Thus by excavating the nesting burrows we increased our knowledge of burrow contents by only 2 %. The rest of the burrows were impossible to gain access to because they extended underneath the bases of trees, large roots or were inaccessible under immense fallen logs. In the permanent plots, although we did not excavate any burrows, we were still able to determine the status of 42% of the burrows in 1996, 29% in 1991 and 20% in 1985.

For Cassin's Auklets, whose burrows are longer and more complex, we were able to determine the status of 16 (39%) of the 41 burrows encountered in the quadrats, but in only 3 (7.3%) of these could we reach the nest chamber without excavating the burrow. In an additional 6 burrows we were able to determine the status from evidence, such as a latrine, reached before the actual end of the burrow. Only 8 of the remaining 32 burrows were accessible by digging small access holes, and in 7 of these we were able to determine the current year's occupancy status. Thus, for Cassin's Auklets, excavating "unreachable" burrows increased our knowledge of the burrow contents by 17%. However, it added substantially to the time required to conduct the survey.

To complete the census of the six transects on the island, required 3 people and five long days, while the eight permanent plots were resurveyed by 3 people in three days. There are inherent problems with both transects and permanent plots. In both methods there is the same difficulty in identifying burrows under complex root bowls of trees or raised roots around the bases of trees. With the current method of determining occupancy status, some burrows will always be inaccessible. With both transects and permanent plots there is the concern that if burrows persist after abandonment by the birds, a decline in nesting population may not be detected in a timely manner.

Not all burrows are occupied in any given year, and while a burrow may be empty in one year, the following year it might support a breeding bird. The results from the permanent plots show that within the 5 year period, some Ancient Murrelet burrows once unoccupied, do disappear without a trace and do not linger long after the birds cease to use the burrow. Although we do not know the status of the burrows in the years between surveys, some insight into a burrow's longevity can be gleaned. We knew the 1991 occupancy status of 12 of the 42 burrows which disappeared from the permanent plots between 1991 and 1996. Of these 12 burrows, 10 had held evidence of breeding in 1991. Between 1985 and 1991, 24 burrows disappeared from the permanent plots. Four burrows of 6 with known occupancy status had been occupied in 1985. Of the 13 burrows which were known to be empty in 1985, seven were either occupied or were of unknown status in 1991 and 1996. Two burrows had disappeared by 1991 and one with an unknown status in 1991 had disappeared by 1996. Three burrows were empty in all 3 survey years. Of a further 15 burrows that were recorded as empty in 1991, 8 were either occupied or present with undetermined occupancy status in 1996, 5 were present but empty in 1996, and 2 burrows had completely disappeared. Unoccupied burrows in looser soil whether directly into the ground or under rotting logs or stumps are likely to disappear in a shorter period of time than those that extend under the bases of trees or their massive roots.

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TABLE 1. Transect parameters and seabird colony extents along transects on George Island in 1996.

Trans.	Bearing (°)	Random start (m)	Total length (m)	Colony extent (in m) Ancient Murrelet	Cassin's Auklet	Storm Petrel
1	215	12	292.5	0 - 292.5	0 - 27 272 - 292.5	no colony
2	35	5	626	50 - 626	0 - 54 540 - 626	0 - 80
3	215	9	547	0 - 269 325 - 547	0 - 35 532 - 547	no colony
4	35	9	544	0 - 294 390 - 544	0 - 25 510 - 544	no colony
5	215	7	365.5	0 - 52 142 - 335	0 - 5 335 - 365.5	no colony
6	35	13	230	30 - 230	0 - 30 215 - 230	no colony

TABLE 2. Number of Ancient Murrelet burrows in 7m x 7m quadrats along transects on George Island in 1996. Quadrats considered outside the colony are indicated with a dash.

	TRANSECT					
QUAD	1	2	3	4	5	6
1	4	-	1	2	3	-
2	0	-	0	0	5	7
3	0	2	3	0	-	6
4	13	8	0	7	-	4
5	2	3	3	8	-	6
6	1	4	5	4	5	12
7	6	5	5	7	11	9
8	2	3	2	3	5	3
9	0	2	1	0	2	
10	1	0	-	0	5	
11		7	-	-	5	
12		3	1	-	-	
13		2	2	-		
14		0	2	1		
15		6	4	11		
16		7	7	1		
17		2	4	8		
18		*	6	2		
19		4				
20		7				
21		2				

* - quadrat not surveyed due to impenetrable regenerating spruce, but Ancient Murrelet burrows are present nearby.

TABLE 3. Occupancy of Ancient Murrelet burrows along transects on George Island in 1996.

		CONTENTS							
Trans.	Quad.	empty	1 cold egg	2 cold eggs	'96 hatch membr.	dead chick	pred. egg	Total occup.	Total Known
1	4	3	1		2			3	6
1	5				1			1	1
1	6				1			1	1
1	7				3			3	3
1	8	1						0	1
1	10	1						0	1
2	3	1			1			1	2
2	4	2			4			4	6
2	5				2			2	2
2	6				2	1		3	3
2	8	1			2			2	3
2	9				2			2	2
2	11	1			2			2	3
2	12	1			2			2	3
2	13				1			1	1
2	15				4			4	4
2	16	2						0	2
2	19				1			1	1
2	20	1			1			1	2
3	1				1			1	1
3	3				2			2	2
3	5		1					1	1
3	6			1				1	1
3	9	1						0	1
3	14			1	1			2	2
3	15	1			2			2	3
3	16				3			3	3
3	17				3			3	3
3	18	1			4			4	5
4	1				1			1	1
4	4				2			2	2
4	5				4			4	4
4	7	2						0	2
4	15				1			1	1
5	2	1	1		1			2	3
5	6				2			2	2
5	7				4		1	5	5
5	8				4			4	4
5	9		1					1	1
5	10				1			1	1
5	11				2			2	2
6	2	1			5			5	6
6	3	2			1			1	3
6	4				2			2	2
6	5				4			4	4
6	6				7			7	7
6	7	1			4			4	5
6	8				1			1	1
TOTALS	48	24	4	2	93	1	1	101	125

TABLE 4. Population estimates of Ancient Murrelets, Cassin's Auklets, and Leach's Storm-Petrels on George Island in 1985 and 1996.

Variable		Ancient Murrelet		Cassin's Auklet		Leach's S.P.
		1985	1996	1985	1996	1996
Burrows/m^2	mean	0.0558	0.0783	0.1130	0.0644	0.0340
	s.e.	0.0074	0.0074	0.0290	0.0225	0.0245
	N	57	74	11	13	3
Occupancy	mean	0.768	0.8080	0.75	0.9375	1.0
	s.e.	0.056	0.0388	0.0722	0.0593	0.0
	N*	27	48	4	6	2
nest status	occupied	43	101	6	15	2
nest status	known	56	125	8	16	2
Colony area	(ha)	27.1	27.47	7.0	7.17	1.26
Total Burrows	mean	15,122	21,509	7,910	4,617	429
	s.e.	2,005	2,033	2,030	1,613	309
Nesting Pop. (pairs)	mean	11,614	17,384	5,933	4,326	429
	s.e.	1,751	1,835	1,619	1,534	309

N* - N is the number of quadrats where an occupancy rate was determined, and from which the mean occupancy rate of the colony was determined.

nest status occupied - total number of burrows that were occupied
nest status known - total number of burrows with known occupancy status (occupied or empty)

TABLE 5. Depredated remains of Ancient Murrelets within 7m x 7m quadrats and 7m strips between quadrats along transect lines on George Island in 1996.

TRAN.	QUAD.	Pred. egg	feather pile	single wing	pair wings	BAEA pellet	dug up burrow
1	0-1		2				
1	1		1	1			
1	2		1				
1	2-3		1				
1	5	1					
1	7-8	1					
1	8		1				
1	10	1					
2	3					2	
2	4		1				
2	4-5		1				
2	5		2				
2	8-9	1	1				
2	10-11		1				
2	11					1	
2	11-12		1				
2	12	2					
2	12-13	2					1
2	15	1	1				
2	16	1					
2	16-17		1				
2	18-19		4				
2	19		2				
2	20		2				
2	20-21	1					
2	21		1				
3	1		1				
3	1-2		1				
3	2		1				
3	2-3	1	1				
3	3		1				
3	3-4		1				
3	4					1	
3	4-5	1					
3	6	1					
3	6-7		2				
3	7-8		1				
3	8	1					
3	11-12		1	1			
3	12		1				
3	14-15		2				
3	16		1				
3	17		1				
3	17-18		4				
4	3-4				1		
4	4	1					
4	5		1	1			
4	6-7		2				
4	7		1				

TABLE 5. cont'd

TRAN.	QUAD.	Pred. egg	feather pile	single wing	pair wings	BAEA pellet	dug up burrow
4	7-8	1	1				
4	8	1	1				
4	10		1				
4	10-11		2				
4	11-12		1				
4	14		1				
4	14-15		2				
4	15	1					
4	16		1	1			
4	16-17		1				
4	17		2			1	
5	3	1	1				
5	3-4		1				
5	5		1				
5	6-7	1					
5	7		1				
5	8-9	not done	not done	not done	not done	not done	not done
5	9		1				
5	9-10	3					1
5	10		2				
5	10-11	1	1				
5	11-12	1					
6	0-1		1				
6	1		1				
6	1-2		1				
6	2		1				
6	2-3	not done	not done	not done	not done	not done	not done
6	3-4		1				
6	4-5	1	1				
6	5-6		2				
6	6		1				
6	8		1				
TOTAL	in quads.	12	36	3	0	5	0
TOTAL	along transects	27	78	4	1	5	2

TABLE 6. Number of Cassin's Auklet burrows in 7m x 7m quadrats along transects on George Island in 1996. Quadrats considered outside the colony are indicated by a dash.

QUAD.	TRANSECT 1	2	3	4	5	6
1	0	9	1	0	-	7
2	-	11	-	-	-	-
3-7	-	-	-	-	-	-
8	-	-	-	-	-	0
9	-	-	-	-	-	
10	0	-	-	-	-	
11		-	-	-	-	
12		-	-	-	1	
13-17		-	-	-		
18		*	-	1		
19		4				
20		7				
21		0				

* - quadrat not surveyed due to impenetrable regenerating spruce, but the quadrat lies outside of the Cassin's Auklet colony boundaries.

TABLE 7. Occupancy of Cassin's Auklet burrows along transects on George Island in 1996.

		CONTENTS									
Trans.	Quad	empty	chick	'96 hatch membr.	chick down	chick latrine	regurg. food	cold egg	dead chick	Total occup.	Total known
2	1		1	1*					1	3	3
2	2		1		1	1		1	2	6	6
2	20	1				3				3	4
3	1					1				1	1
4	18						1			1	1
6	1					1				1	1
Totals		1	2	1*	1	6	1	1	3	15	16

* - the end of this burrow was reached, but no chick or other sign of habitation was found - assumed predated.

TABLE 8. Number and percent increase of burrows in permanent plots on George Island.

Plot	number 1985	of ('85 - 91)* (compare)	burrows 1991	1996	percent increase 85 -91	91 - 96	85 - 96
1	31	31	43	48	39	12	55
2	49	49	71	77	45	8	57
3	11	11	18	26	64	44	136
4	32	31	41	45	32	10	40
5	37	35	47	53	34	13	43
6	23	23	26	33	13	27	43
7	37	35	38	39	9	0	5
8	38	36	39	46	8	15	21
Total	258	251	323	367	29	14	42

* - in four of the plots the status of a few of the burrows was not recorded in 1991, so the numbers in this column are the total numbers of burrows in the plots in 1985 without those particular burrows, and are used to determine the percent change between 1985 and 1991.

TABLE 9. Numbers of Ancient Murrelet burrows in permanent plots on George Island in 1985, 1991 and 1996.

Plot	year	"new" burrows	starts to burrows	unknown status	unk.burr. found	unk.burr lost	"lost" burrow	"new" starts	"lost" starts	Total starts	Total burrows
1	1985	-	-	-	-	-	-	-	-	n/a	31
	1991	16	-	0	-	-	4	9	-	9	43
	1996	11	3	0	-	-	9	6	4	8	48
2	1985	-	-	-	-	-	-	-	-	n/a	49
	1991	26	-	0	-	-	4	1	-	1	71
	1996	14	0	0	-	-	8	5	0	6	77
3	1985	-	-	-	-	-	-	-	-	n/a	11
	1991	7	-	0	-	-	0	0	-	0	18
	1996	8	0	0	-	-	0	1	0	1	26
4	1985	-	-	-	-	-	-	-	-	n/a	32
	1991	11	-	1	-	-	1	2	-	2	41
	1996	7	1	0	-	1	4	5	0	6	45
5	1985	-	-	-	-	-	-	-	-	n/a	37
	1991	12	-	2	-	-	0	6	-	6	47
	1996	11	2	0	0	2	7	7	1	10	53
6	1985	-	-	-	-	-	-	-	-	n/a	23
	1991	5	-	0	-	-	2	2	-	2	26
	1996	7	0	0	-	-	0	7	1	8	33
7	1985	-	-	-	-	-	-	-	-	n/a	37
	1991	11	-	2	-	-	8	1	-	1	38
	1996	3	1	0	1	1	4	4	0	4	39
8	1985	-	-	-	-	-	-	-	-	n/a	38
	1991	8	-	2	-	-	5	8	-	8	39
	1996	9	2	0	1	1	5	7	3	10	46

TABLE 10. Occupancy of Ancient Murrelet burrows in permanent plots on George Island in 1985, 1991, and 1996.

		CONTENTS												
PLOT	YEAR	empty	1 cold egg	2 cold egg	adult	adult + 1 egg	adult + 2 eggs	adult + 2 chick	hatch memb.	dead chick	pred. egg	pred. burr.	Total Occup.	Total known
1	1985				2		6						8	8
	1991						2		12				14	14
	1996	5	2	1					17	1			21	26
2	1985	6			3								3	9
	1991	3	1	1	1		1		9		1		14	17
	1996	4	1						30				31	35
3	1985												0	0
	1991								5				5	5
	1996		1						2				3	3
4	1985	1					3						3	4
	1991	2	1						10				11	13
	1996	2		1					7	3			11	13
5	1985	4	2		8						1		11	15
	1991	5	1						15				16	21
	1996	6	2	1			1		17	1			22	28
6	1985	1	1		1	1	4						7	8
	1991	2							5				5	7
	1996	3	1						14				15	18
7	1985	1					3						3	4
	1991	2			1		1						2	4
	1996	4	1						7				8	12
8	1985		1				2						3	3
	1991	5							7				7	12
	1996	2							16			1	17	19

Appendix 1: Incidental observations

We recorded any incidental observations of other bird and mammal species seen in the course of our work on the island, and I include that list here.

Bald Eagle - Three nests were present on the island (Fig. 1).

1. This nest, in a spruce tree near shore on the northeast point of the island, is the same one that we mapped in 1985. Adult eagles were seen and heard calling around this nest most of the days that we were on the island.
2. The nest on the east coast of the island, mapped in 1985 is still present in a spruce set back from shore. Adult eagles were heard in the vicinity.
3. This nest on the western side of the island is situated in a dead spruce tree that is leaning against another snag. The nest is built where the two trunks intersect, and two adults were present at the site on June 27. No nest was found here in our previous survey of the island.

In 1985, there was also a nest on the west side of the southern bay, but we couldn't find a nest there during our time on the island this year. A large 2.5m dbh spruce, now a snag, that had broken off halfway up the trunk, could have been the tree which held the nest in 1985.

Peregrine Falcon - heard on June 25.
Pigeon Guillemot
Rufous Hummingbird
Red-breasted Sapsucker
Pacific Slope Flycatcher
Northwestern Crow
Common Raven
Chestnut-backed Chickadee
Winter Wren
Swainson's Thrush
Hermit Thrush
Orange-crowned Warbler
Townsend's Warbler
Song Sparrow
Red Crossbill
Pine Siskin

River Otter - Runways and scats were present around much of the perimeter of the island, with concentrations on mossy roots of trees near the northern end of transect 1, and on the south coast near the small notch bay. Otters also frequented the interior low wetland area, and we found a den under a stump on a low forest ridge on the border of this area.

We found no sign of raccoons or rats on the island.

VARIATION IN THE MASS OF ANCIENT MURRELET CHICKS AT COLONY DEPARTURE: WHAT HAVE WE LEARNT FROM THE PAST 7 YEARS?

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ABSTRACT

At East Limestone Island, Ancient Murrelet chicks have been trapped at colony departure, en route from their burrows to the sea, since 1990. Evidence from the analysis of the proportion of chicks recaptured as adults suggests that their weight at departure may be an important factor determining their subsequent survival and recruitment. I analysed data from the past seven years to detect factors that cause variation in departure weights. Significant variation occurred among years, and also seasonally, with the weights of chicks taken from burrows and those captured at departure, declining with date. In addition, departure weights became more variable as the season progressed. Time of night also was found to have some effect on weights at departure, being most noticeable during the middle of the chick-rearing period.

Introduction

The conditions of young seabirds at the time when they leave the colony may be important for their subsequent survival. In the case of the Ancient Murrelet (*Synthliboramphus antiquus*), where chicks leave the burrow at 1-3 days old and have to swim non-stop for 12-18 h before they begin to be fed by their parents (Duncan and Gaston 1988), their weight at departure may be an indication of the fat deposits that they are carrying, and hence their likelihood of surviving the initial dispersal from the colony. An analysis of the proportion of chicks recaptured at the colony as adults (Laskeek Bay Science 6) suggested that few chicks departing at weights of less than 24 g are likely to survive to return as adults.

The weight of chicks at departure varies from about 18 g to 34 g (Gaston 1992): a very large range relative to the variation in egg size. Much of the variation in chick weights is probably caused by variation in the duration spent in the burrow, because chicks lose about 2 g/day while they remain on land (Duncan and Gaston 1988).

The time elapsing from hatching to departure may be determined by the length of incubation shifts, which average 3 days, but may be as much as 5 days (Gaston 1992). Both parents must be present for normal departure to take place, so that if the off-duty parent does not return from feeding for several days, departure is correspondingly delayed.

It is probable that incubation exchanges are more frequent close to hatching than earlier in incubation. Nevertheless, if non-return of the off-duty parent is a likely cause of delay at departure, we can speculate on a number of possible effects. For instance, young, inexperienced breeders may be less likely to maintain a high rate of incubation exchange, resulting in their chicks having to wait longer, on average, between hatching and departure, than those of more experienced birds. As inexperienced breeders tend to lay later than experienced birds among seabirds (Saether 1990), this leads to the prediction that departure weights should become lower and more variable as the season proceeds.

Methods

Ancient Murrelet chicks departing from their burrows at East Limestone Island proceed on foot to the sea, their parents flying ahead and reuniting with them on the water. To trap them for banding, chicks departing from the colony are directed towards collection points along the shore by plastic barriers (Gaston et al 1989). They are collected at regular intervals and transported to a nearby banding station where they are banded and weighed. Captures are carried out nightly from the start of chick departures to the first date following the peak on which no chicks are captured. During 1990-1995 the trapping funnels were kept active from the start of departures, about 2 h after sunset, to half an hour after the last chick was trapped. In 1996, this protocol was modified so that the funnels were operated until 2 am, irrespective of the time of last capture. During 1990-1995 only 12% of chicks were captured after 2 am.

Results

Departure dates

Most chicks departed between 10 May and 10 June in all years (>99%), although a few chicks were heard departing after the end of the trapping period in most years. The median departure date combining all years was 23 May with 90% of chicks leaving between 8 days before and 8 days after the median for that year and 99% between 10 days before and 20 days after. The distribution of departure dates for all years combined was somewhat skewed, with the peak coming just before the annual median and a long tail extending beyond the median (Figure 1). Skewness in the distribution of departure dates was not apparent in all years, being most extreme in 1993 and 1996, when peak departures came 8 and 6 days respectively after the departure of the first chicks (19 and 17 May) and distributions departed significantly from normality (Figure 3). Peak nights in other years were later (1990, 23; 1991, 28; 1992, 22; 1994, 22; 1995, 23 May). In some years departures were significantly bi-modal (1990, 1992 and 1995, Figure 4).

Mean dates of departure differed among most years (Tables 1 and 2), with an overall pattern of decreasing date of laying from 1990 to 1993 and later laying thereafter. All of the median dates are as early, or earlier, than any recorded at Reef Island in 1984-89, showing that the timing of breeding in the 1990s was generally earlier than in the preceding decade.

Weight at departure

Chick weight at departure during 1990-1996 averaged 27.11 ± 2.56 g (N=4566) and ranged from 17.5-38.5 g. The distribution was an excellent fit to a normal distribution (Figure 5) and 96.9% of all weights fell between 22-32 g. Hatchling murrelets lose at least 2 g before they depart from the burrow (Gaston 1992). As the weight of hatchling murrelets averages 73% of fresh egg weight and as the largest egg weighed to date weighed 50 g, the heaviest weights recorded (>36 g) may represent reading or recording errors and have been excluded from further analyses: they constitute <1% of all chicks weighed.

Table 1. Mean date of capture (from 1 April) for chicks departing from East Limestone Island

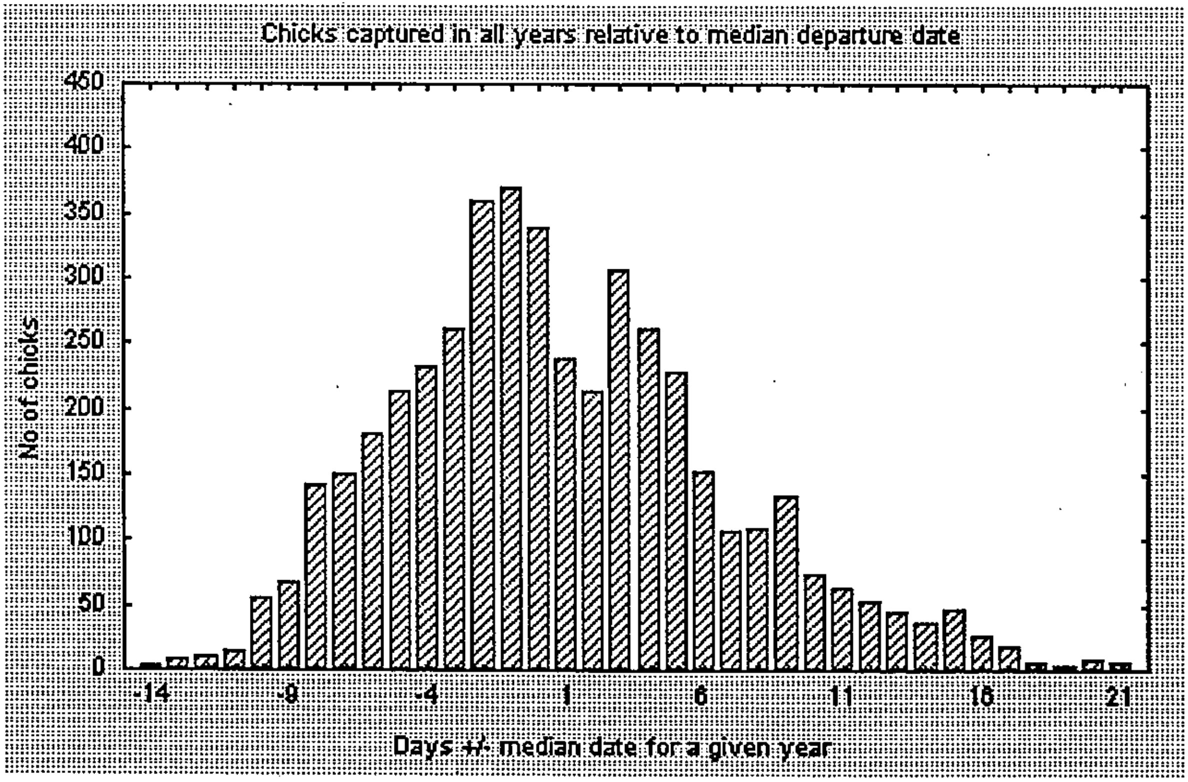
	Means	N	Std.Dev.	Median
1990	54.88	848	6.25	54
1991	53.96	592	5.66	54
1992	53.57	692	4.36	53
1993	51.67	643	5.73	50
1994	51.93	636	5.73	52
1995	54.71	543	6.53	54
1996	53.19	599	6.98	51
All Years	53.45	4553	6.03	53

Table 2. Duncan multiple range test for variation in mean dates of chick capture among years, 1990-1996. Combinations marked in bold differ at $P < .05$

	1990	1991	1992	1993	1994	1995	1996
Mean	54.88	53.96	53.57	51.67	51.93	54.71	53.19
1990		**.008067**	**.000164**	**.000004**	**.000004**	.609417	**.000005**
1991	**.008067**		.236105	**.000004**	**.000003**	**.024663**	**.025856**
1992	**.000164**	.236105		**.000003**	**.000012**	**.000874**	.249825
1993	**.000004**	**.000004**	**.000003**		.429051	**.000004**	**.000017**
1994	**.000004**	**.000003**	**.000012**	.429051		**.000004**	**.000160**
1995	.609417	**.024663**	**.000874**	**.000004**	**.000004**		**.000011**
1996	**.000005**	**.025856**	.249825	**.000017**	**.000160**	**.000011**	

Variation among years was small, the difference between the largest and the smallest annual mean being only 1.1 g, but it was highly significant ($F_{6,4551} = 23.25$, $P < 0.001$). However, the results from 1990 are suspect. This was the only year in which there was a significant variation in the mean weights of chicks captured in different areas. It was also the only year for which the distribution of weights appeared skewed (Figure 6). One of the spring balances used to weigh chicks was found, part way through the season, to be reading inaccurately

Figure 1. Distribution of departures in relation to median laying for each year, 1990-96 combined



and this was presumably the cause of the inter-area variation. However, we cannot be sure that the same balance was not used in other funnels. Consequently, all of the data for 1990 must remain suspect from the point of view of inter-year comparisons. With 1990 removed, variation among years was still present (Figure 7), but the probability was not as low ($F_{5,3692} = 7.95$, $P < 0.001$, Table 3). Years fall into two groups: (1) 1991, 1993, and 1994 are high weight years, while 1992 and 1995 are low weight years, all years in each group differ significantly from all years in the other group. 1996 is intermediate, being significantly different from 1994, but not from any other year (Table 4).

Table 3. Mean weight of Ancient Murrelet chicks at departure from East Limestone Island, 1991-96

	MASS (g)		
Year	Means	N	Std.Dev.
1991	27.11	589	1.89
1992	26.66	691	2.09
1993	27.00	646	2.39
1994	27.25	623	2.08
1995	26.66	550	2.17
1996	26.87	599	2.09
All years	26.93	3698	2.14

Table 4. Duncan multiple range test for inter-year differences in chick weight

Marked differences are significant at $P < .05$

	1991	1992	1993	1994	1995	1996
Mean	27.118	26.665	27.007	27.257	26.664	26.876
1991		.000384	.363452	.253826	**.000442**	.058776
1992	**.000384**		**.006839**	**.000007**	.989310	.083794
1993	.363452	**.006839**		.051594	**.008192**	.278633
1994	.253826	**.000007**	.051594		**.000007**	**.003133**
1995	**.000442**	.989310	**.008192**	**.000007**		.099691
1996	.058776	.083794	.278633	**.003133**	.099691	

Weight at departure declined during the course of the breeding season in all years, although the effect was very small (and statistically insignificant) in 1992. Overall, weight declined by 0.06 g/day, so that the change in mass over the entire, 30 day, departure period was of the order of 2 g. The weight of chicks weighed in burrows declined in relation to date at almost twice the rate: 0.11 g/day, this difference being significant (ANCOVA, $F_{1,3882} = 5.28$, P = 0.02; Figure 8). For departing chicks, there was substantial inter-year variation in the rate of weight decline with date (Table 5, Figure 9) ranging from 0.02 g/day in 1992 to 0.1 g/day in 1990. The same applied to chicks weighed in burrows, although the smaller sample sizes make this comparison less reliable (Figure 10).

Table 5. Correlation (*r*) and regression (B) coefficients for chick weights in relation to date. Coefficients in bold are significant at $P < 0.05$

Year	Chicks at departure			Chicks in burrows		
	r	B	*N*	*r*	B	*N*
1990	**.265**	-.100	865	-	-	-
1991	**.199**	-.067	589	.054	+.025	36
1992	.041	-.020	692	.111	+.093	27
1993	**.134**	-.056	647	**.366**	-.196	38
1994	**.136**	-.051	624	**.544**	-.334	29
1995	**.252**	-.081	550	**.468**	-.152	32
1996	**.194**	-.058	587	**.409**	-.145	40

The time of night at which chicks departed seemed to have relatively little relationship to their departure weights when all data were considered together (excluding 1990). However, when the data were split into early (<20 May), middle (20-29 May) and late (>29 May) periods, there was a tendency for chicks leaving in the early part of the night to be lighter than those that left later. This applied especially to those departing in the middle period (comparing half-hour periods, ANOVA $F_{6,2062} = 3.79$, $P < 0.01$; Figure 11). A smaller effect was apparent for the early period ($F_{6,1094} = 2.77$, $P = 0.01$; Figure 12) and no such effect was apparent for the late period (Figure 13). When the data for the early and middle periods were further split up among years, no trend was apparent for chicks departing during the early period in 1995 and 1996 (Figure 14), nor in 1994 or 1996 for chicks departing during the middle period (Figure 15).

Variation in departure weights, as measured by the coefficient of variation (SD/mean), showed a general increase over the course of the breeding season (r

= 0.46, N = 32, P < 0.01; Figures 16 and 17).

Discussion

Overall, chick weight at departure has shown relatively little variation over the years analysed (Cf. Thick-billed Murres *Uria lomvia*, Gaston et al. 1983; Cassin's Auklets *Ptychoramphus aleuticus*, Ainley and Boekelheide 1990). This is hardly surprising, because, with no provisioning in the burrow, departure weight of Ancient Murrelet chicks is bound to be closely related to hatching weight and hence to egg size, which has not varied much among years. However, individual variation (from 18-38 g) is very large and presumably results partly from variation in the length of time spent in the burrow.

The most constant feature of the weight data was the decline in departure weights with date, although even this trend was virtually undetectable in 1992. Part of the trend probably is accounted for by a similar trend in egg size, with mean egg volume index (Length* breadth^2) declining by an average of 0.04 - 0.46 ml/day (Gaston et al. 1995). The seasonal declines in departure weight were generally less steep than seasonal declined in egg volume, which were similar to seasonal declines in weight for chicks weighed in burrows. The difference suggests that later-hatching chicks lose less weight while in the burrow than those that hatched at the start of the season. This might be accounted for by the increase in burrow temperature that takes place during the departure period (Gaston 1992), causing hatchlings to expend less energy on thermoregulation after hatching. However, this is speculative. In addition, feeding conditions for breeders may improve as the season progresses, making it easier for the off-duty bird to return frequently to the colony during the period when hatching is about to occur.

The effect of time of night on chick weights at departure is difficult to interpret. It was a relatively small effect in most years, and most prominent in the middle of the departure period (20/21 to 29/30 May). One possible interpretation is that off-duty parents which have spent longer than usual away from the colony tend to arrive earlier in the night, and hence depart earlier. If this was the case, a higher than average proportion of chicks departing early in the night might have spent longer than usual in the burrow.

Increased variation in departure weights as the season proceeds was predicted on the basis that a high proportion of late-laying breeders probably are young, inexperienced birds. The fact that variation increases, but mass does not decrease as much as predicted by egg volume, indicates that these late-laying, less-experienced birds may be less regular in their attendance than experienced breeders, but apparently visit the colony as often, on average.

In summary, we have found significant variation in chick weights, both within and between years, and in relation to time of night as well as date. The effect of time of night has not been described before and emphasizes the importance of using a standard period of capture if we wish to compare weights among years.

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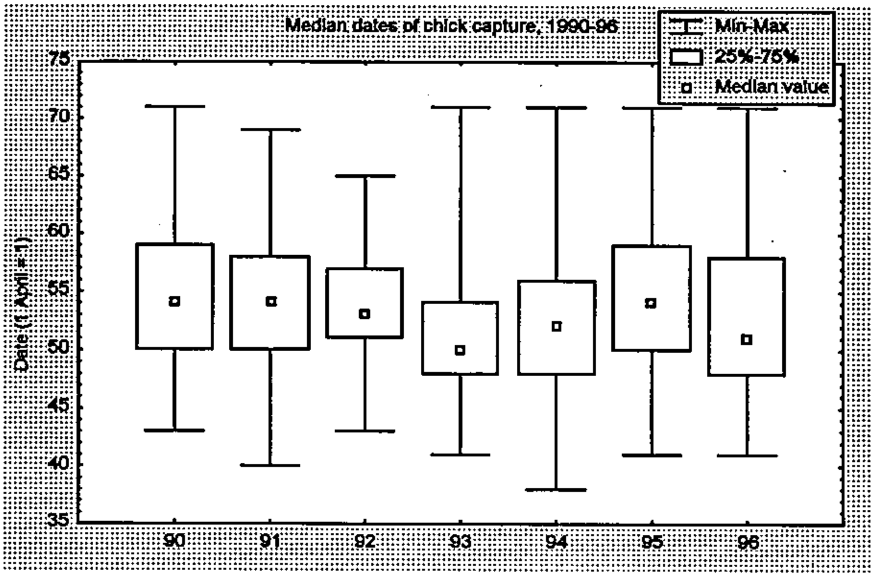


Figure 2

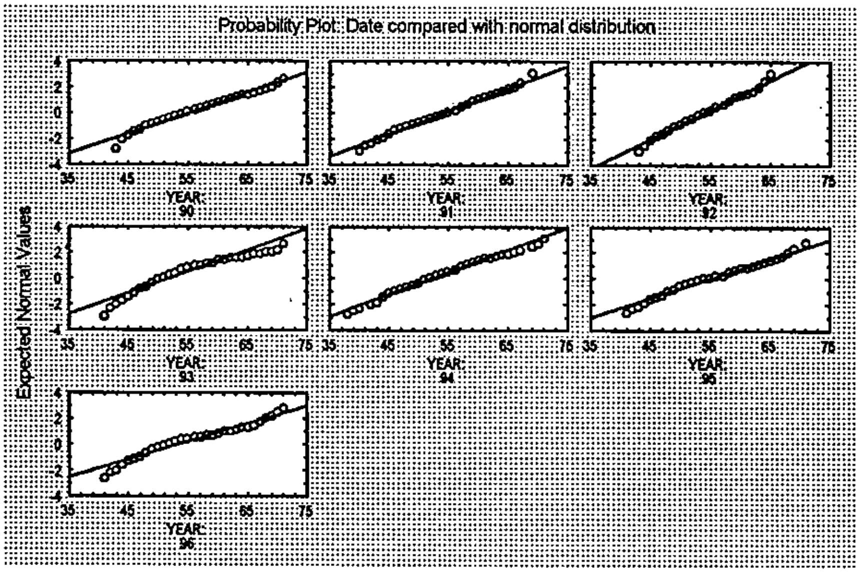


Figure 3

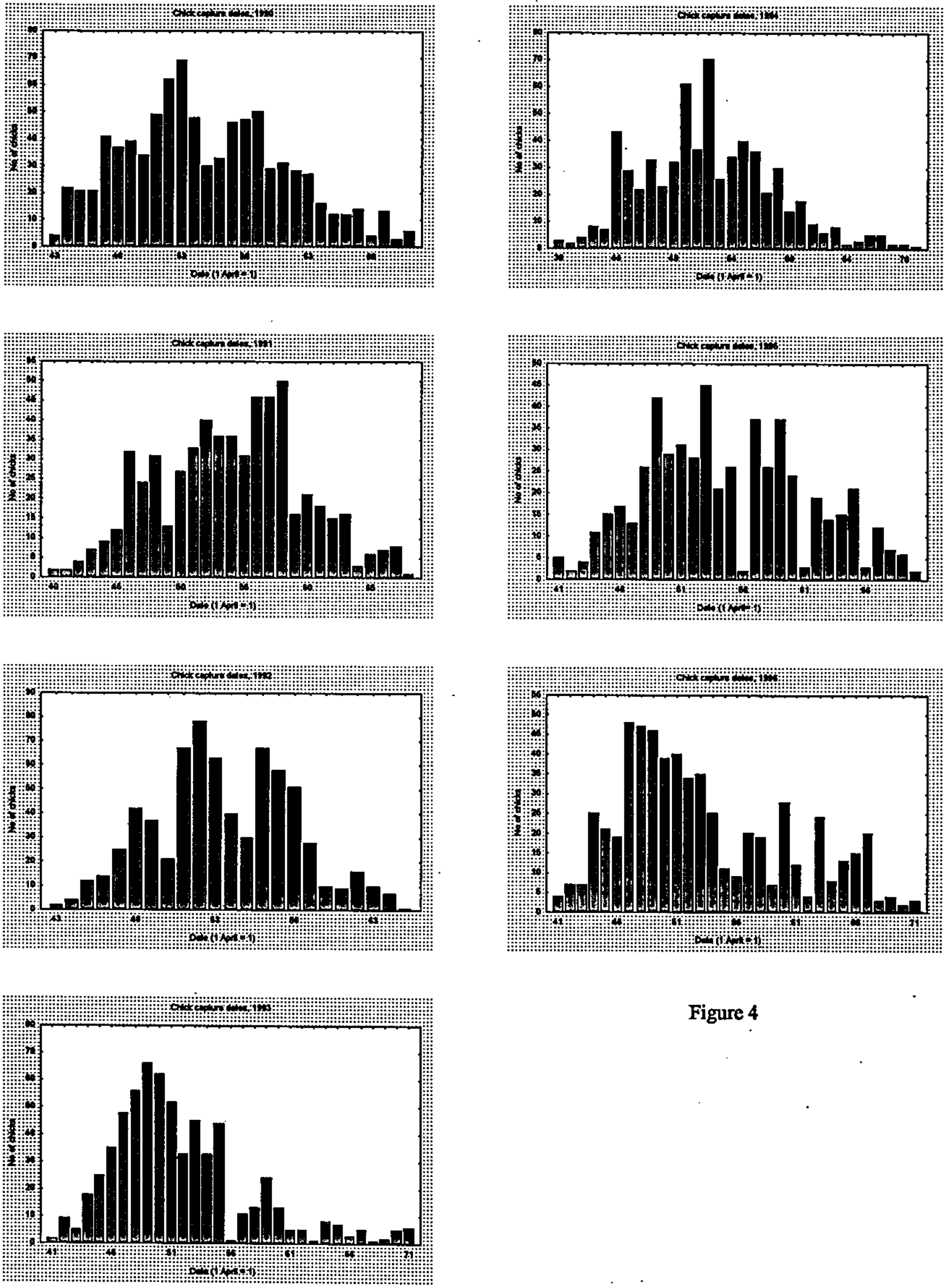

Chick capture dates, 1990
Chick capture dates, 1991
Chick capture dates, 1992
Chick capture dates, 1993
Chick capture dates, 1994
Chick capture dates, 1995
Chick capture dates, 1996
No of chicks
Date (1 April = 1)

Figure 4

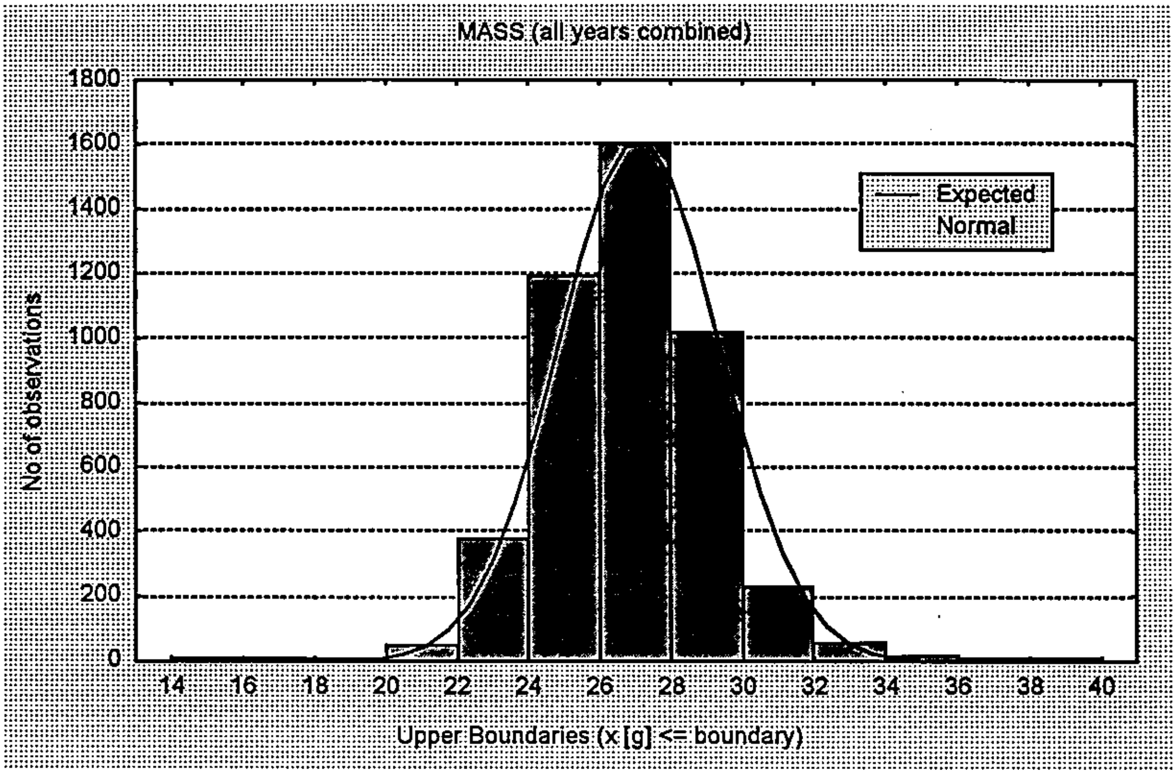


Figure 5

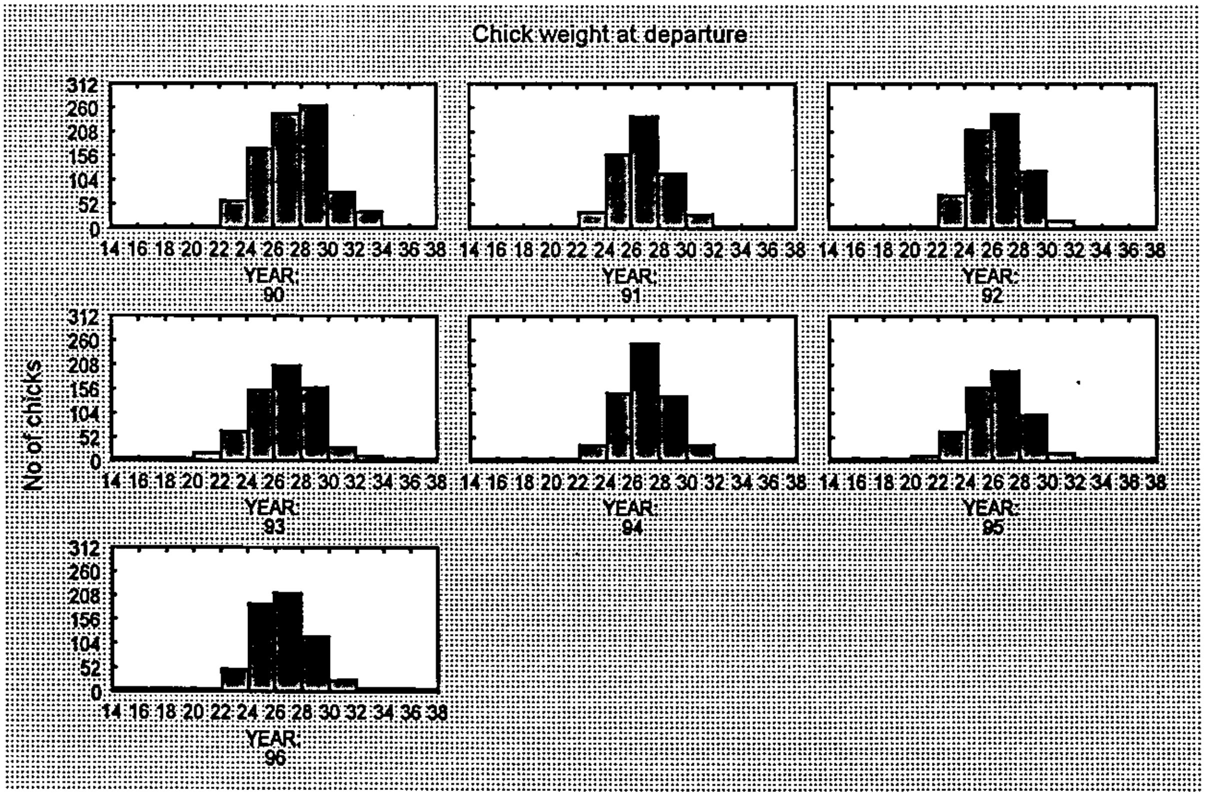


Figure 6

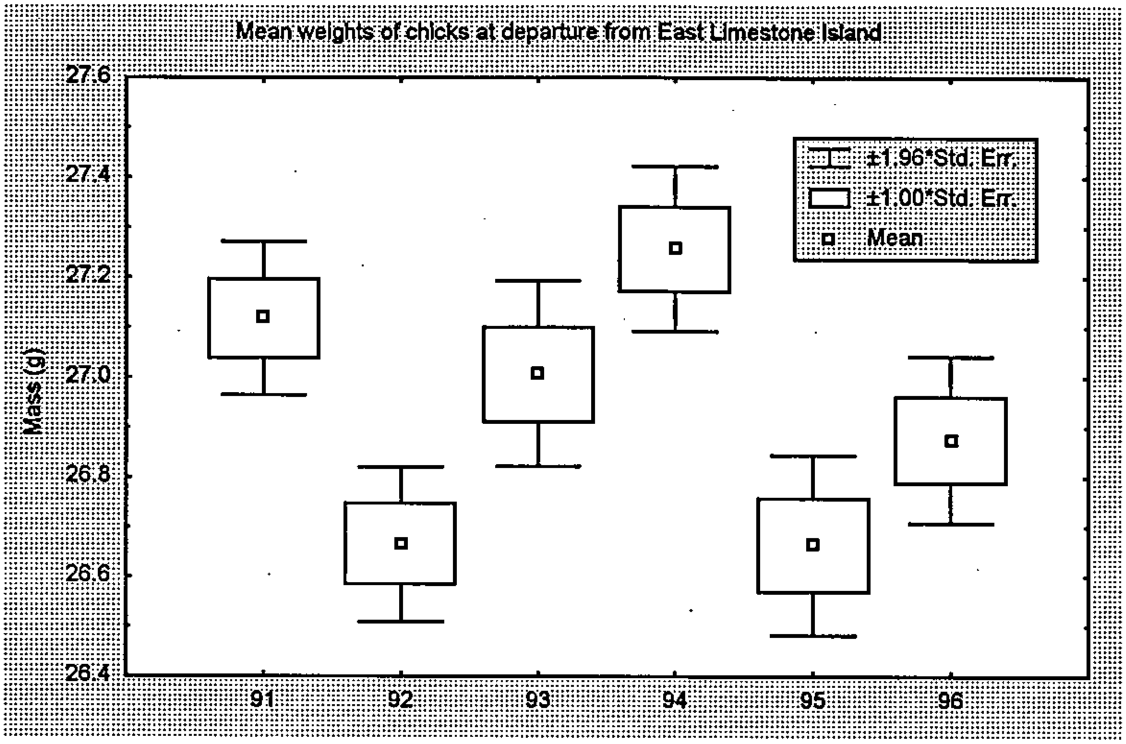


Figure 7

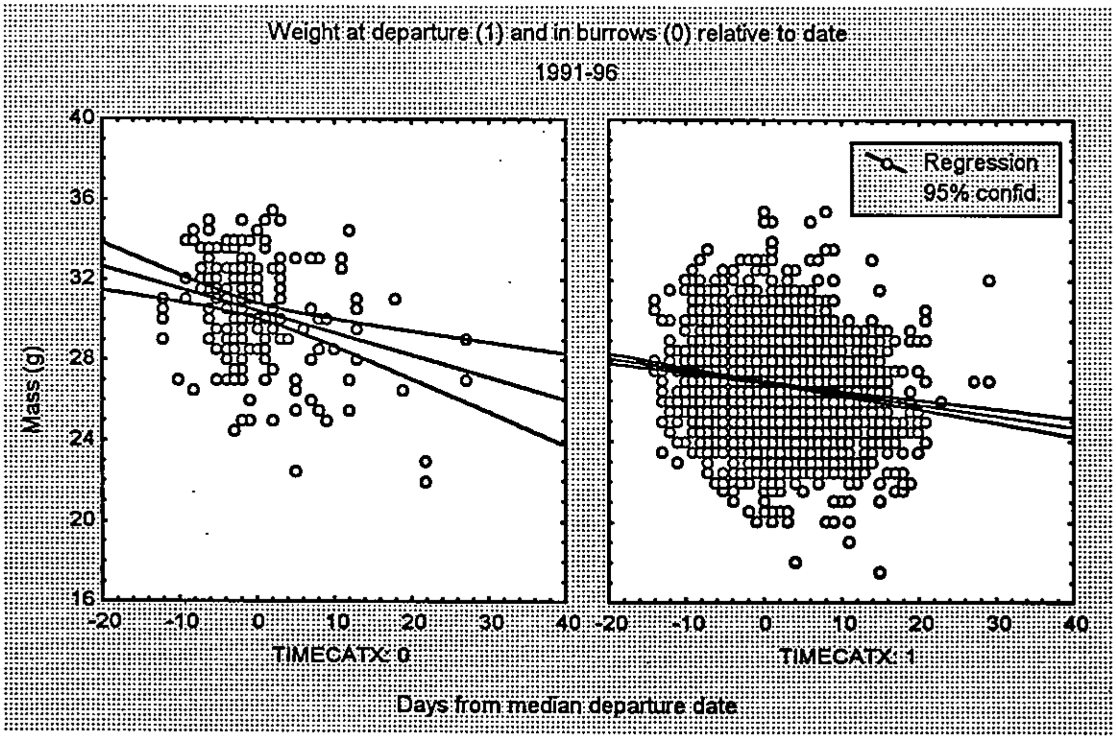


Figure 8

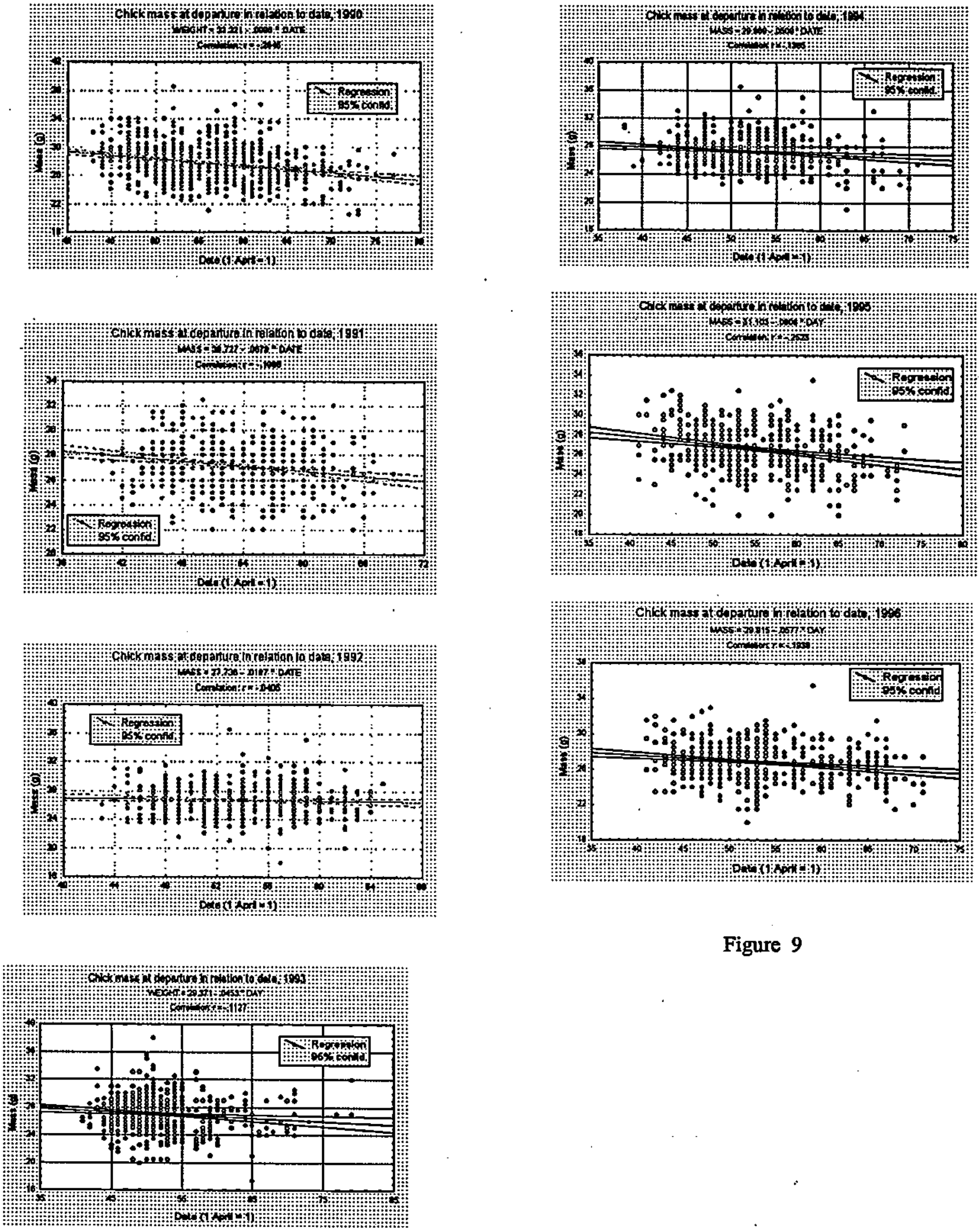
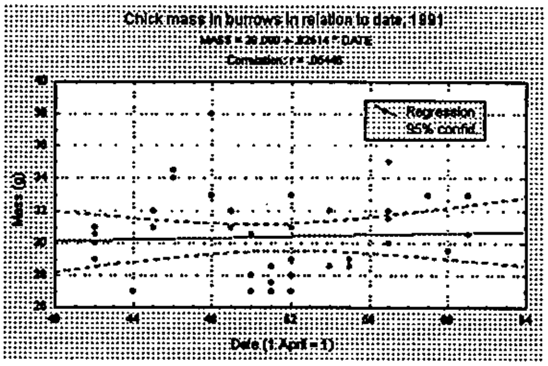
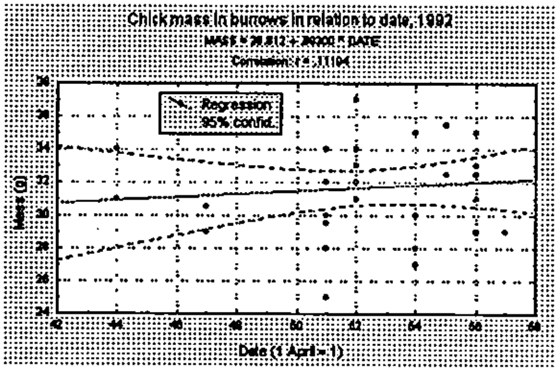
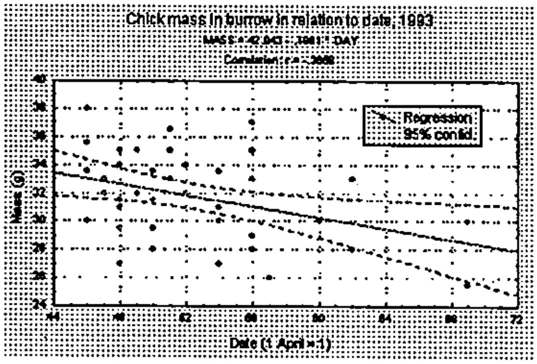
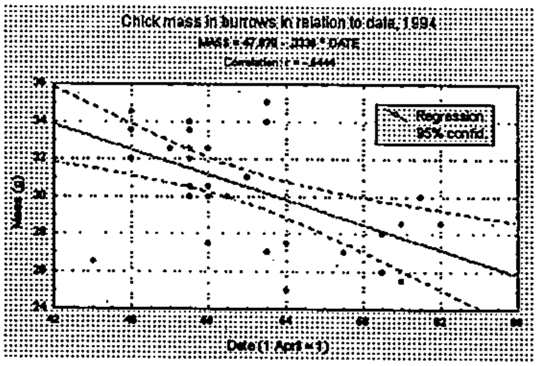

Chick mass at departure in relation to date, 1990
Correlation: r = -.2445
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1991
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1992
MASS = 27.736 - .0187 * DATE
Correlation: r = -.0406
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1993
WEIGHT = 29.371 - .0453 * DAY
Correlation: r = -.1127
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1994
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1995
MASS = 31.103 - .0904 * DAY
Correlation: r = -.2523
Regression
95% confid.
Mass (g)
Date (1 April = 1)
Chick mass at departure in relation to date, 1996
MASS = 29.815 - .0577 * DAY
Regression
95% confid.
Mass (g)
Date (1 April = 1)

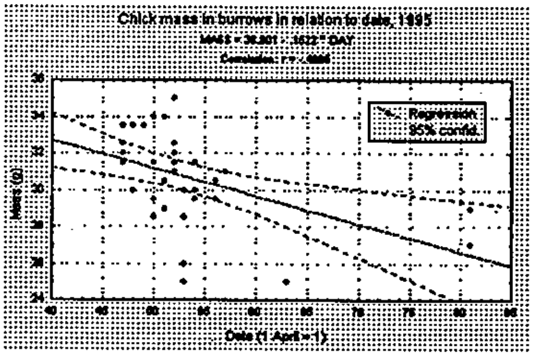
Figure 9


Chick mass in burrows in relation to date, 1991


Chick mass in burrows in relation to date, 1992


Chick mass in burrow in relation to date, 1993


Chick mass in burrows in relation to date, 1994


Chick mass in burrows in relation to date, 1995

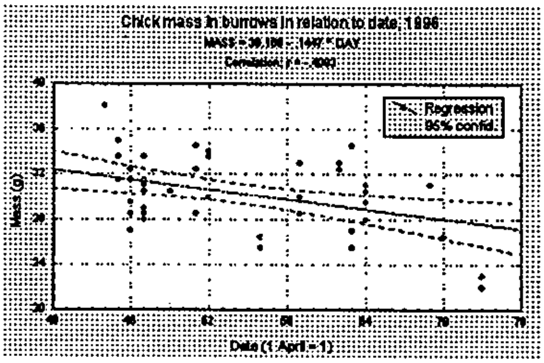

Chick mass in burrows in relation to date, 1996

Figure 10

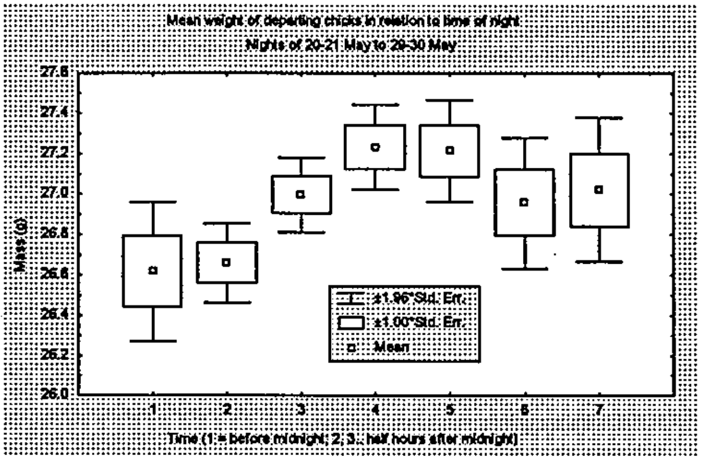


Figure 11

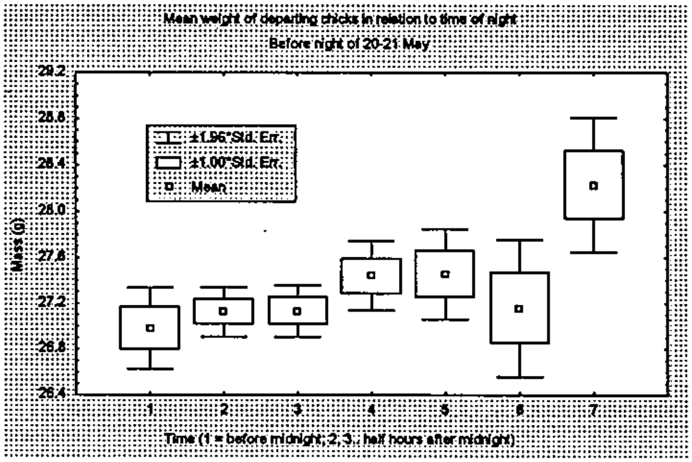


Figure 12

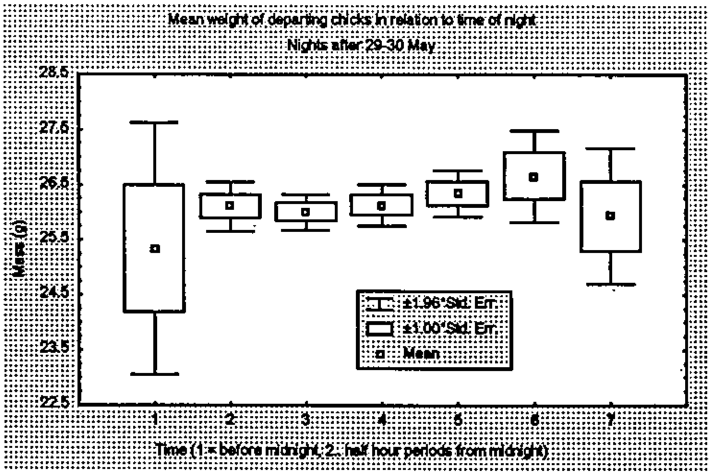


Figure 13

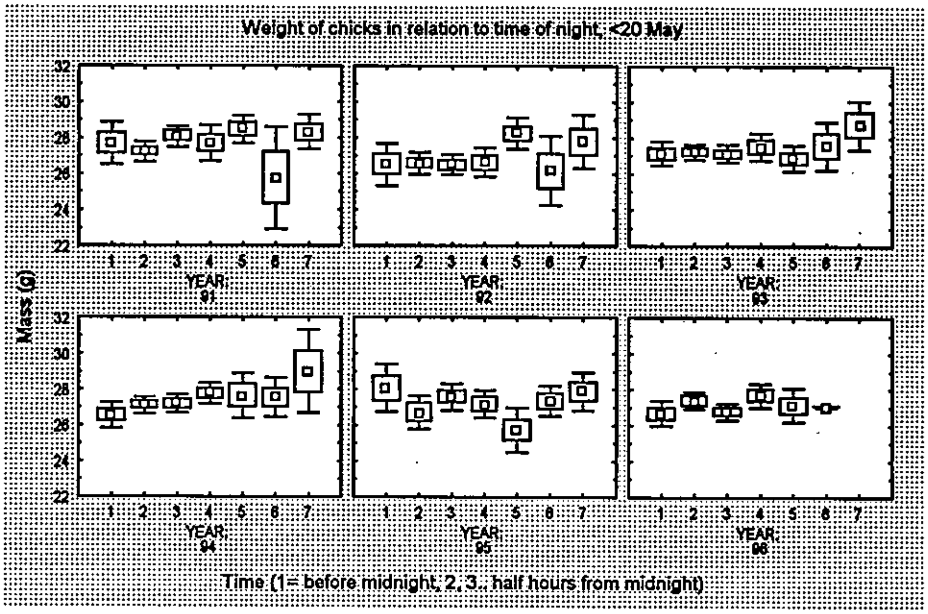


Figure 14

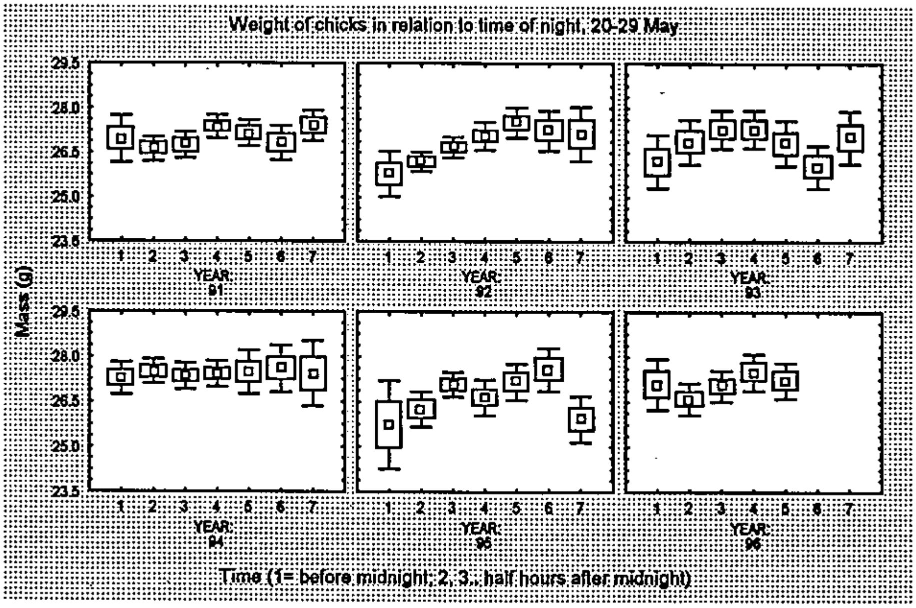


Figure 15

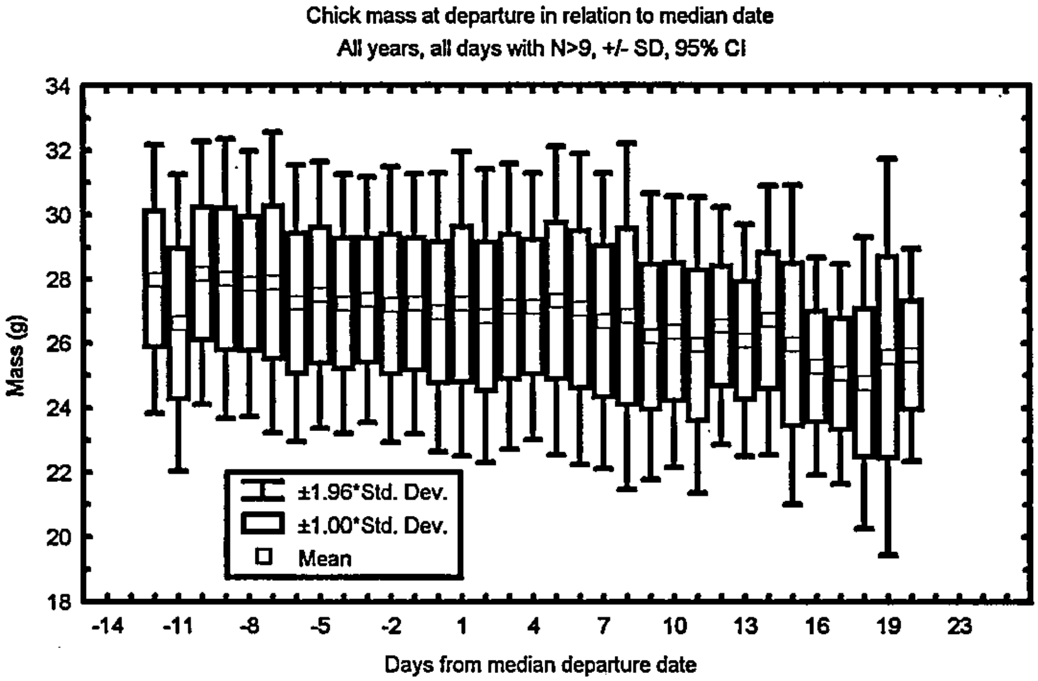


Figure 16

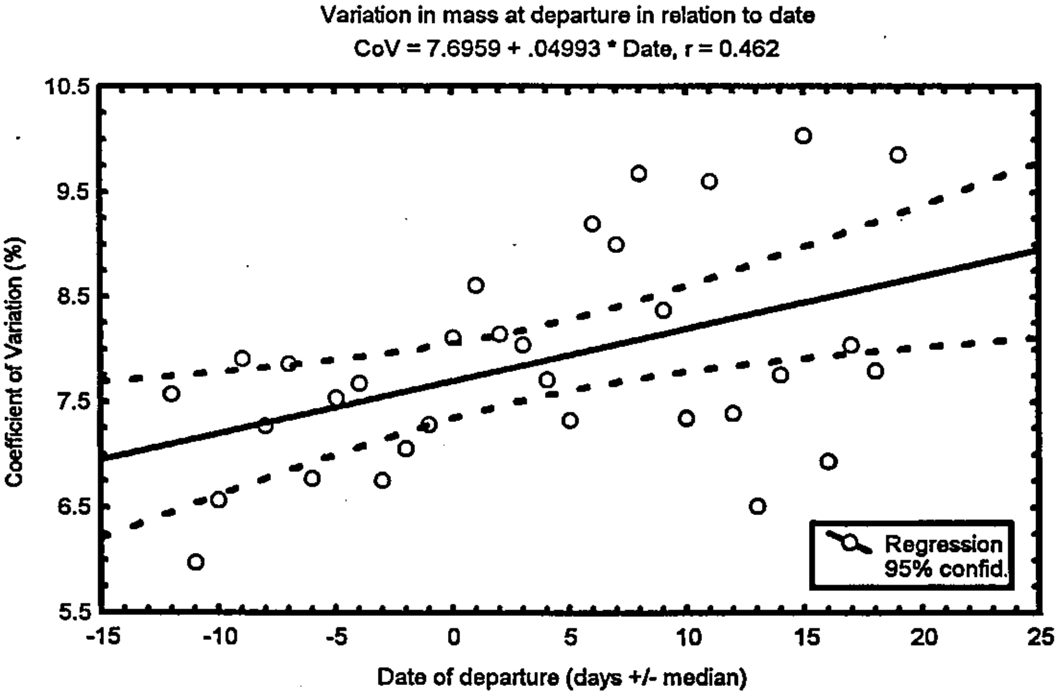


Figure 17