BIOLOGICAL CONTROL OF ALEUTIAN ISLAND ARCTIC FOX

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University of California, Davis
in cooperation with
U.S. Fish and Wildlife Service

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Final Report

Under Contract 14-16-0007-80-5519

between the

U. S. Fish and Wildlife Service

and the

University of California, Davis, 95616

Termination Date: June 30, 1982

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ABSTRACT

Empirical and literature data on the resource utilization patterns of arctic fox (Alopex lagopus) and red fox (Vulpes vulpes) are evaluated to assess the potential for using red fox as biological control agents to eliminate arctic fox from the Aleutian Islands. A high degree of overlap in food, home range, and den site requirements suggests that if neutered red fox are introduced onto islands supporting arctic fox populations, they will effectively outcompete the arctic fox for access to these resources. Red foxes are apparently behaviorally dominant in areas of sympatry and are able to displace arctic foxes from preferred feeding and den sites. Spatial and temporal heterogeneity in resource availability on islands with diverse topography, however, may permit coexistence of the two species. Additional field research is recommended to determine if red fox can completely exclude the arctic fox if introductions are made in sufficient numbers.

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ACKNOWLEDGEMENTS

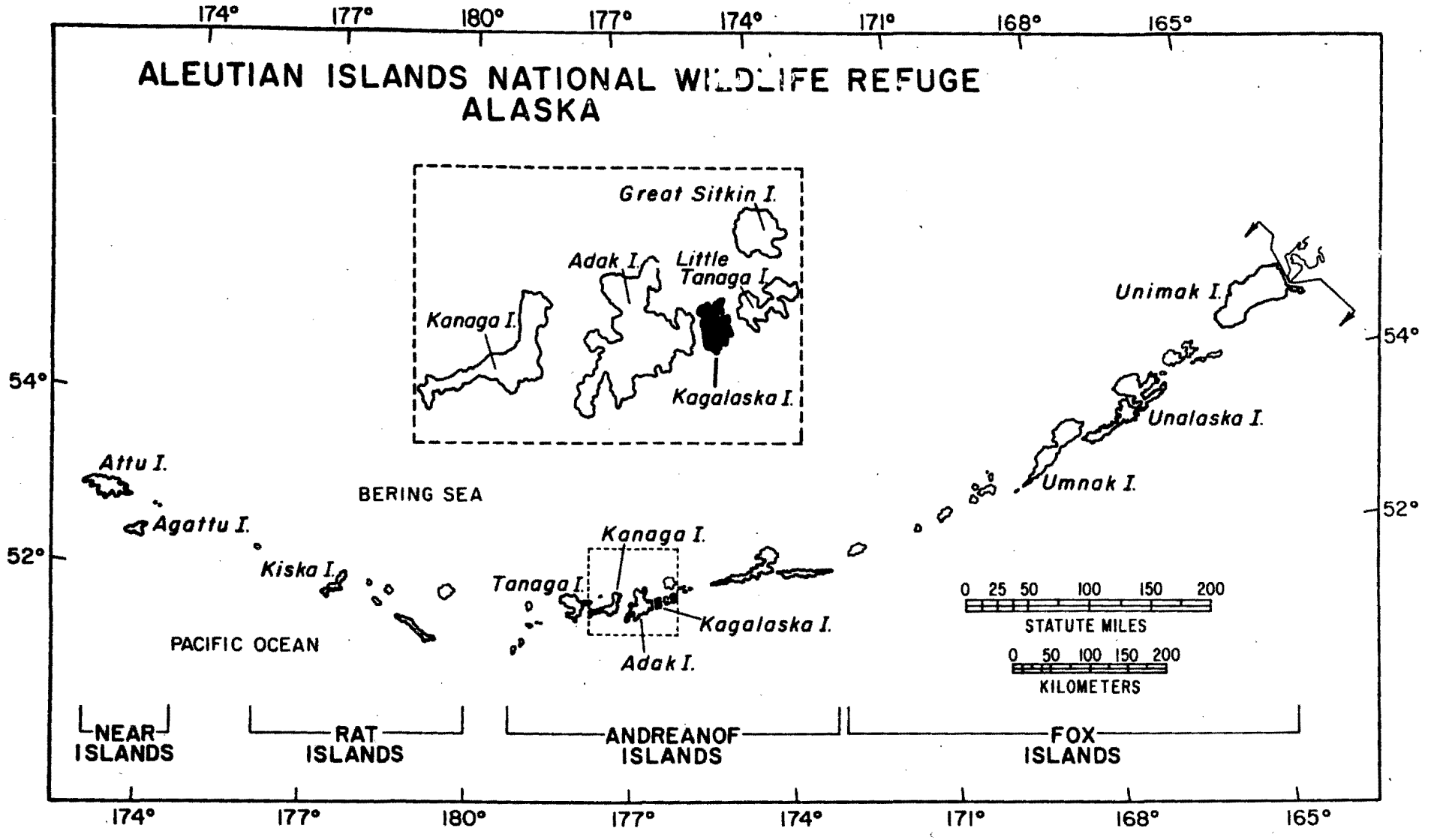
We would like to express our sincere gratitude to the following persons who assisted in many ways in implementing this project. Dr. Ronald L. Garrett spent endless hours coordinating the operations of the University and the USF&WS. His efforts in getting the project underway are gratefully acknowledged. Ed Bailey suggested the possibility of using red fox as biological control agents and provided insightful information on the history of fox farming in the Aleutian Islands. Les Eberhardt, Dr. Phil Gibson, Dr. Eric Fullman, Dr. Larry Underwood, and Don Rudzinski generously shared their experience and knowledge of arctic fox biology and contributed many useful references, without which this report would not be complete.

In the field the assistance of the staff of the USF&WS headquarters in Adak was invaluable. John Martin and C. Fred Zeillemaker, successive refuge managers, greatly facilitated operations by providing expert logistical support. Kent Hall, Bev Minn, Tom Early, Barry Rieswig, Fred Dines, Van Klett, Leslie Slater, Ron Bowers, and the YACC's Mark Masteller, Steve Kendall, Justine Logan, and Patti Beach helped in endless ways to establish and maintain our field camp. Doug Forsell generously arranged for the loan of a weatherport tent that kept us warm and dry through many gales and storms.

INTRODUCTION

The delicate balance of natural island ecosystems can be easily upset by the introduction of foreign organisms. Island species, isolated from complex mainland ecosystems, evolve to form relatively simple communities (MacArthur and Wilson 1967). These systems generally lack sufficient natural controls to respond effectively to competition or to predation by introduced species. Without strong checks on their growth, non-island species will also increase rapidly in number, invariably at the expense of many forms of endemic fauna.

On the Aleutian Islands in Alaska (Figure 1), arctic fox (Alopex lagopus), which were introduced onto the islands, have eliminated many breeding populations of marine bird species and threaten the total extinction of a race of Canada Goose (Branta canadensis leucopareia). In an effort to restore island ecosystems to their natural state, research was initiated by the University of California at Davis in cooperation with the U.S. Fish and Wildlife Service, to develop a management program to remove the arctic fox using biological control methods. This program was designed to test the hypothesis that red fox (Vulpes vulpes), an apparent competitively superior species to the arctic fox in sympatric mainland habitats, will eliminate the arctic fox by competitive exclusion if introduced onto the same island. Major federal budget cuts, however, forced a premature termination of the project. In this report we summarize the work completed to date, and discuss the


ALEUTIAN ISLANDS NATIONAL WILDLIFE REFUGE
ALASKA
174°
177°
180°
177°
174°
171°
168°
165°
54°
52°
Great Sitkin I.
Adak I.
Little Tanaga I.
Kanaga I.
Kagalaska I.
Unimak I.
Unalaska I.
Umnak I.
Attu I.
Agattu I.
Kiska I.
BERING SEA
PACIFIC OCEAN
Tanaga I.
Kanaga I.
Kagalaska I.
Adak I.
0 25 50 100 150 200
STATUTE MILES
0 50 100 150 200
KILOMETERS
NEAR ISLANDS
RAT ISLANDS
ANDREANOF ISLANDS
FOX ISLANDS

biological potential for the use of red fox as effective biological control agents.

Historical Background

Foxes were first introduced to the Aleutian Islands by the Russian-American Company beginning in 1886 for the purpose of establishing fur "ranches" (Ashbrook and Walker 1925). Pairs of fox were transported to various islands and left there to breed. After several years, trappers would return to harvest the foxes. Enough animals were left to rebuild the population. Islands were frequently selected for fox introduction on the basis of the local bird abundance which provided a natural food source (Osgood et al 1915). By 1925 foxes had been introduced to 77 islands along the Aleutian archipelago; by 1936 over 25,000 animals had been harvested. The economic depression of 1929 however, destroyed the market for wild furs (Chesemore 1975), and with the onset of World War II fur farming was virtually eliminated in Alaska (Merrit and Fuller 1977). But the foxes remained.

Without the frequent harvest by trappers the number of foxes increased to the full carrying capacity of the islands. As a result many endemic bird populations were markedly reduced or eliminated.

The full impact of the fox introductions was first assessed in 1936. Murie (1959) conducted a two-year survey of the fauna on 22 islands along the chain. His findings showed significant reductions in bird species

diversity, distribution and productivity. Large colonies of ancient murrelets (Synthliboramphus antiquum) and Cassin's auklets (Ptychoramphus aleutica) vanished from Sanak Island following the introduction of foxes. Storm petrels were entirely eliminated from Salt and Ilak Islands. Cassin's auklets disappeared from Keegaloo and Adukak Islands, as well as from small unnamed islands off Amila and Ilak Islands. Whiskered auklets (Aethia pygmaea) went extinct on the Near Islands (Turner 1886).

Recent bird surveys of other Alaskan Islands document a continued and more widespread reduction in bird populations by the foxes (Stephenson 1970, Bailey 1976, 1977, 1978, Bailey and Faust 1980a, 1980b). Crested auklets (Aethia cristatella) and parakeet auklets (Cyclorrhynchus psittacula) are still heavily preyed upon by the foxes on St. Lawrence Island in the Bering Sea. Horned puffins (Fratercula corniculata) and tufted puffins (Lunda cirrhata) are also taken in high numbers there (Stephenson 1970). On Big Koniuju Islands in the Shumagin Islands, Moe (1977) determined that 6 adult and 7 juvenile foxes killed 763 crested auklets and 95 horned puffins over a three month period. On a recent survey of over 100 islands south of the Alaska peninsula, which have, or have had foxes on them, no nocturnal seabirds were found (Bailey 1978, Bailey and Faust 1980).

Secondary prey species such as waterfowl, ptarmigan, and small passerines have also been affected—their numbers often being reduced to small groups of breeding pairs (Murie 1959). Cliff-nesting species as the Kittiwake

(Rissa sp.), murres (Uria sp.) and cormorants (Phalacrocorax sp.) have been least affected and still flourish on most islands.

The most significant and currently the most pressing ecological damage was the near extinction of the Aleutian Canada goose (Branta canadensis leucoparea). This species has vanished from its former extensive nesting range in the Aleutians except for a small population on Buldir Island (Jones 1963, Jones and Byrd 1979). In 1909 this goose was extremely abundant on Agattu Island in the western Aleutian Islands (Clark 1910). Foxes were first introduced on this island from 1923 to 1929 (U.S.F. & W.S. trapping records). Murie (1959) found that the geese had dwindled in number to be "... so scarce that migration was no longer noticeable".

The foxes have clearly upset the natural balance of these islands. Reversal of the present ecological damage and restoration of the bird communities to pre-introduction levels will not be a simple task. Realizing that suitable breeding habitats for pelagic birds of the world are rapidly disappearing due to development and human activities, coupled with the fact that artificial mortality factors (e.g., ocean fishing nets) are reducing existing populations at an astonishing rate, sobers one to the reality that if the birds are to survive they must have safe breeding sanctuaries.

Early Management Programs

In 1949 the U. S. Fish and Wildlife Service began an island restoration program to eliminate the arctic fox from selected Aleutian islands

(Martin et al 1978). This program entailed standard eradication procedures of broadcasting lethal baits. In 1956, 11,000 strychnine pellets concealed in seal blubber were dropped from a plane around Amchitka Island. In addition 130 stations of 1080-treated baits were established. Between 1956 and 1957, 30,000 additional strychnine pellets were dropped on the island. These methods proved effective in significantly reducing the fox population. Follow-up work involving trapping, shooting and hand placement of lethal baits resulted in complete eradication of the fox by 1960.

In 1964 lethal baits were broadcast around Agattu Island. Follow-up ground work was continued through 1967 after which time it was concluded that no foxes remained. In 1974 however, a check survey revealed that nearly 100 foxes were present. Ground work was resumed but, because of an executive ban on the use of strychnine and 1080 in 1972, efforts were curtailed to shooting, trapping and the use of M44's. This work continued through 1979 at which time only 1 fox was taken and the project was considered a success.

In 1975 and 1976 the program was expanded to Alaid/Nitzki Island(s). Follow-up work through 1978 revealed that no foxes remained on the island. In 1977 a pilot trapping program was implemented on Kanaga Island to estimate the endemic fox density in prelude to complete eradication. Sample shoreline fox density estimates were extrapolated for the entire island giving a total estimate of 700 foxes. Follow-up work was not pursued.

While these programs demonstrate effective control techniques, because of the ban on the use of lethal baits, they were comparatively slow, expensive, and difficult to support logistically. It was clear that a more expedient method was required to achieve the long-range management objectives of extirpating the foxes from the islands.

In 1979 Edgar Bailey, a U.S. Fish and Wildlife biologist, observed from records of fur-farming practices that in situations in which arctic and red foxes were introduced onto the same island, the red fox predominated and the arctic fox disappeared. He also noted that it was common practice at the time for fur ranchers to trap off all red foxes before introducing arctic fox. Bailey recommended that a program using red fox as biological control agents be investigated. In 1980 the cooperative agreement between the University of California and the United States Fish and Wildlife Service was entered into to achieve this objective.

RESEARCH DESIGN AND MODIFICATIONS

To test the hypothesis that red foxes introduced onto islands inhabited by arctic foxes will completely exclude the arctic fox, a three phase experimental program was established. Phase I was designed to expediently test the hypothesis with a challenge experiment. Red foxes were to be captured, neutered and introduced onto Shemya Island at twice the normal carrying capacity. The changes in behavior, resource utilization patterns and population density of the two fox species would then be monitored to determine if the red fox was competitively superior to the arctic fox.

Phase II was designed to analyze the possible mechanisms for competition between the two species. It was proposed that red foxes be introduced onto a series of small islands with a range of different topographies. The population dynamics of both the arctic and red foxes would then be monitored to ascertain the relative importance of spatial heterogeneity in resource availability in competitive interactions.

Phase III was to develop a management program to remove arctic foxes from islands targeted for avifaunal restoration.

Phase I of the program was scheduled to be initiated during the spring of 1981. This objective was postponed until the spring of 1982 however, when funding for the acquisition of the red foxes was not made available for 1981. Operations were then moved to Kagalaska Island (Figure 2) where preliminary baseline data were obtained on the ecology of the arctic

Figure 2. Map of Kagalaska Island, Alaska.

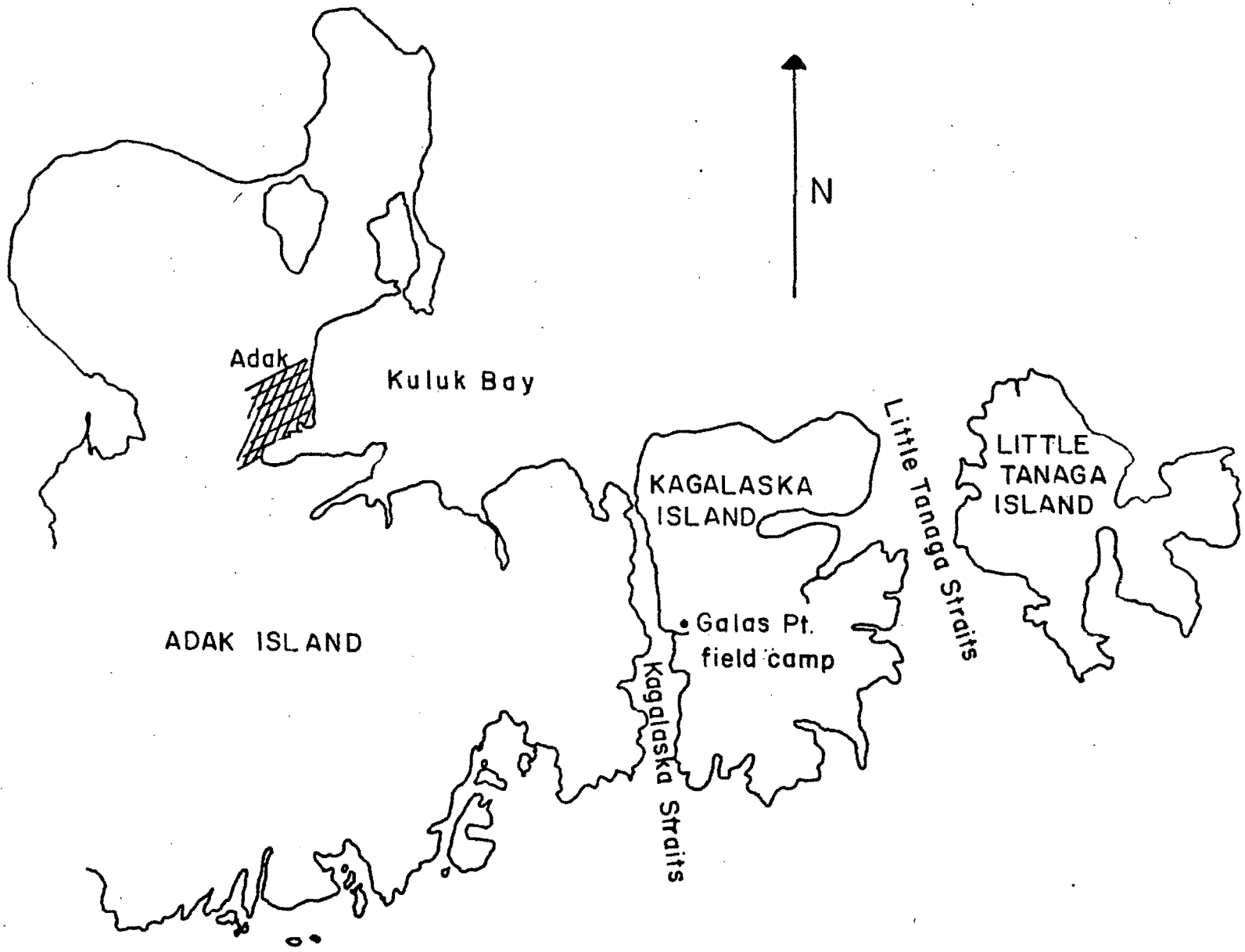

N
Adak
Kuluk Bay
KAGALASKA ISLAND
Little Tanaga Straits
LITTLE TANAGA ISLAND
Galas Pt. field camp
ADAK ISLAND
Kagalaska Straits

Figure 3. White phase arctic fox in winter pelage with tail dyed for visual identification.

Figure 4. Blue phase arctic fox tail treated with perioxide prior to application of dye.

FIGURE 3

FIGURE 4

Figure 5. Steep mountainous shore typical of many Aleutian Islands.

Figure 6. West shore of Kagalaska Island showing beach strand and headlands.

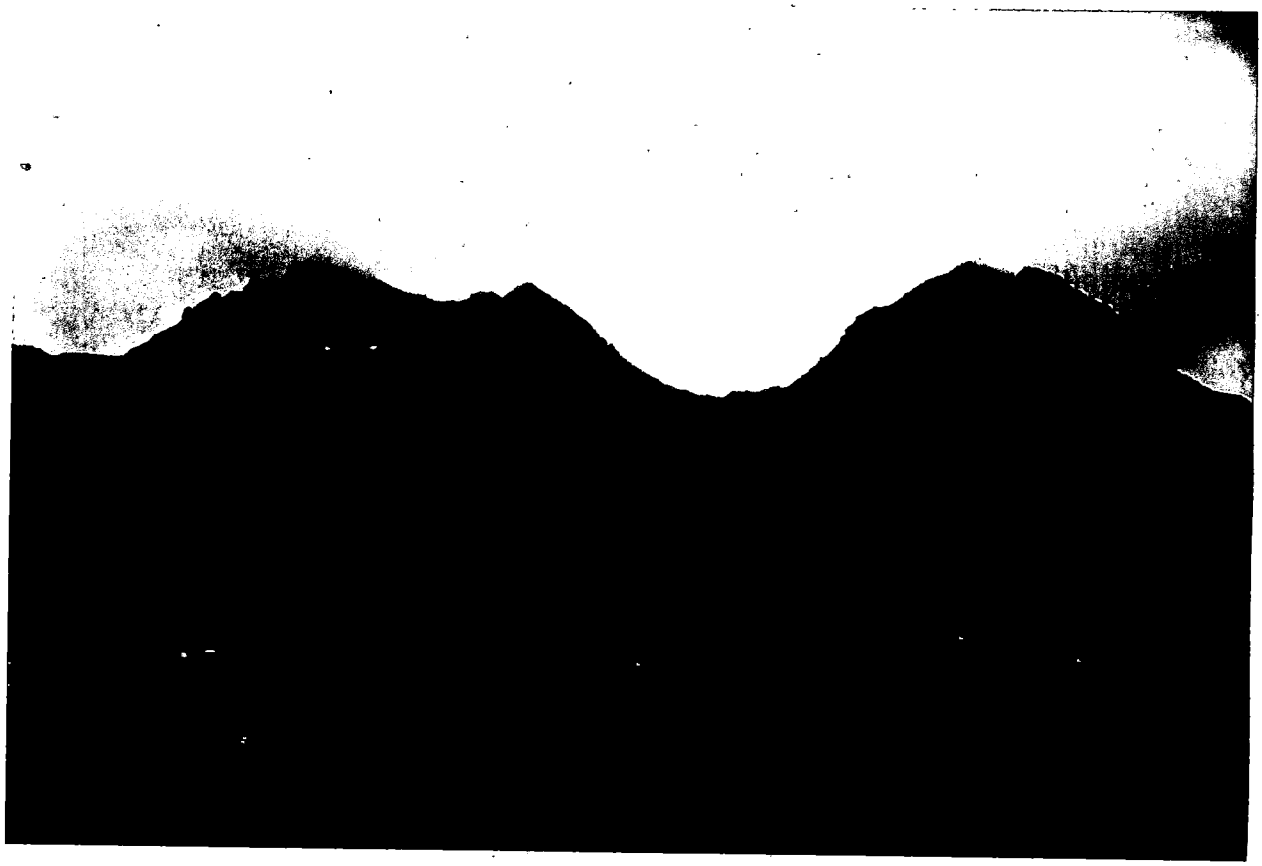


FIGURE 5

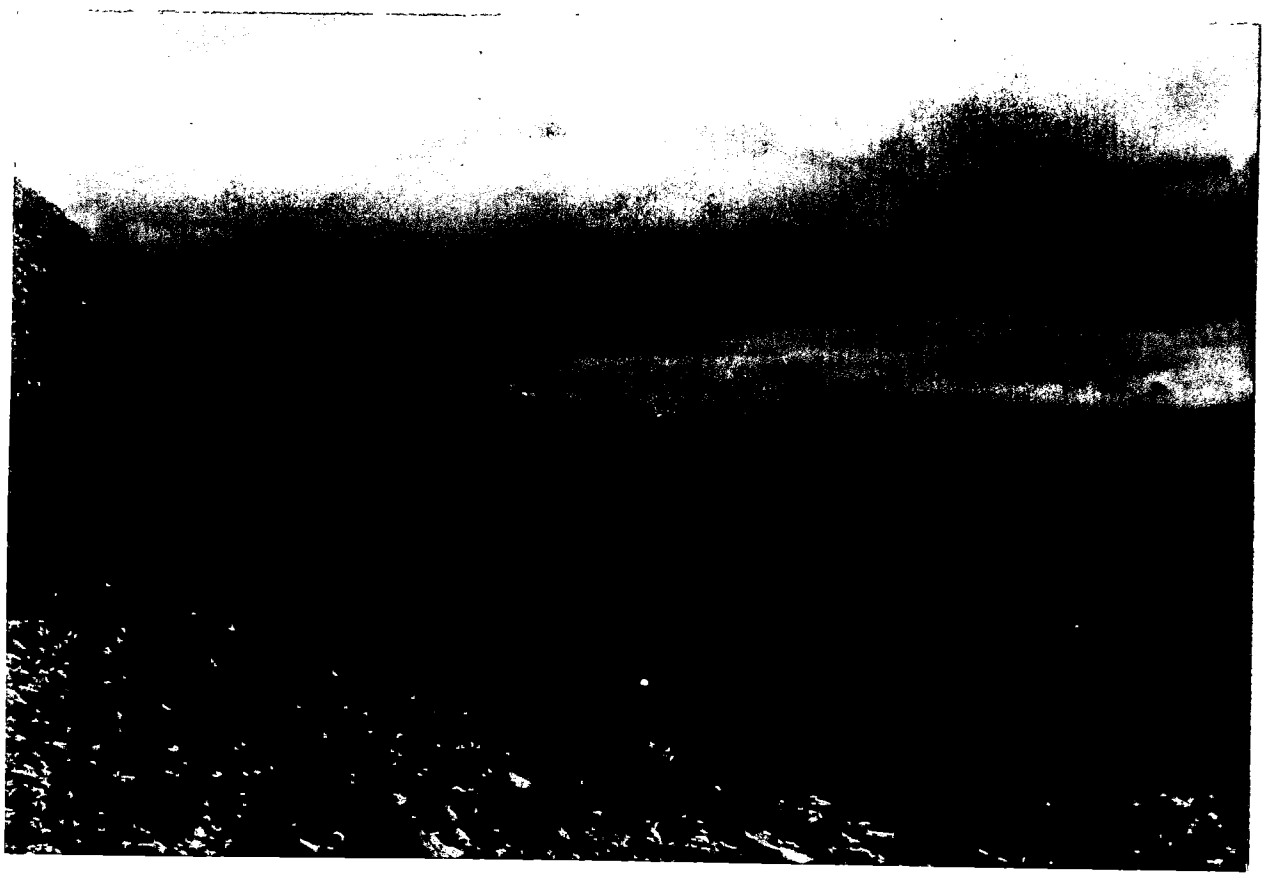


FIGURE 6

Figure 7. Mountains and lake located in interior Kagalaska Island.

Figure 8. Galas Point field camp, Kagalaska Island.

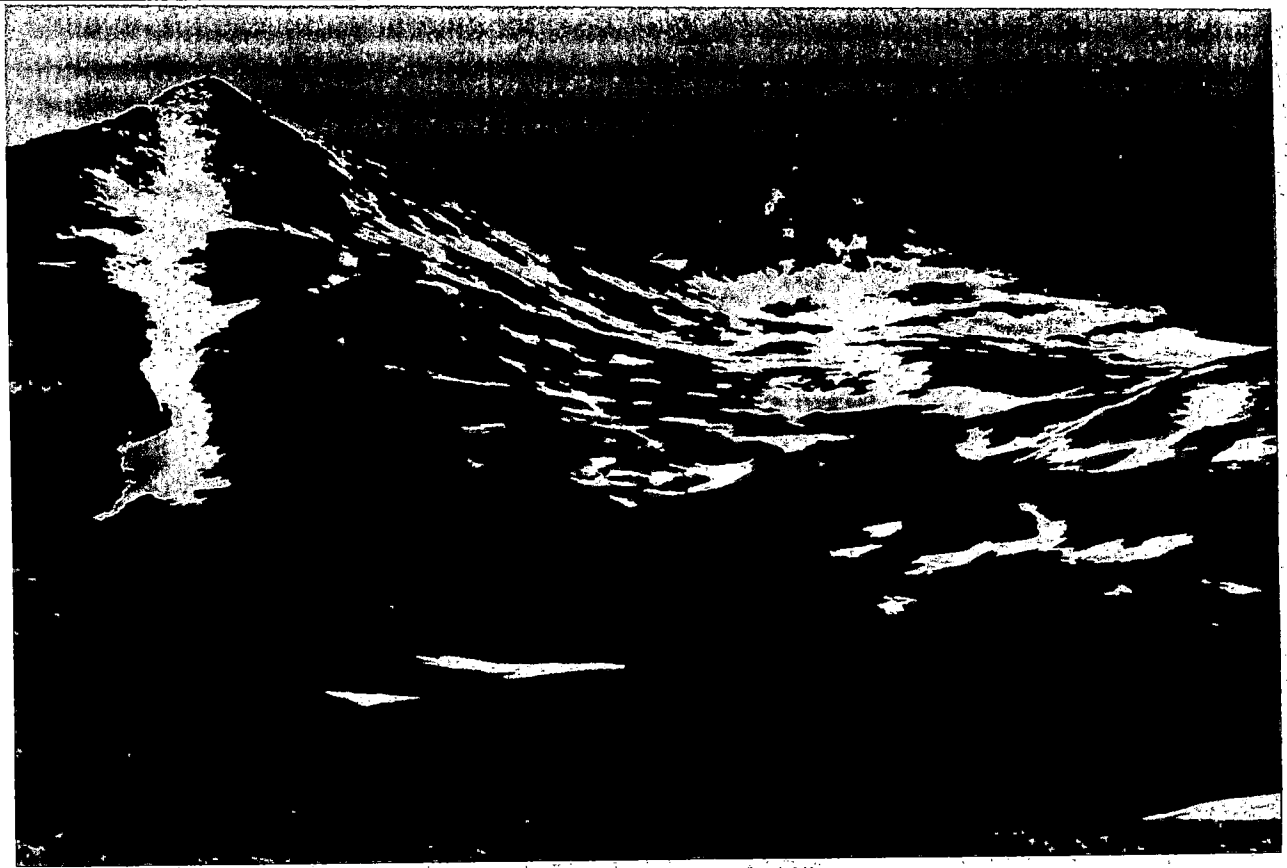


FIGURE 7

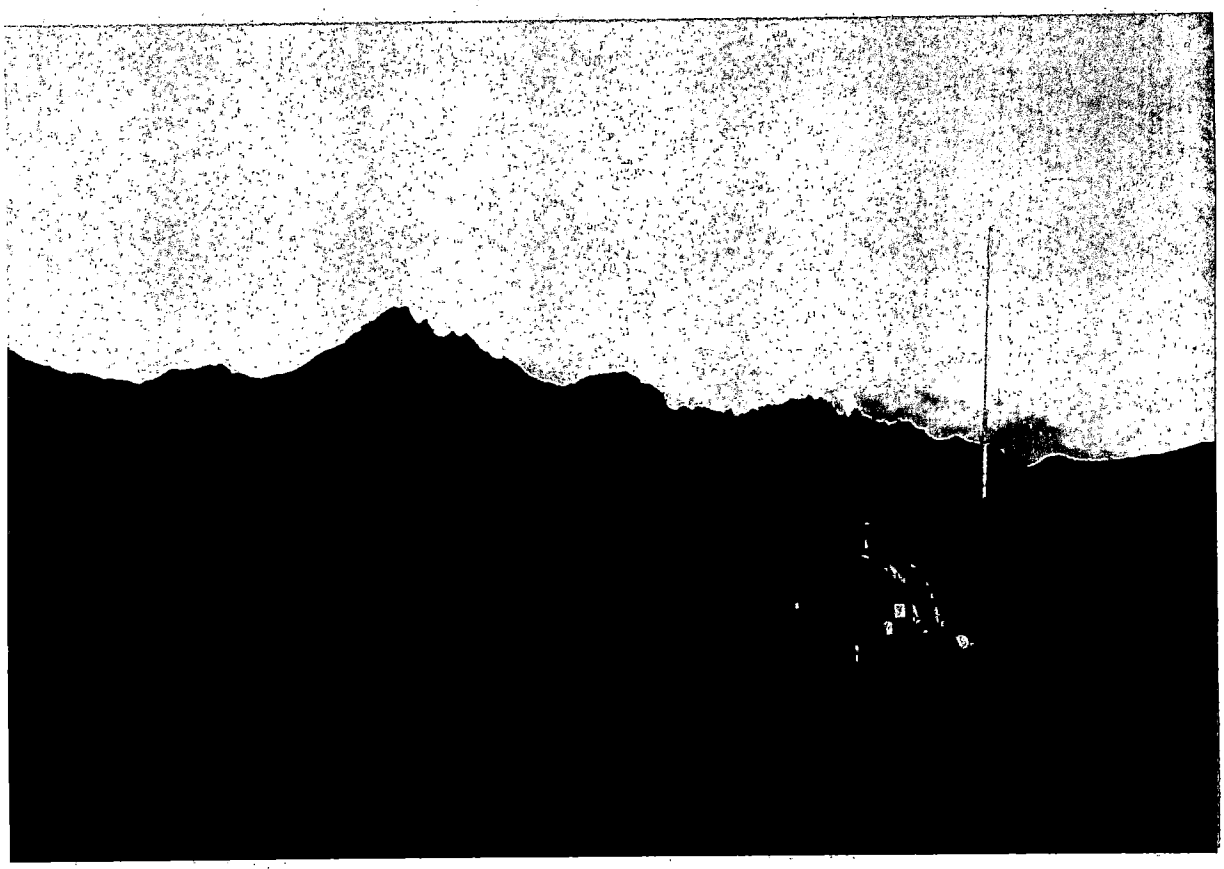
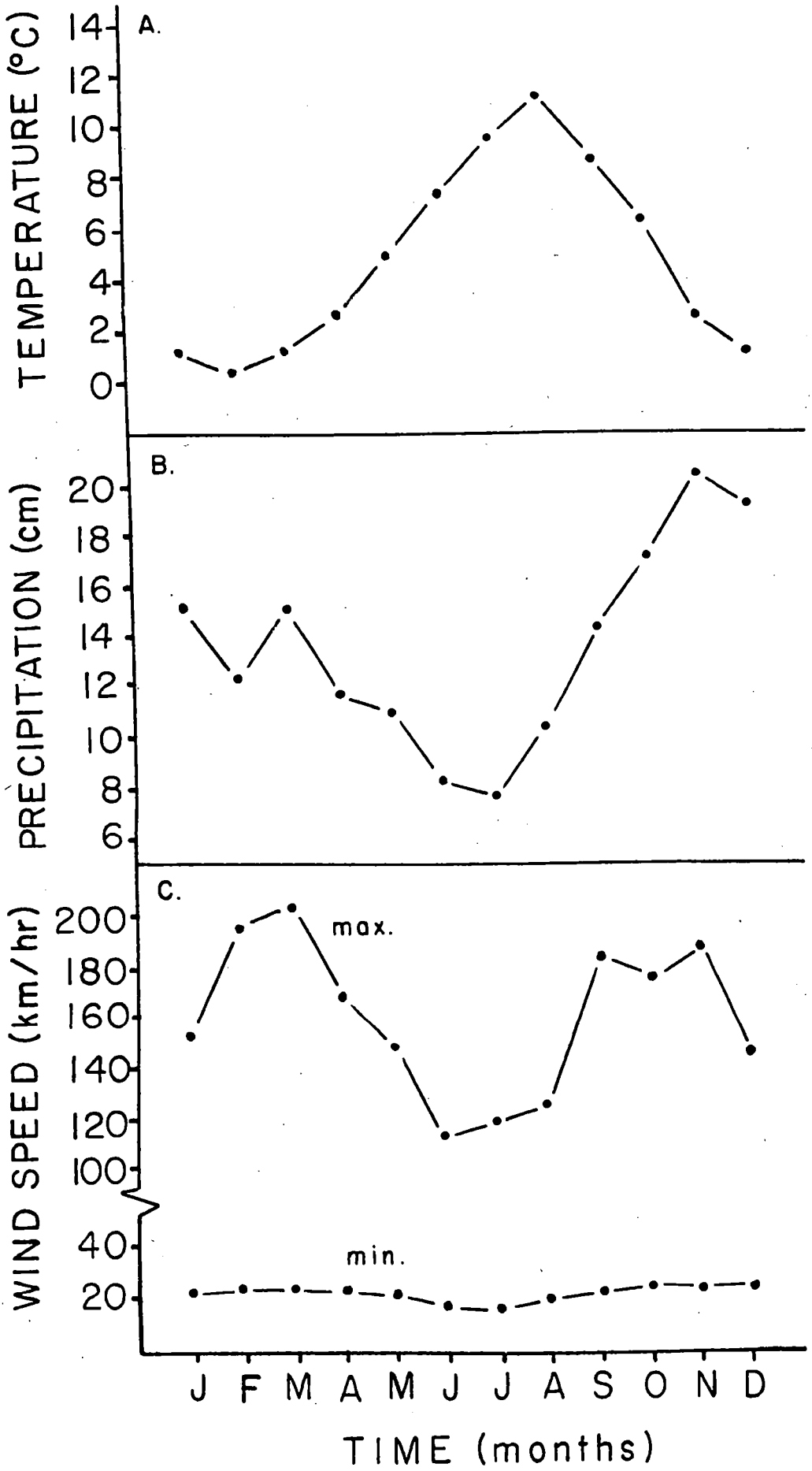


FIGURE 8

Figure 9. Mean monthly temperature (a), precipitation (b), and minimum and maximum windspeeds (c) for Adak Island, January 1950- December 1977.(Data from Naval Station Adak weather records.)


A.
TEMPERATURE (°C)
14
12
10
8
6
4
2
0
B.
PRECIPITATION (cm)
20
18
16
14
12
10
8
6
C.
WIND SPEED (km/hr)
200
180
160
140
120
100
40
20
max.
min.
J F M A M J J A S O N D
TIME (months)

fox. Major federal budget cuts finally forced a premature termination of the entire project. Although we were not able to achieve the final objectives of the study, we feel this report will provide a systematic appraisal of the potential for using this method of biological control. It should therefore be of use should further consideration be given to the problem.

GENERAL METHODS

THE STUDY AREA

The Aleutian Islands (Figure 1) make up an archipelago of over 200 volcanic islands curving in a 1400-mile arc westward from the Alaska Peninsula. Physiographically they range from small, relatively flat islands of a few hundred hectares to large, rugged, mountainous islands of over 50,000 hectares rising over 3000m from the sea.

Description of Study Island

Kagalaska Island (Figures 1 and 2) is typically rugged and mountainous, lying just east of Adak Island (176-1/4 25'W 51-1/4 50'N). It is 13km long, 8km wide and encompasses about 11,884 hectares. The shoreline is 105km long and very irregular. Five major coves and bays indent the coastline. For the most part the shores are steep and rocky (Figure 5) except along the west side where they have a more gradual slope (Figure 6). A series of lakes and streams bisect the lower third of the island and flow into Kagalaska Straits. About one dozen other small lakes are found sporadically distributed in the alpine regions and lowlands (Figure 7). Our field camp was located at Galas Point (Figure 8).

Weather

The weather of the Aleutian Islands is characteristically maritime with persistent overcast skies, rain and frequent violent storms. Locally the weather is very capricious, changing from occasional sunny periods to fog, driving rain, or snow in a matter of minutes. This process may just

as quickly reverse to sunny skies, only to repeat the cycle as another gale passes through.

Mean monthly temperatures are cold though not severe (Figure 9a). The warm waters of the Japanese Current to the south provide a moderating effect which prevents climatic extremes. Winter lasts six to nine months and frost can be expected every month except possibly July and August.

Precipitation is predominately rain and snow (Figure 9b). During the summer months of July and August a high pressure system in the Pacific Ocean south of the islands brings warm moist air northward. When this air reaches the islands, the cooling effect of the local ocean surface creates widespread fog and rain. During the winter the islands are affected by a Siberian high pressure system. This system brings cold continental air in contact with the warmer, oceanic air around the islands causing frequent severe cyclonic storms. The Aleutian Islands have been justifiably called the birth place of the winds. The nearly continuous exchange of air masses between Bering Sea and Pacific Ocean frontal systems creates chronic windy conditions. The mean monthly minimum wind speed on Adak is 20km/hr (Figure 9c), with maximum mean wind speeds of up to 200km/hr. Extreme maximum wind speeds of an estimated 224km/hr have been recorded for Shemya Island. Locally on mountainous islands, strong gusts exceeding 150km/hr called "williwaws", are created by local orographic conditions and sweep down mountain passes to the lowlands.

Flora

The vegetation of the Aleutian Islands is predominately maritime tundra (Amundsen 1977, Hulten 1968). Four floristic communities can be recognized: 1) beach strand, 2) lowland tundra, 3) upland tundra, and 4) alpine. Beach communities are located above high tide level in regions where storm flooding does not occur. Typical vegetation is dominated by Elymus grass with Calamagrostis, Festuca, and Poa species intermixed. Herbaceous cover is provided by Ranunculus spp., Geum macrophyllum, Potentilla villosa and Mimulus guttatus. In the storm-washed periphery decumbent succulent herbs such as Senecio pseudoarnica, Mertensia Maritima, Honckenya peploides and Lathyrus maritimus are found.

The lowland tundra forms a continuum of vegetation zones from the wettest areas--ephemeral pools dominated by Juncus arcticus, Alopecurus aequalis, or Sparangium hyperboreum--to the driest areas--meadows of crowberry Empetrum nigrum, Carex spp. and Calamagrostis nutakensis.

Upland tundra occurs in well-drained regions and is characterized by crowberry and grass spp. including Elymus arenarius, Calamagrostis nutakensis, Festuca rubra and a mixture of sedges (Carex sp.) and rushes (Juncus sp.), Willow (Salix spp.), blueberry (Vaccinium), and Loiseleuria procumbens are dominant components of the subshrub community.

Above the tundra on wind-swept mountain ridges the tundra heath gives way to an alpine carpet of mosses and lichens interspersed with open gravel patches. Here small grasses, sedges and creeping willows survive

tenaciously in small recesses or gullies which provide protection from the wind.

Fauna

The most prominent feature of the Aleutian Island fauna is the birdlife. Rich marine upwellings provide ample food for a myriad of pelagic avifauna. These birds also find good breeding sites on the numerous cliffs and rocks of the islands. Many shorebirds also use the islands as a stopover point on long migrations. Only a few passerines reside permanently on the islands, however, primarily due to the absence of trees and suitable shelter from the constant, strong winds. A list of the more common bird species found on the islands and their resident status is provided in Appendix 1.

The arctic fox (Alopex lagopus) and the Norway rat (Rattus norvegicus) are the only mammals found on the islands in large numbers. Caribou (Rangifer arcticus), red fox (Vulpes vulpes) and ground squirrels (Citellus parryii) have been introduced onto several islands. Marine mammals common off the shores of the islands include sea otter (Enhydra lutras), Stellar's sea lion (Eumetopias jubata), harbor seal (Phoca vitulina), Bering Sea Beaked whale (Mesoplodon stejnegeri), Goosebeaked whale (Ziphius cavirostris) and minks whales (Balaenoptera acutorostrata).

FOX TRAPPING AND MARKING TECHNIQUES

Arctic foxes were trapped in Kagalaska Island from 27 January 1982 until 9 April 1982. Both padded leghold traps (Victor Oneida #2) and

custom-made box traps (see Appendix 2) were used. The use of the leghold traps was abandoned after 1 February 1982 because of difficulties encountered in checking the traps at night on a regular basis. During the winter months live-trapped animals must be marked and released as soon as possible after capture to prevent injuries to animals due to frostbite or hypothermia. Frequent storms with driving snow and intense chill factors prevented us from checking the traps with any regularity. With box traps, however, captured foxes could be left overnight with adequate shelter until they could be checked the following day.

The traps were baited with tuna fish or sardines and set by fox trails or on beaches at one-quarter mile intervals along the coast (Figure 19). After capture the fox was released into a large nylon net secured around the door of the trap. The animal was pinned to the ground by stepping on the net between the fox and the trap. A firm handhold was secured on the dorsal neck fur whereby the fox could be safely controlled. Each animal was given a sedative by a subcutaneous injection using 0.5cc Rompin and 0.5cc Ketamine (mixed in the syringe). The drugs took effect in approximately 10 minutes. Occasionally an additional injection of 0.25cc of each drug was required to subdue hyperactive animals.

Each animal was sexed, weighed, and measured for total length, tail length, hind foot length and ear depth. The color phase was recorded and a photograph of each animal was taken. A small, numbered, plastic, ear tag (Rototag) was then fitted to the right ear for females and to the left ear for males (Figure 12). Before insertion, the tag was sprayed

with antiseptic (Iodine spray- Cadco, Inc.). Each tag was attached so that the pointed end of the connecting pole was directed outward. The procedure prevented undue irritation of the ear lining.

The tail of each fox was then color coded in three sections by using a combination of three dyes: Rodamine B (red/purple), Malachite green, and Picric acid (yellow). The tails of white foxes were dyed directly (Figure 3). With blue foxes it was necessary to use hair color remover (16% peroxide) to bleach the tail before the dyes were applied (Figure 4).

Finally the foxes were given an injection of antibiotic (Benzapen) to offset potential infection or illness. Each animal was then placed back in the box trap and allowed to recover from the effect of the drugs before release.

ECOLOGY OF THE ALEUTIAN ISLAND ARCTIC FOX

PHYSICAL DESCRIPTION

Origin of Breeding Stock

After the initial introduction of arctic foxes to the Aleutian Islands, introductions were made on a regular basis until World War II. The origins of the breeding stock are not well known, but they are undoubtedly diverse. It is believed that following the first Russian introductions, breeding stock was obtained from mainland Alaska, from fur farms in the "lower 48" states and from other islands previously stocked. The physical characteristics of the arctic fox on the Aleutian Islands therefore represent a melting pot of genetic material from many different sources.

Weight

Adult Aleutian arctic foxes (Figures 3, 10, 12, 13) are small in comparison to the red fox (Figure 11). On Kagalaska Island arctic foxes weighed on the average 3.8 ± 0.47kg (Table 1). Males weighed slightly more than females (3.82 ± 0.67kg for males and 3.72 ± 0.16kg for females) but this difference was not significant ($t = 0.032$, $p > 0.35$). Henry (1977) provided weight measurements of 16 foxes collected on Kanaga Island. The mean adult weight for these animals was calculated to be 3.48 ± 0.32kg. Males from this island also weighed more than females ($\bar{X}$ ± S.D. = 3.7 ± 0.30kg for males and 3.35 ± 0.27kg for females), but this difference was not significant ($t = 2.42$, $P > 0.05$, d.f. = 14). Females from Kagalaska Island were

Figure 10. Blue phase arctic fox in summer pelage.

Figure 11. Alaskan red fox (Vulpes vulpes).

U.S.F. & W.S. photo

FIGURE 10

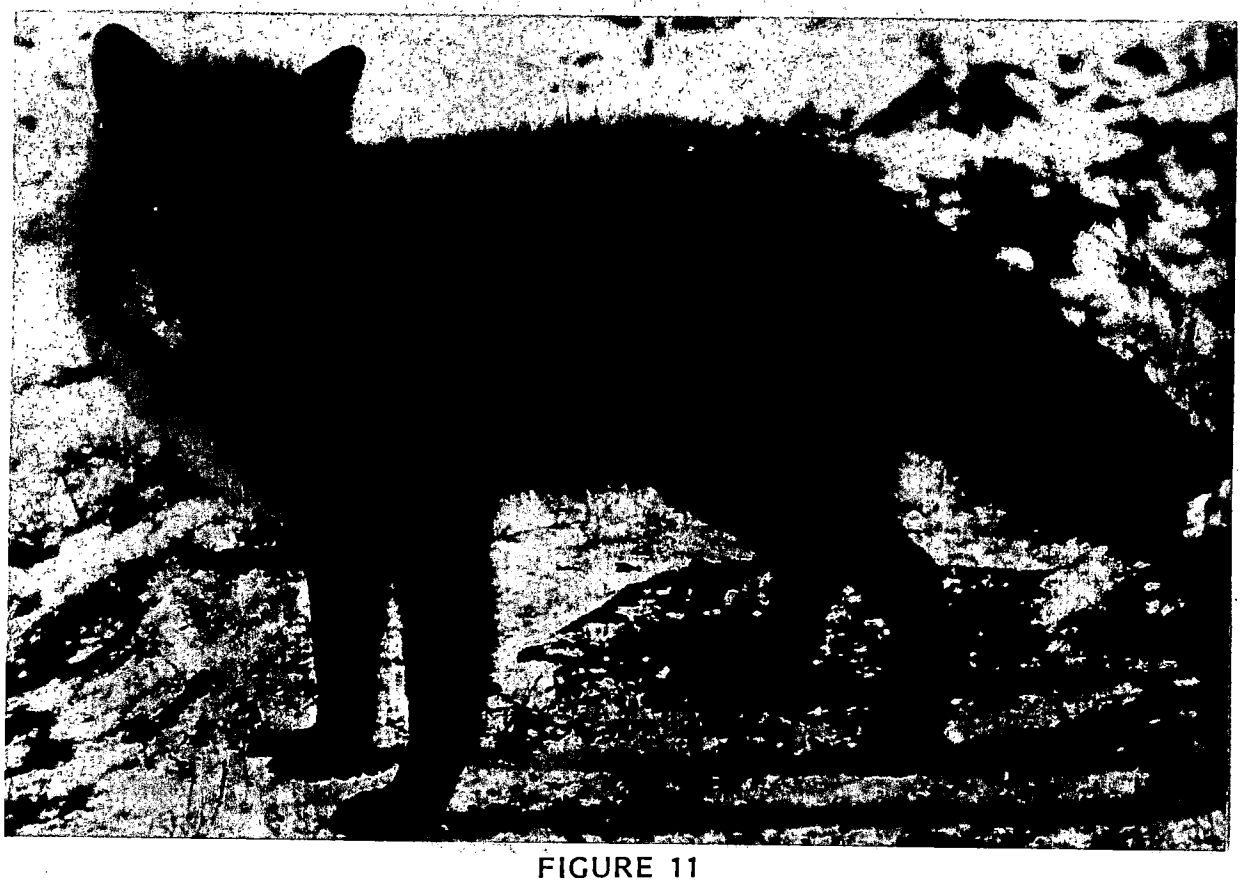


FIGURE 11

Figure 12. Blue phase arctic fox in winter pelage.

Figure 13. Arctic fox den site at Laska Cove, Kagalaska Island.

FIGURE 12

FIGURE 13

Table 1. Color phase, sex, weight, and body measurements of Arctic foxes captured on Kagalaska Island. W= white, B= blue; m= male, f= female.

Ear tag no.	Color Phase	Sex	Weight (kg)	Total Length (cm)	Tail Length (cm)	Hind foot Length (cm)	Inner Ear (cm)
3	W	m	3.3	90	31	--	5.1
4	B	m	4.5	98	32	12	6.0
5	W	m	3.5	88	29	11	5.5
6	B	f	3.5	80	32	--	--
7	W	f	3.6	86	28	12	5.2
8	B	f	3.9	90	32	13	5.5
9	W	m	4.6	88	32	13	5.0
10	B	f	3.8	83	32	12	4.9
11	B	f	3.8	88	34	12	5.5
13	B	m	3.2	82	29	13	--
14	W	m	--	--	--	--	--
15	B	m	--	--	--	--	--
16	B	f	--	--	--	--	--
N= 13	62% B 38% W	54% m 46% f	N= 10 Mean= 3.8 S.D.= 0.47	10 87 5.1	10 31 1.8	8 12 0.7	8 5.3 0.36

significantly heavier than females from Kanaga Island ($t = 2.78$, $P < 0.01$, d.f. = 13), but the weights of the males from each island were not significantly different ($t = 0.40$, $P > 0.2$, d.f. = 9). The pooled mean weight for males from both islands was 3.75 ± 0.48kg (N=11) and 3.47 ± 0.30kg for females (N-15). The mean weight for all adult foxes from both islands was 3.59 ± 0.40kg (N-26).

Underwood (1971) reported that for a colony of captive arctic foxes maintained in northern Alaska the mean adult weight was 4.2 ± 0.1kg. If this value is representative of mainland arctic foxes, the Aleutian Island foxes are significantly smaller in weight ($t = 4.36$, $P < 0.001$, d.f. = 24).

Size

Table 1 presents measurements on the body dimensions of 10 arctic foxes captured on Kagalaska Island. No statistical differences were found between males and females for total length ($t = 1.21$, $P > 0.2$, d.f. = 8); tail length ($t = 0.84$, $P > 0.5$, d.f. = 8); hind foot length ($t=0$, $P > .9$, d.f. = 4); or inner ear depth ($t = 0.37$, $P > .8$, d.f. = 6). This size monomorphism is also characteristic of mainland Alaska arctic foxes (Underwood 1980). Chesemore (1967) however noted that males had significantly longer tails than females.

Color Phase

Arctic foxes show two different and distinct winter pelages, a white phase (Figures 3,13) and a blue phase (Figure 12). Pelage color is genetically controlled, with the white phase being a homozygous recessive (Johansson

1960). The blue phase fox is rare in the central arctic region of North America, but increases in frequency in the eastern Greenland and western Alaska (Anderson 1937, Fetherston 1947, Chesemore 1970, 1975). On the Aleutian Islands blue foxes were introduced preferentially to the white. Some of these animals, however, are undoubtedly heterozygotes with recessive white phase alleles, since white phase foxes appeared regularly in fox trapping records (Table 2).

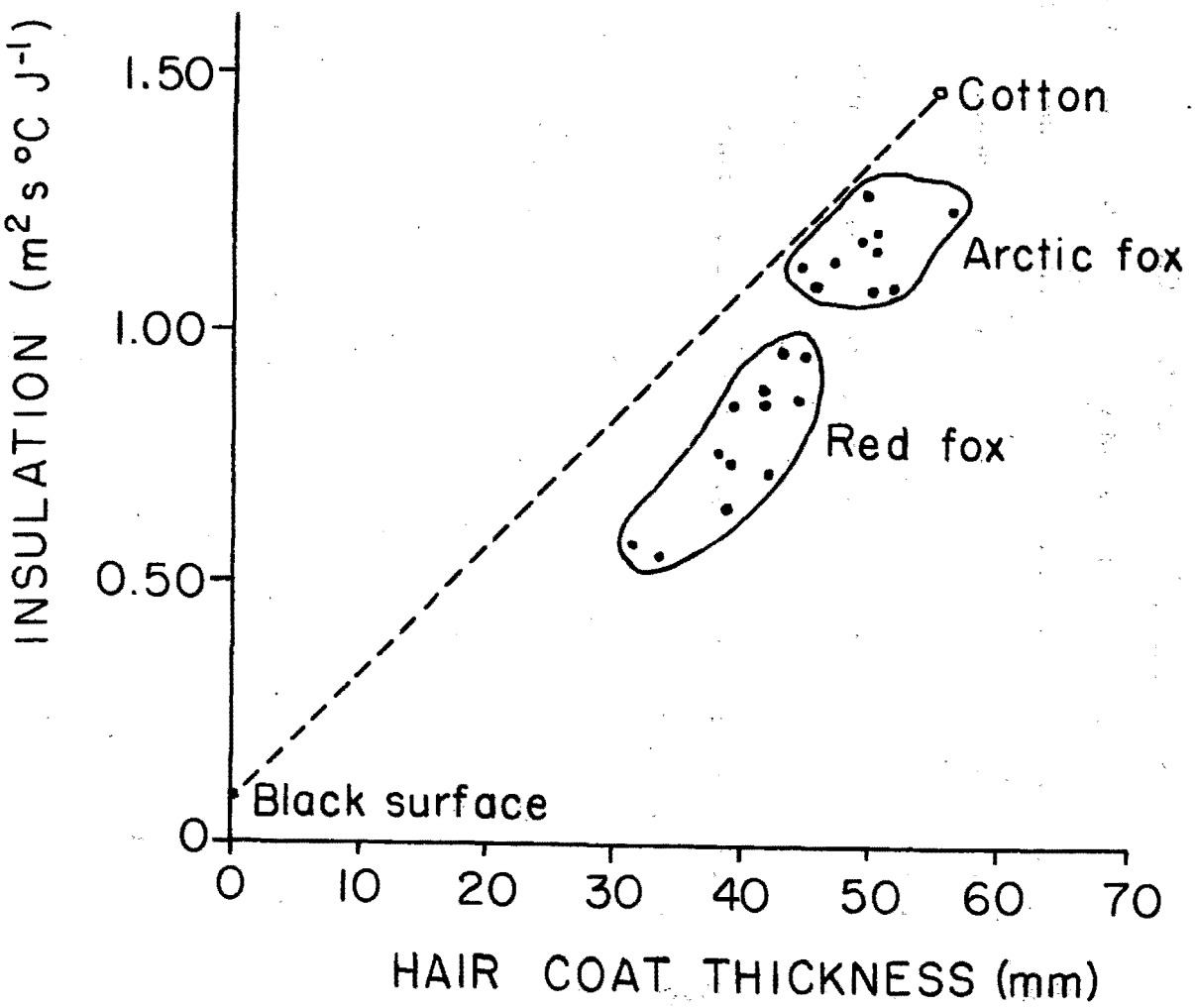
On Kagalaska Island 38% of the foxes trapped were white (Table 1). This percentage is higher than the percentage recorded for this island in 1934-1935 (Table 2), but it is not significantly different from the overall mean for all the islands ($t = 1.18$, $P > 0.2$, d.f. = 16). The increase in the number of white foxes may be due to inbreeding. Most of the Aleutian Island foxes descended from a small number of foxes originally introduced as breeding stock. Although fur farmers would occasionally introduce new animals to the islands, it is highly probable that a great amount of inbreeding has occurred over the years. An immediate consequence of inbreeding is that individuals frequently inherit the same gene from each parent (Crow and Kimura 1970). Inbreeding thus increases the amount of homozygosity within the population and recessive genes previously hidden by heterozygosity with dominant alleles are expressed. White phase individuals will become more common in the population with each generation when inbreeding occurs.

The white phase fox molts during the spring and the pelage changes

Table 2. Percentages of white phase foxes trapped on the Aleutian Islands, 1930-1942. (From U.S.F.& W.S. trapping records on file at Aleutian Islands National Wildlife Refuge, Adak, Alaska.)

Island	Year	White	Blue	% White Phase
Attu	1942	10	202	5.0
Agattu	1942	10	107	9.3
Kiska	1942	26	179	14.5
Little Tanaga	1942	3	26	11.5
	1934	5	50	10.0
	1938	5	78	6.4
	1939	1	14	7.1
Umak	1942	3	11	27.3
	1937	3	37	8.1
	1939	6	9	66.7
Hog	1942	3	36	8.3
Segula	1942	13	52	25.0
Great Sitkin	1931	16	45	35.6
Kagalaska	1934	1	38	2.6
	1935	2	20	10.0
Igitkin	1930	5	13	38.5
	1932	6	30	20.0
			N=	17
			$\bar{X}$=	18.00
			S.D.=	16.49

Figure 14. Maximum insulation of fur of arctic and red foxes as a function of thickness (redrawn from Gates 1980).


INSULATION (m^2 s °C J^{-1})
1.50
1.00
0.50
0
Cotton
Arctic fox
Red fox
Black surface
0
10
20
30
40
50
60
70
HAIR COAT THICKNESS (mm)

to a brown-grey color (Figure 13). Blue phase foxes molt to a sooty-brown color (Figure 10). During the summer the fur becomes much less dense and looses its prime quality. The molt usually lasts from late March until June or July (pers. obs., McEwen 1951, Chesemore 1975). The autumn molt into winter pelage begins in September and is completed by late October or November.

MORPHOLOGICAL AND PHYSIOLOGICAL ADAPTATIONS

Arctic foxes are well adapted to the Aleutian Island environment. Morphologically they are small with reduced leg, snout, and ear size, their feet are heavily furred and they have a dense winter pelage. All these features act to reduce body heat loss and thereby conserve energy. The small size offers a limited surface area for radiant heat loss (Gates 1980). The hair on the feet insulates the fox from heat loss by conduction. The dense winter pelage provides an effective barrier against convective heat loss (Figure 14).

Body heat may also be conserved by physiological means through regional heterothermy and countercurrent heat exchange (Gordon et al 1968). Because all parts of the body are mechanically impossible to insulate with equal effectiveness, the temperatures of extremities- the legs, ears and muzzle- generally fall to temperatures much lower than that of the body core. These lower temperatures result in a reduced temperature gradient between the body surface and the environment, thereby minimizing heat loss. Countercurrent heat exchange also prevents excessive heat loss by shunting heat from the blood in arteries (supplying the appendages) to the blood in

the veins (the blood returning to the lungs).

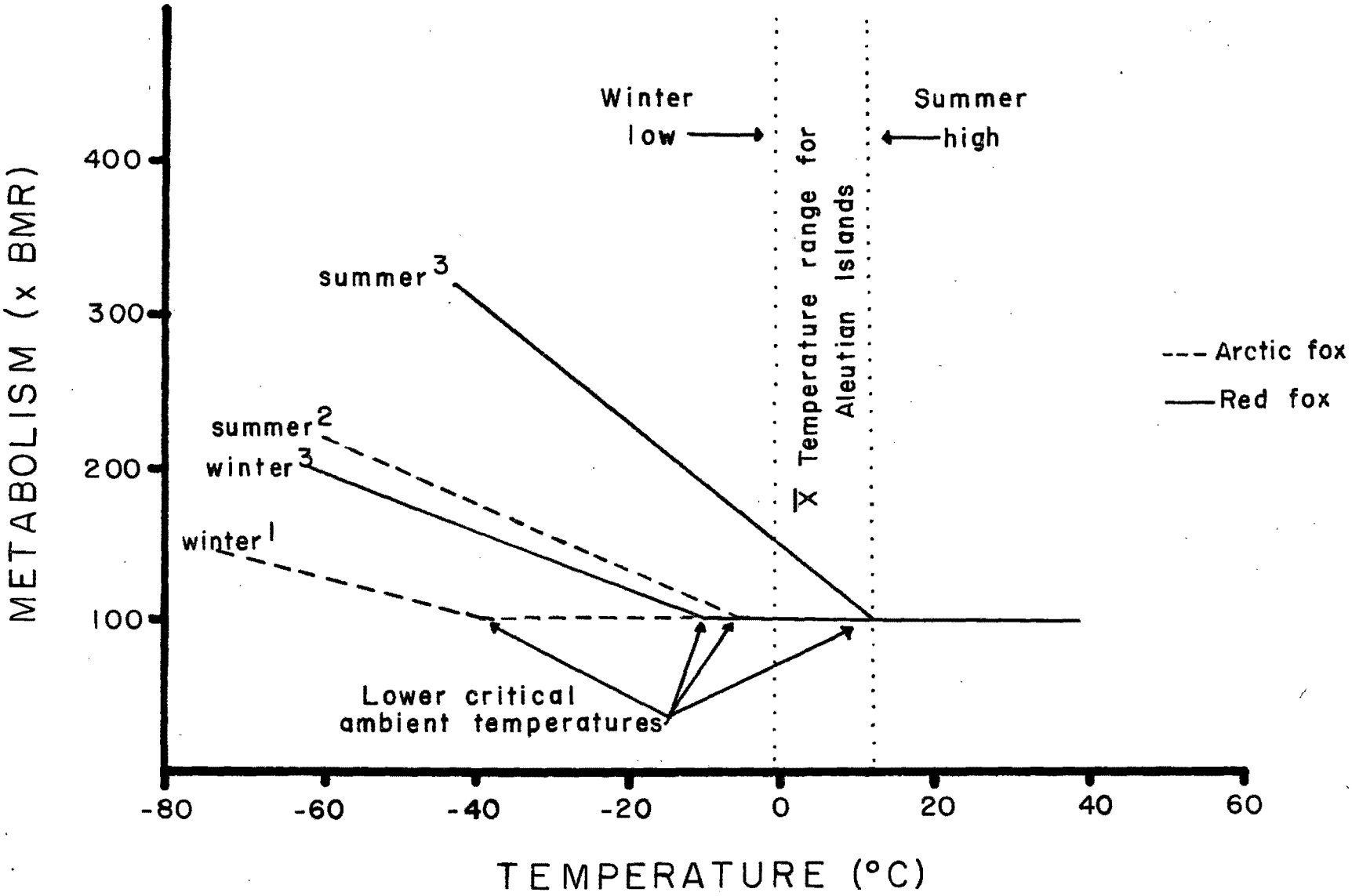
Combined, the above adaptations enable the arctic fox to withstand temperatures down to -40°C before additional metabolic expenditures are required to maintain normal body temperatures (Figure 15). Red fox in comparison must increase their metabolism at higher ambient temperatures (higher critical temperatures) in order to maintain thermal balance. The weather of the Aleutian Islands, however, usually is mild enough so that ambient temperatures do not generally fall below the lower critical temperature of either species. This means that both fox species generally will not be required to produce extra metabolic heat above normal maintenance levels for thermoregulation. In situations of extreme cold caused by high winds and chill factors, foxes can usually avoid exposure by remaining in a burrow or den.

REPRODUCTION

Mating System and Gestation Period

Arctic foxes breed as monogamous pairs (Chesemore 1975, Underwood 1980). Females mate once annually with estrous lasting from 12 to 14 days (Dementyeff 1958). Mating usually occurs from March through April (Fay 1973). Variation in local environmental conditions such as food availability, day length, and severity of the winter, however, may result in some populations breeding earlier or later within this period (Dementyeff 1955, Sokolov 1957, Chesemore 1975, Underwood 1980). Gestation lasts

Figure 15. Metabolic rate of arctic and red foxes as a function of ambient temperature, summer and winter. BMR= Basal metabolic rate- the stable minimal rate of energy metabolism, which represents an approximation of the rate of fasting metabolism of an animal at rest and under no thermal stress (Gordon et al 1968). 1- Scholander et al 1950, 2- Underwood 1971, 3- Hart 1964.


Winter
low
Summer
high
Temperature range for Aleutian Islands
summer 3
summer 2
winter 3
winter 1
Lower critical ambient temperatures
Arctic fox
Red fox
METABOLISM (x BMR)
400
300
200
100
-80
-60
-40
-20
0
20
40
60
TEMPERATURE (°C)

approximately 52 days (Chesemore 1975) and litters are produced from May through early July.

Reproductive Capacity

Litter size in arctic fox appears to be strongly correlated with local food availability (MacPherson 1969, Bannikov 1970, Speller 1972) and varies considerably between years and between geographical regions. The mean primary reproductive potential for mainland arctic fox, as indicated by embryo or uterine scar counts, is 9.28 ± 3.03 embryos (Table 3). The mean maximum potential is near 19 embryos. Aleutian Island populations show a lower mean number of embryos (7.81 ± 1.75 embryos) (Table 4). This difference is not significant ($t = 1.81$, $P > .05$, d.f. = 45). The mean maximum embryo count for Aleutian Island foxes is 12.5 ± 0.71 embryos. This number is significantly lower than the value determined for mainland populations ($\bar{X}$ ± S.D. = 19.29 ± 3.15 embryos; $t = 2.89$, $P > .05$, d.f. = 7).

The secondary reproductive capacity or litter size of arctic foxes averages 6 pups per litter with a mean maximum of 14 pups (Table 5). For Aleutian Islands populations the mean litter size ($\bar{X}$ ± S.D. = 4.74 ± 1.31, N = 5), is significantly lower than for mainland populations ($\bar{X}$ ± S.D. = 6.8 ± 2.1 pups). Also the mean maximum litter size for island foxes is less ($\bar{X}$ ± S.D. = 9.0 ± 3.37 pups, $t = 2.14$, $P < 0.025$). The mean litter size for Aleutian foxes is not significantly different from the mean of other island populations listed in Table 5 ($t = 0.86$, $P > .5$, d.F. = 2). Chirkova et al. (1959) also noted a lower fecundity for island fox populations in Russia.

Table 3. Primary reproductive rate of mainland arctic fox populations.

Embryo or Uterine Scar Count		
$\bar{X}$	Maximum	Reference
-	16	Zhitkoff 1913*
-	16	Schaaning 1916*
11.5	16	Sutton and Hamilton 1932*
-	21	Braestrup 1941
4.8	23	Gavin 1945*
10.2	22	Chirkova et al 1959
10.6	21	McPherson 1969
N = 4	7	
$\bar{X}$ = 9.27	19.29	
S.D.= 3.03	3.15	

* In Chesemore 1967

Table 4. Uterine scar count from arctic fox on Kanaga and Agattu Islands, Alaska.

# Scars	# Females	
	Kanaga[1]	Agattu[2]
5	3	--
6	6	--
7	11	--
8	10	1
9	3	3
10	2	1
11	1	--
12	1	--
13	-	1
N	37	6
$\bar{X}$	7.51	9.67
S.D.	1.57	1.75

Pooled $\bar{X} \pm$ S.D. = 7.81 ± 1.75

1 Henry 1977
2 U.S.F.&W.S. (1975)

Table 5. Secondary reproductive capacity of the island and mainland arctic fox populations.

Litter Size		Habitat [1]	Reference
$\bar{X}$	Maximum		
5.0	--	M	Fabricus 1788*
5.0	25	M	Middendorff 1875*
7.0	10	M	Muller 1906*
7.0	18	M	Collet 1912*
8.0	--	M	Hartman 1929*
4.5	11	M	Seton 1929*
4.5	13	M	Lavrov 1932*
---	21	M	Høst 1935*
6.0	16	M	Dubrovskii 1937*
6.4	--	M	Braestrup 1941*
5.0	8	M	Gavin 1945*
12.0	--	M	Dufrensne 1946*
6.5	12	M	Cahalane 1947*
8.5	13	M	Dement'yeff 1955*
10.0	22	M	Chirdova et al 1959
5.4	14	M	MacPherson 1969
8.0	11	M	Eberhardt 1977
6.5	10	I	Barabash-Nikiforov 1938*
4.0	--	I	Soper 1944*
5.2	8	AI	U.S.F.& W.S. 1975
3.0	5	AI	Henry 1977
5.0	13	I	Chirkova et al 1959

1. M= Mainland, I= Island, AI= Aleutian Island. *In Chesemore 1967.

Table 5. Cont'd.

	$\bar{X}$	Maximum
N_M	16	13
X_M	6.80	14.92
SD_M	2.10	5.15
N_I	5	4
$\bar{X}_I$	4.74	9.00
SD_I	1.31	3.37
N_{total}	21	11
$\bar{X}_{total}$	6.31	13.53
SD_{total}	2.11	5.36

Den Sites

Three active arctic fox den sites were located on Kagalaska Island (Figure 13), two on Adak Island, and one on Great Sitkin Island. All except one were located in rock outcroppings near the shore (one on Great Sitkin Island was found under an old WWII building). Two factors appear to be important in determining the location of these den sites in general:

1) The tundra of the Aleutian Islands at lower elevations is usually saturated with water. Any attempt by foxes to maintain a burrow system under these conditions would be ruined by flooding.
2) The primary food source (beach invertebrates) is located on or near the beaches. By having dens located nearby, foxes would minimize energy expenditures in obtaining food.

Mortality Factors

Winter starvation, sibling aggression and predation by eagles may be the primary causes of mortality among arctic fox whelps on the Aleutian Islands. Little is known about the real abundance of winter food for foxes on the islands, but it is believed to be relatively scarce compared to the summer when nesting birds are available. For whelps winter is a difficult time of year when extra energy is required for growing as well as for self-maintenance. On the mainland winter starvation is a major cause of death of foxes over six months old (Vibe 1967, MacPherson 1969, Bannikov 1970, Speller 1972).

MacPherson (1969) found that in times of food shortages, older whelps often attacked and killed younger whelps. While no direct evidence was found for this type of behavior on Kagalaska Island, the highly seasonal nature of the food sources suggest that it is possible during winter when food is scarce.

The only predator of foxes on the island is the bald eagle (Haliaeetus leucocephalus). No fox-eagle interactions were observed during our study but Murie (1959) reported that fox remains have been found in eagle nests on the Aleutian Islands. Murie believes that eagle predation does not occur frequently. He observed that many fox families were being raised successfully in the vicinity of eagle nests.

MacPherson (1969) constructed a survivorship curve for arctic foxes in Canada (Figure 16). The highest mortality occurs just after parturition. Only a few individuals survive beyond the age of four years. Banfield (1977) estimated the maximum life expectancy for arctic fox to be 8 to 10 years.

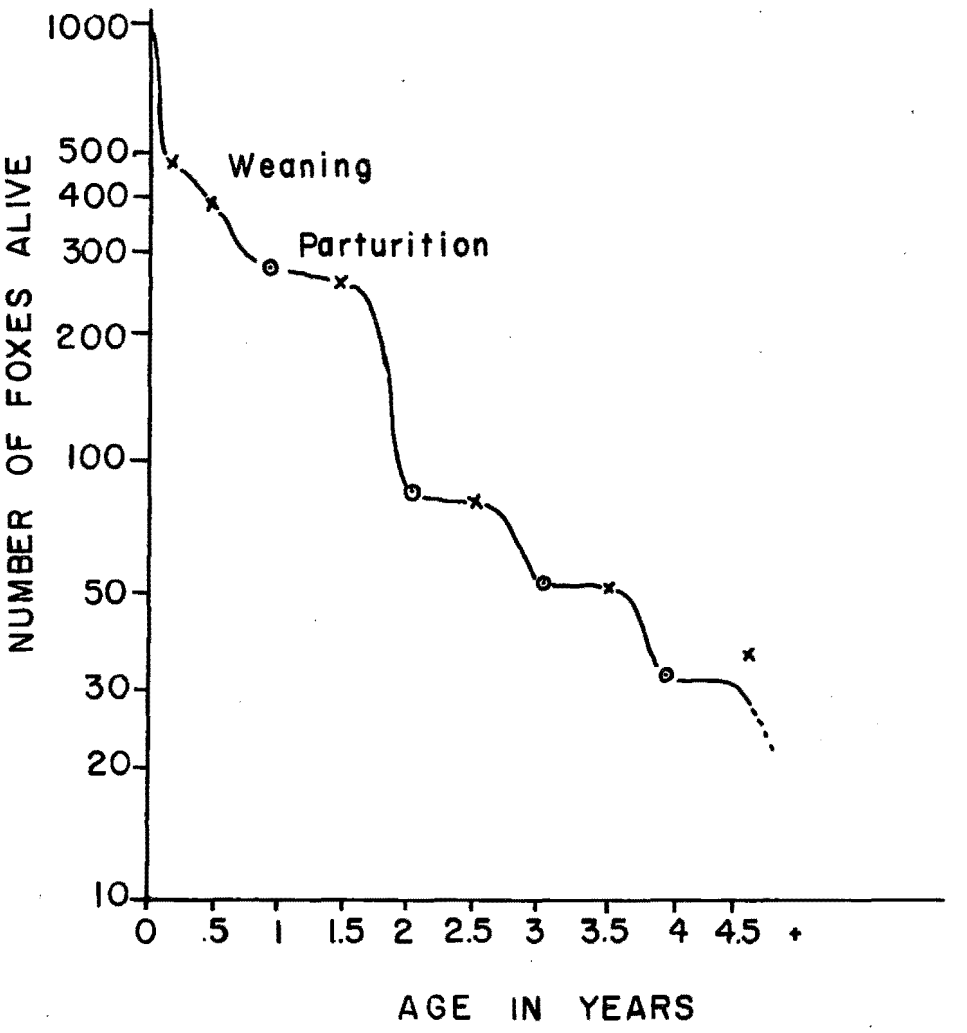
DISCUSSION

Populations of Aleutian Island arctic foxes show a much lower productivity than mainland populations. This difference appears to be partially due to a slightly lower embryonic implantation rate, but is also strongly affected by a higher post-implantation failure rate. Island populations show a 40% reduction in the average litter size between implantation, or birth, and weaning. By contrast, mainland populations sustain only an average of 26% reduction.

Several hypotheses may be proposed for the observed differences in reproductive success. These include 1) the founder effect- the original breeding stock was genetically predisposed to produce smaller litters, 2) the environment of the Aleutian Islands is biologically harsher than the mainland habitat; therein causing reduced survivability of the offspring; 3) intense inbreeding has resulted in reduced fitness of the offspring.

The founder effect hypothesis may be tentatively rejected on the basis that the primary reproductive rates of island and mainland populations are not significantly different. These data suggest that there is at least a genetic potential for producing equal sized litters. The principal difference in productivity is due to post-implantation embryonic failure or whelp mortality.

Figure 16. A survivorship curve for arctic fox in the Northwest Territories (from MacPherson 1969).


1000
500
400
300
200
100
50
30
20
10
NUMBER OF FOXES ALIVE
Weaning
Parturition
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
+
AGE IN YEARS

If the Aleutian Island environment is biologically harsher than mainland areas (e.g., less predictable food resources, particularly during the breeding season), vixens may reduce their litter size by embryo reabsorbtion, abortion, or cannibalism of whelps. These responses are not uncommon among animals that experience strong seasonal changes in food availability (Wilson 1975). Preweaning mortality of whelps may also occur as a result of sibling competition for limited food (MacPherson 1969). Combined, these factors could explain the observed differences in productivity.

When the fox populations are small, as they are on many of the Aleutian Islands, inbreeding is likely to cause a reduction in the overall fitness of individuals within each population. This phenomenon, called inbreeding depression, is a result of an increase in deleterious alleles occurring in a homozygous state (Simberloff 1982). Most individuals of diploid species carry alleles which are lethal or cause sterility or debilitation if expressed. In large populations parents are generally unrelated and offspring receive different alleles from each parent at birth. Usually only one of these alleles, if any, is deleterious and it is generally recessive. Consequently, the deleterious effect is not expressed but is masked by the dominant allele, and the individual appears normal. When inbreeding occurs however, the chances that two parents are related, and therefore share deleterious genes, is higher. Offspring of inbred parents therefore have a greater probability of receiving the deleterious allele from each parent. These alleles would be expressed in a homozygous condition and their deleterious effects would be manifested. Individuals so affected are commonly less fit and do not survive.

Several lines of evidence suggest that substantial inbreeding has occurred on the islands. There has been an apparent increase in the percentage of white-phase foxes on Kagalaska Island (see Color Phase section), a characteristic indication of increasing homozygosity within the population. Also, numerous islands formerly supporting viable fox populations do not now have foxes (Nysewander et al. 1980). Inbreeding depression may have strongly contributed to the extinction of these populations.

At this time however, it is impossible to make any conclusions about the causes for the differences in productivity between mainland and island fox populations. More work must be done on the comparative suitability of respective habitats with regard to breeding success. Also, an analysis of the genetic structure of island populations should be conducted to determine the extent to which inbreeding has occurred.

FOOD HABITS

METHODS

Food Preferences

The food habits of arctic fox on the Aleutian Islands were studied by scat and stomach analysis. A total of 193 scat was collected along trails at two localities on Kagalaska Island. The contents of 82 stomachs were also analyzed. These were taken from foxes collected by the U.S.F.& W.S. during the 1971 Fox Eradication program on Nitzki/Alaid Island(s).

Each scat was placed in a plastic bag, dated, and labeled with the location where it was collected. In the laboratory, scats were put in separate plastic vials filled with a dilute detergent and were left to soak for several hours. They were then mechanically broken down and mixed by stirring with a probe. This process provided sufficient separation of the contents to allow for easy identification of food items. The contents of each vial were poured into a white enamel tray and examined with a 7-20X power dissecting scope. Identification of the food items was made by comparison to a reference collection of local fauna.

Two measures were used to estimate frequency of use of each food item: total occurrence and relative abundance. Total occurrence was measured by recording the number and percentage of scat that contained each food item. Food items were scored only once for each scat. Relative abundance

was measured by estimating the percent composition of each food item in the scat. To do this a 5 point scale was established where: 1= trace amounts, 2= 1-10%, 3= 11-50%, 4= 50-75%, and 5= 76-100% composition.

Stomach contents were analyzed first by washing with water in a 12- mesh sieve (Newark), after which they were examined with a microscope. Only total occurrence was used to estimate diet preferences in this analysis.

Food Availability

Foxes obtain food on the island from numerous sources: birds, beach invertebrates, rats, beach carrion, and occasionally fish. Because of time limitations, only beach carrion availability was estimated using U.S.F.& W.S. beach survey reports.

RESULTS

Kagalaska Island

The food habits of arctic fox on Kagalaska Island appear to reflect the seasonal and regional distribution of available prey species (Tables 6 and 7). In both Laska Cove and Galas Point small invertebrates made up a major portion of the diet, both in total occurrence and in relative abundance. Amphipods are readily available along all beach strand areas, especially where decaying kelp deposits are found. Barnacles, mussels, crabs, snails, and clams occurred less frequently in the diet and are apparently taken opportunistically. The relatively high occurrence of sea

Table 6. Food items in Arctic fox scat collected in Laska Cove on Kagalaska Island. N= 112 scat.

Item	Relative Abundance X ± S.D.	Total Occurrence Freq.	Total Occurrence %
Amphipods	3.6 ± 1.40	78	69.6
Isopods	2.4 ± 1.54	19	17.0
Sea cucumbers	-- --	--	--
Barnacles	-- --	--	--
Sea urchins	1.1 ± 0.32	27	24.1
Mussels	-- --	--	--
Crabs	1.0 ± 0.00	2	1.8
Snails	1.0 ± 0.00	6	5.4
Clams	1.0	1	0.9
Insects	1.0 ± 0.00	3	2.7
Fish	1.4 ± 0.74	8	7.1
Birds	2.0 ± 1.17	50	44.6
Blue fox hair	3.0 ± 1.48	11	9.8
White fox hair	-- --	--	--
Rats	1.3 ± 0.58	3	2.7
Sea otter	-- --	--	--
Dicots.	1.5 ± 1.08	22	19.6
Kelp	1.2 ± 0.54	38	33.9
Grass	1.2 ± 0.54	41	36.6
Moss	1.0 ± 0.23	36	32.1
Gravel	1.3 ± 0.58	3	2.7

Table 7. Food items in Arctic fox scat collected at Galas Point on Kagalaska Island. N= 81 scat.

Item	Relative Abundance X ± S.D.	Total Occurrence Freq.	Total Occurrence %
Amphipods	2.7 ± 1.42	45	55.5
Isopods	2.7 ± 0.58	3	3.7
Sea cucumbers	1.2 ± 0.45	5	6.2
Barnacles	1.0	1	1.2
Sea urchins	1.3 ± 0.71	38	46.9
Mussels	1.0	1	1.2
Crabs	2.0 ± 1.15	4	4.9
Snails	-- --	--	--
Clams	-- --	--	--
Insects	1.9 ± 1.37	21	25.9
Fish	1.2 ± 0.45	5	6.2
Birds	1.9 ± 1.42	23	28.4
Blue fox hair	3.2 ± 1.50	36	44.4
White fox hair	1.0	1	1.2
Rat	1.4 ± 0.50	11	13.6
Sea otter	3.9 ± 1.69	9	11.1
Dicots.	1.3 ± 0.58	3	3.7
Kelp	1.7 ± 0.86	51	63.0
Grass	1.0 ± 0.00	25	30.9
Moss	1.0 ± 0.00	13	16.1
Gravel	1.0	1	1.2

urchins in scat collected at Galas Point suggests that either the urchins were abundant there, or that foxes were selectively hunting for them more there than in Laska Cove. While we did not measure relative availability of the prey item at either site, the fairly extensive intertidal regions on the headlands of Galas Point suggest that sea urchins may be more available there than in Laska Cove where there is little intertidal area. Insects and fish appear to be taken incidentally, though more frequently, at Galas Point.

Bird remains occurred frequently in the scat collected at both localities, but were more prevalent in scat from Laska Cove. Passerine birds (song sparrows, winter wrens, lapland longspurs) appeared to be the most common species of birds taken. Ducks and alcids occurred less frequently in the diet. Surprisingly rats were taken only occasionally. Vegetation, both marine and terrestrial, occurred frequently in the scat. Gravel also occurred occasionally in the diet but it was presumed to be accidentally acquired. The fox hair present in the scat was probably ingested by the foxes while grooming. No evidence of cannibalism was found.

Nitzki/Alaid Island(s)

Birds were the major food item in the diet of foxes on Nitzki/Alaid Island(s) (Table 8). Alcids and cormorants appeared to be taken most frequently. Amphipods were also commonly ingested. Fish, particularly small tidepool species, were consumed by 15% of the foxes. Also a

Table 8. Stomach content analysis of Arctic foxes collected on Nitzki/Alaid Island (s). N= 82.

Item	Frequency	%
Amphipods	13	15.8
Sponge	1	1.2
Sea Cucumber	4	4.9
Barnacles	1	1.2
Crabs	1	1.2
Insects	22	26.8
Mites	1	1.2
Ticks	1	1.2
Intestinal Worms	21	25.6
Fish	12	14.6
Birds	38	46.3
Bird eggs	1	1.2
Blue fox hair	10	12.2
Rat	2	2.4
Sea lion	14	17.1
Seal	2	2.4
Unidentified tissue	37	45.1
Dicots.	15	18.3
Kelp	23	28.0
Grass	35	42.7
Moss	3	3.6
Seeds	15	18.3
Veg. Misc.	4	4.9
Gravel	54	65.8
Wood	6	7.3
Plastics/rubber	2	2.4
Unidentified digesta	12	14.6

substantial number of fox (14) had sea lion fur in their stomachs. Presumably this food item was available as carrion. A sea lion haul-out zone was located on an isthmus between the two islands. Insects were commonly found in the stomachs as were ticks. In one specimen 250 ticks were removed from the stomach and intestine. It is uncertain whether this item was actively hunted for or was the result of incidental ingestion of infested birds.

Vegetation was regularly included in the diets in small quantities. An unexpectedly large amount of gravel was found in 66% of the stomachs analyzed. In several specimens the stomachs were full of gravel. It is probable that this item was ingested incidentally while the foxes foraged for beach invertebrates. Berns (1969) observed foxes scooping up gravel with their noses and lower jaws, and then snapping in different directions while picking up amphipods as they were uncovered. Miscellaneous debris such as small pieces of plastic and rubber were found in a few animals. Again we assumed these items were consumed accidentally while sampling beach debris.

DISCUSSION

Regional Foraging Patterns

Arctic foxes are opportunistic foragers. They will feed on whatever prey items are readily available to fulfill their energetic and nutritional needs. This study shows apparent regional differences in foraging preferences on Kagalaska. Stephenson (1970) also found significant

Table 9. Frequency and biomass of bird and mammal beach cast carcasses (data from U.S. Fish and Wildlife Service surveys on Adak (1973-1975) and Amchitka (1978-1980).

Adak Island

Species	Weight (kg)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Birds														
Fulmar	1.4			1										1
Black Scoter	1.0						1							1
Bald Eagle	2.6			1									1	2
Glaucous-winged gull	1.4				2							2		4
Thick-billed murre	0.4						1							1
Puffin	0.8			11	2									13
Total birds		0	0	13	4	0	2	0	0	0	0	2	1	23
Total biomass		0	0	12.9	4.4	0	1.4	0	0	0	0	2.8	2.6	23.9

Table 9. Cont'd.

Species	Weight (kg)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Mammals														
Sea Otter	27.0	2	2	13	11		1						3	32
Steller's Sea Lion	2860	1		1										2
Harbor Seal	770			1										1
Dall's Porpoise	880											2		2
Total Mammals		3	2	15	11	0	1	0	0	0	0	2	3	37
Total Biomass		2914	54	3981	297	0	27	0	0	0	0	1760	81	9114
Total biomass- birds plus mammals		2914	54	3994	301.4	0	28.4	0	0	0	0	1763	83.6	9137.9
Biomass/km beach		119.3	3.1	376.8	16.7	0	1.4	0	0	0	0	181.7	3.8	702.8

$\bar{X} \pm$ S.D.= 58.6 $\pm$ 116.1

Table 9. Cont'd.

Amchitka Island

Species	Weight (kg)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Birds														
Fulmar	1.4								1					1
Bald Eagle	2.6	1		1	1							1		4
Kittiwake	0.7	1												1
Cormorant	1.3				1					1				2
Jaeger	0.4							1						1
Mallard	1.2		1											1
Harlequin	0.6			1										1
Total birds		2	1	2	2	0	0	1	1	1	0	1	0	11
Total biomass		3.3	1.2	3.3	3.9	0	0	0.4	1.4	1.3	0	2.6	0	17.5

Table 9. Cont'd.

Species	Weight (kg)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Mammals														
Sea otter	27	4	1	4	6	6	2	0	0	2	0	0	4	29
Harbor seal	770					1								1
Unid. Whale*	6000				1							1		2
Total mammals		4	1	4	7	7	2	0	0	2	0	1	4	32
Total biomass		108	27	108	162	6932	54	0	0	54	0	6000	108	13553
Total biomass- birds plus mammals		111.3	28.2	111.3	165.9	6932	54	0.4	1.4	55.3	0	6002.6	108	13570.4
Biomass/km beach		23.2	5.9	23.2	27.6	1155.3	11.2	0.08	0.4	15.4	0	1667.4	18.0	2947.7

$\bar{X} \pm$ S.D.= 245.6 $\pm$ 555.4*

* Estimated weight of beaked whale

On Adak the total biomass available to foxes averaged 58.6 kg/km/mo with peak availability of 376kg/km in March. On Amchitka the total available biomass was considerably higher (X ± S.D.= 245.6 ± 555.4 kg/km/mo). This difference was due primarily to more whales being washed ashore on Amchitka.

Beach carrion does not appear to be a predictably plentiful food source. When available, it is likely to be used by many animals, especially during the winter when nesting birds are not available as prey.

Rats

It is not known why rat remains were found so infrequently in the fox scat. In other regions, both on the mainland and on the islands, where rodents are available they comprise a substantial portion of the foxes' diet (Braestrup 1941, Dementyeff 1958, Chesemore 1968, MacPherson 1969, Stephenson 1970, Speller 1972).

Fish

Only bones and vertebrae of small fish were found in the scat samples. These were probably from small intertidal fish, possibly blennies (Pholis laetus). Foxes are also known to take salmon (Murie 1959). On Great Sitkin Island we found a partially eaten salmon at the entrance of a fox den. During the summer and fall, spawning salmon are readily available in most streams on the islands. They could be taken live by foxes in the shallow waters of the spawning beds, or as carrion later in the season.

Seasonal Diet Pattern and Energetics

With the arrival and departure of breeding seabirds on many islands the food resources change drastically. Accordingly the diets of island foxes change with the seasons. Stephenson (1970) found beach carrion was seldom used during the summer when birds were available. Only during the mid and late winter did these items become important. Undoubtedly beach invertebrates also become important as food items during the winter.

Arctic foxes are also known to cache food in large quantities (Seton 1929, Soper 1944, Osgood et al 1915, Braestrup 1941, Stephenson 1967). These caches are believed to serve as winter food supplies. On Kasatochi Island, Murie (1959) found a cache with 65 crested auklets, 37 least auklets, 1 parakeet auklet, and 1 pigeon guillemot. On Bobrof Island he found remains of 103 petrels, 6 tufted puffins, 4 least auklets, and 1 pigeon guillemot. Each of these caches would weigh approximately 8 kilograms. Assuming 50% of this material was nondigestible feathers and bones, on first approximation each cache would contain 4 kilograms of consumable biomass.

In a study on arctic fox bioenergetics Underwood (1971) found that penned arctic foxes consumed up to 370 kilocalories per kilogram of body weight per day in the summer, and 63 kilocalories per kilogram of body weight per day in the winter. Using a value of 5100 calories per

gram of dry weight for animal tissue (Golley 1961) and 35% as the dry matter composition, the bird caches described above would provide approximately 7400 kcals or 30 fox-days of food during the winter. This time would be considerably less if the food was utilized during the summer (5 fox-days) when energy demands were higher. The temporal nature of utilization of these resources by foxes however, is not known.

Another supplemental energy source used by foxes during periods of food shortage is subcutaneous fat (Underwood 1971). Fat is deposited primarily along the back and midventral line. Deposits may develop to 1cm in thickness and weigh up to 1.8kg. The estimated caloric content of such a deposit is about 16,200 kilocalories (Underwood 1971). These energy reserves then could maintain an arctic fox at moderate activity levels for approximately 14 days (Underwood 1971) to 30 days (Rieve 1977).

SUMMARY

Arctic foxes on the Aleutian Islands will eat almost any food item that is available, but show definite seasonal preferences for those prey species most abundant and easiest to obtain. Beach invertebrates, carrion, cached food supplies and fat deposits appear to provide sufficient energy and nutrient reserves to sustain most individuals throughout the lean periods of fall and winter.

BEHAVIOR

METHODS

Reconnaissance trips were made to Laska Cove, Kaga Point, Quail Bay, Cabin Cove and several unnamed beaches and lakes east of Galas Point on Kagalaska Island. Basic fox trails were mapped (Figure 18).

The home range size of foxes on Kagalaska Island was estimated from capture records of tagged animals and by direct observations of the movements of foxes with color-dyed tails. Radiotelemetry tracking was initially attempted but the transmitters (DAVTRON) proved inadequate for the job and were not used.

RESULTS AND DISCUSSION

Activity

Foxes were observed foraging along the beaches of Kagalaska Island during the day throughout the year. Our trapping records also show considerable activity during the night (Table 10).

Folk (1964) noted some animals showed a bimodal activity rhythm with peak periods occurring at midnight and noon. Our observations suggest island foxes are active whenever the weather is favorable. During storms foxes seek shelter in dens or temporary burrows along the beaches.

Figure 18. Arctic fox trails and densities on Kagalaska Island.

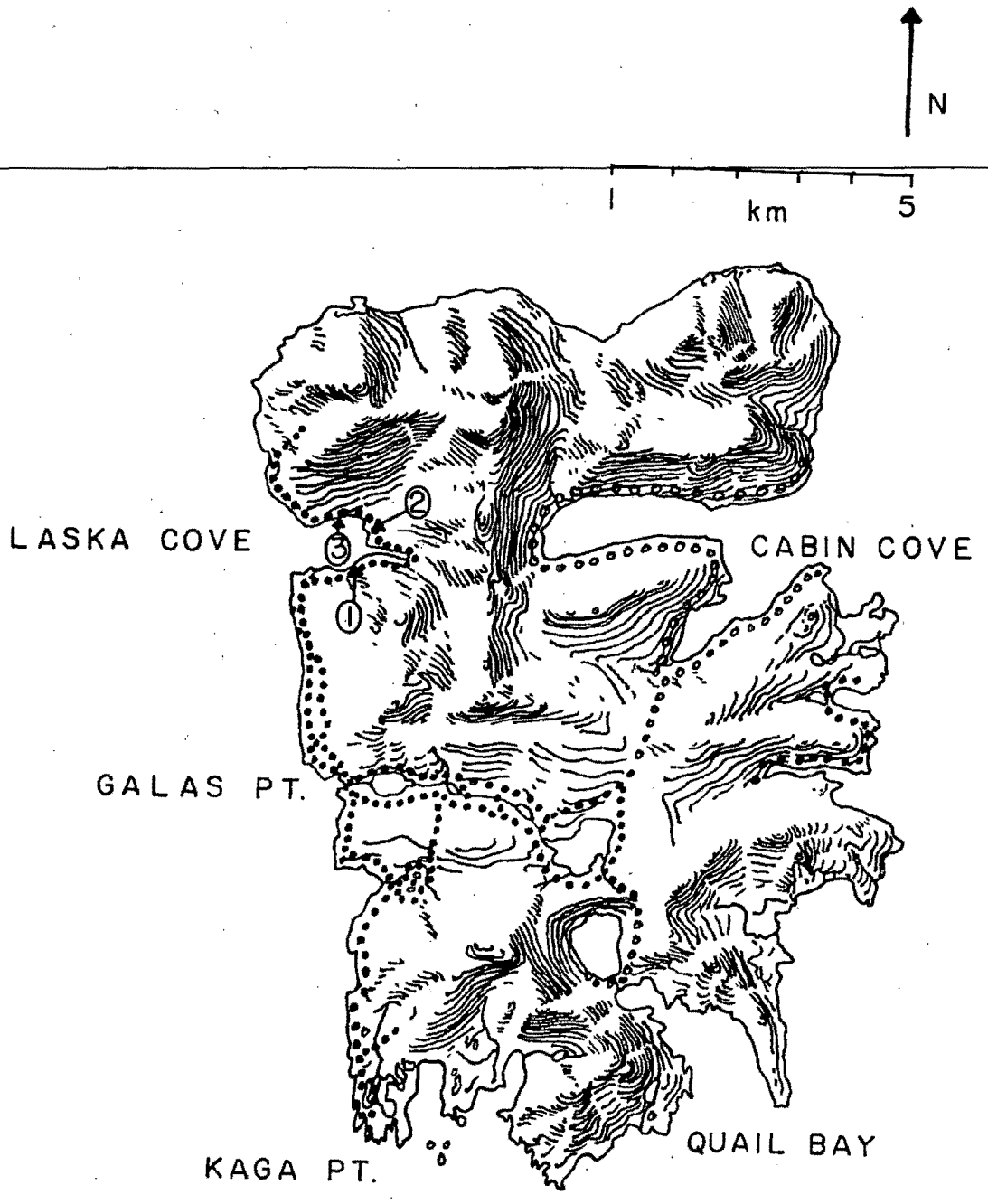

N
1
km
5
LASKA COVE
CABIN COVE
GALAS PT.
KAGA PT.
QUAIL BAY
1
2
3
PRIMARY FOX TRAILS
PROBABLE FOX TRAILS
FOX DENS

Table 10. Arctic fox trapping records and capture success for Kagalaska Island.

Date	1/30	2/1	2/3	2/26	2/27	2/28	3/1	3/2	3/4	3/5+	3/6+	4/7	4/8	4/9
Number of traps	10	10	1	4	11	11	5	5	9	4	4	11	10	9
Type of trap*	LH	LH	B	B	B	B	B	B	B	B	B	B	B	B
New captures	0	1	1**	2**	3	4	0	0	0	0	0	1	0	3
Recaptures	-	0	0	0	0	0	0	1	2	0	0	2	1	0
Number marked	0	1	0	1	3	4	0	0	0	0	0	1	0	3
Total daily captures	0	1	1	2	3	4	0	1	2	0	0	3	1	3
Total captures	0	1	2	4	7	11	11	11	11	11	11	12	12	15
Daily trap success	0%	10%	100%	50%	27%	36%	0%	20%	22%	0%	0%	27%	10%	33%

Total trap nights with leghold traps= 20
Trapping success with leghold traps= 5%

Total trap nights with box traps= 84
Trapping success with box traps= 18%

+ Gale force storms; * Trap type- LH= leghold, B= box; ** 1 Fox escaped unmarked

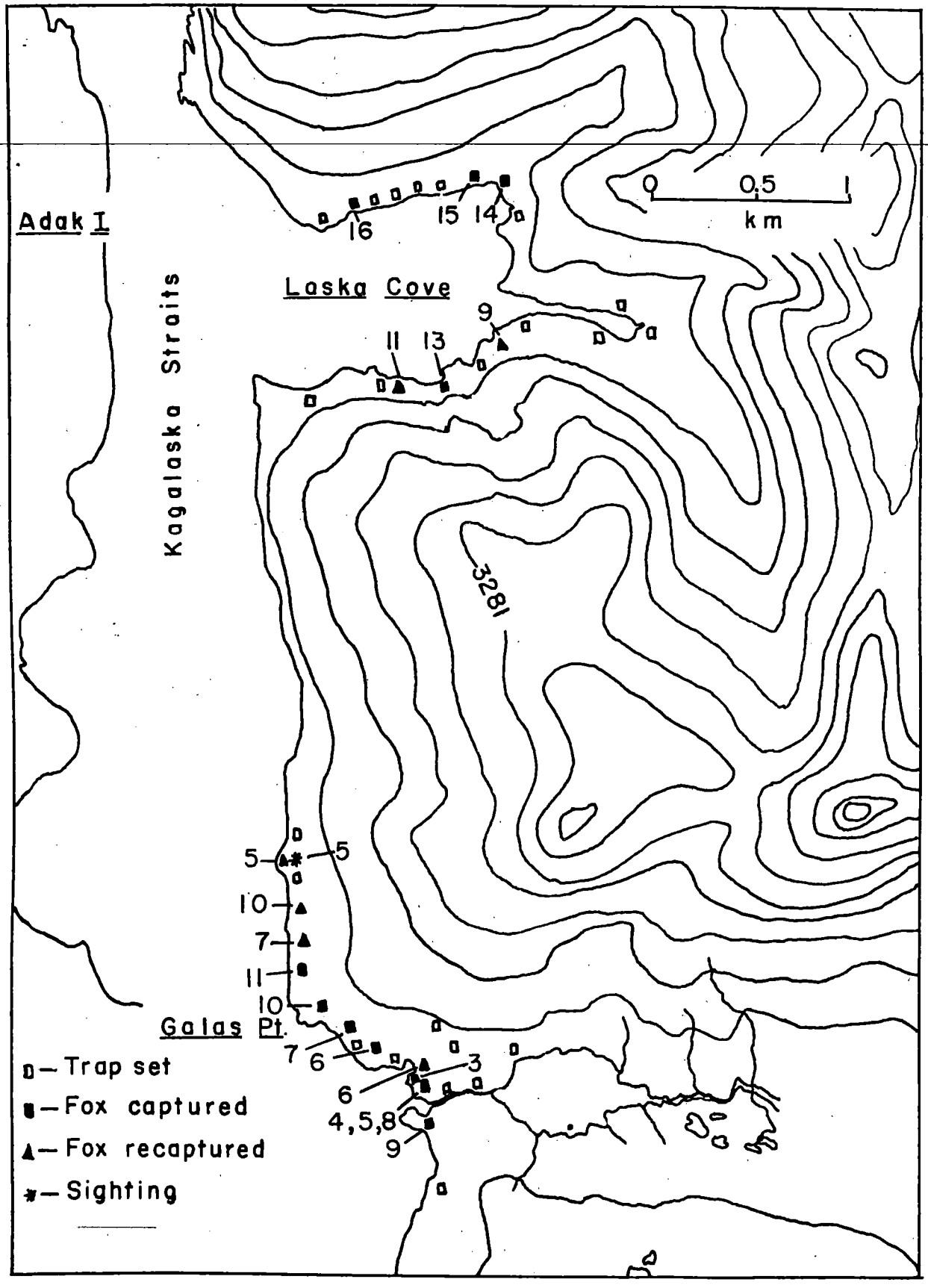
Fox Movement Patterns

Movement patterns closely followed the creeks, lakes, valleys, beaches and shoreline. Main thoroughfares crisscrossed the island connecting all major bays and beaches. These trails generally followed the low passes. No trails were found on the higher hillsides surrounding the valleys. For the most part, the trails were well-worn and appear to have been established for a long time. Even during the peak vegetation growth of summer, the trails were readily evident in that much less vegetation grows on them. Not all trails are used equally. Some areas at Kaga Point showed little sign of frequent use (scat collected was old). Highest use areas were along the shore and beaches (by Laska Cove, Cabin Cove, Galas Point).

Home Range Size

Recapture data on foxes on Kagalaska Island (Figure 19) show individual foxes move freely between Galas Point and Laska Cove. The maximum shoreline distance between captures was 7km (fox #9). Assuming that the foxes are active primarily within 0.4km of the coast (Henry 1977) a reasonable estimate for home range size would be 2.8km^2. This estimate is probably conservative. Direct observation of foxes traveling along the coast showed that they are quite capable of moving quickly through the tundra along trails. A fox could probably traverse the island in several hours without difficulty. Eberhardt and Hanson (1978) noted in a study of long-distance movements of arctic foxes in northern Alaska that individuals traveled up to 24 km per day. At this rate a fox on Kagalaska Island could travel from Laska Cove to Cabin Cove (Figure 18) in 3.4 hours and to Quail Bay in 9.1 hours. Whether or not the foxes do this is

Figure 19. Sightings, trap sets, captures and sites of recaptures of Arctic foxes on Kagalaska Island.


Adak I
Kagalaska Straits
Laska Cove
Galas Pt.
0 0.5 1
km
3281
16
15
14
9
11
13
5
5
10
7
11
10
7
6
3
6
4,5,8
9
▫ — Trap set
▪ — Fox captured
▲ — Fox recaptured
* — Sighting

uncertain. In the only other study of Aleutian Island arctic foxes, where individual foxes were marked and followed, Berns (1969) found that on Rat Island individual foxes appeared to range over the whole island. Studies of movement patterns of foxes in mainland habitats (Table 11) show arctic foxes home ranges to be highly variable and apparently depend on the season, food availability, age of the foxes and geographic location. During the breeding season the adult foxes generally remain in close proximity to the den site traveling short distances for food (Speller 1972). After the pups have been weaned, many foxes disperse and the family group may move to other localities where food is more available (Eberhardt 1977). On the Aleutian Islands food for the foxes is highly seasonal. During the spring and summer, breeding birds provide a large portion of the diet. During the winter beach amphipods and isopods become important in the diet (see Diet Analysis Section). It is likely then that foxes range widely about the island on a seasonal basis. During the summer activities they are likely to concentrate around bird rookeries if present. On Kiska Island foxes were found to be denning within an auklet colony (U.S.F.& W.S. 1976). During the winter home ranges may be extended as individuals disperse and forage along the beaches. Additional trapping and radiotelemetry work will have to be done however, before more definite home range patterns can be described.

Territoriality

The extent to which arctic foxes exhibit territorial behavior is uncertain but circumstantial evidence suggests that it occurs, particularly

Table 11. Estimates of home range size for Arctic fox.

Home Range Size (km^2)	Age Group*	Location	Reference
1.7-2.9	A	N.W.T., Canada	Speller 1972
2.0	A,J	U.S.S.R.	Skrobov 1958
2.8	A,J	Kagalaska Is., Alaska	This study
3.7 ± 1.7	J	Prudhoe Bay, AK	Eberhardt et al 1982
5.0-30	A	Lena R., U.S.S.R.	Bannikov 1969
5.4-14.9	A	Prudhoe Bay, AK	Fine 1980
11.0-30.4	J	Prudhoe Bay, AK	Fine 1980
16.0-25.0	A	Taimyr, U.S.S.R.	Bannikov 1969
20.8 ± 12.5	A	Prudhoe Bay, AK	Eberhardt et al 1982

* A= adults; J= juveniles

during the breeding season. MacPherson (1969) observed a minimal distance of approximately 1.6km between dens. Eberhardt et al. (1982) noted that the home ranges of adjacent adult foxes overlapped very little and both scent marking and direct intraspecific interactions (chasing) were observed. Fine (1980) believes that arctic foxes are territorial; mated pairs appear to maintain exclusive use of areas.

No territorial encounters were observed on Kagalaska Island although members of two dens in Laska Cove appeared to remain on opposite sides of the cove in the spring and summer when pups were active. During the late winter, however, 13 foxes were trapped along 8.8km between Laska Cove and Galas Point. This relatively large number of captures suggests that foxes were not maintaining territories at this time but were freely moving through other foxes' home ranges. Also the large number of foxes recorded as having fed on sea lion carcasses on Nitzki/Alaid Island(s) (Table 8) suggests that individual foxes do not retain exclusive territorial use of such food items. The source of this material is believed to be carcasses remaining at a sea lion haul-out area located on an intermittent isthmus between the two islands. Underwood (1980) noted that on St. Matthew Island an arctic fox drove other foxes away from a reindeer carcass. Chesemore (1975) observed that no more than one fox will feed on a carcass at a time.

Dispersal

Den sites appear to be abandoned at the end of the summer. Generally the males leave first followed by the females a few weeks later (Underwood 1980). On the Aleutian Islands this occurs in July (Berns 1969). After the adults leave, the pups also disperse. No data are available to determine whether island foxes stay in family groups during the winter.

Hunting Behavior

In this study foxes were only observed scavenging for beach invertebrates along the shore. Individuals would remain in one locality for many minutes digging and pawing through the kelp and turning over rocks. Sand fleas and other invertebrates were readily snapped up as they were uncovered.

Several piles of feathers were found along small ponds and fox trails suggesting fresh fox kills. Both Green-winged teal and Harlequin ducks roost on the shore, or on rocks a short distance out in the water. These birds would make relatively easy prey for a fox if it could get to the shore undetected. During heavy storms large numbers of these birds congregate in the small protected bays and coves making them readily accessible to the fox. Ptarmagan and small nesting passerines (song sparrows, winter wrens, grey-crowned rosy finches, and snow buntings) are also probably taken opportunistically during foraging trips.

POPULATION DENSITY

METHODS

The fox density of Kagalaska Island was estimated using a weighted mean version of the Peterson Index (Begon 1979). This measure provides a simple unbiased estimate of population density based on mark and recapture data collected over several days. The mathmatical formula is:

$$N = \frac{\Sigma M_i n_i}{(\Sigma m_i) + 1}$$

where N = estimate of population size

M_i = the number of marked animals in the population on day i
m_i = the number of marked animals in the population on day i
n_i = the number of individuals caught on day i.

The following assumptions were made in accordance with using the standard Peterson Index:

1) All marks are permanent and are correctly noted on recapture.

2) The process of being caught does not affect an individual's subsequent chance of recapture.

3) Being caught does not affect mortality or emigration potential.

4) All individuals have an equal chance of being caught.

5) No births, deaths, immigrations or emigrations occur during the trapping interval.

These assumptions are supported by the following observations. All foxes retained their ear tags during the trapping period. The tags of recaptured foxes were in good condition and no signs were evident suggesting the

foxes had attempted to remove them. Six foxes were recaptured without any modification of the trapping technique. Island foxes are apparently unafraid of entering traps. Continued use of the traps over an extended period would undoubtedly result in a degree of trap shyness in the foxes. No foxes were injured as a result of the trapping process. Recaptured foxes appeared vigorous and healthy. We therefore feel the trapping did not affect the mortality. Emigration from the island is essentially impossible, though local emigration may occur. Our trapping records (Table 10) do not show any bias towards unequal sex or age categories. The trapping period lasted approximately 3 months- during the mating season prior to the birth of pups. We believe that the population structure remained constant over this period.

RESULTS

Population Density Estimate

Over a period of 104 trap days 15 arctic foxes were captured along the western side of Kagalaska Island from Galas Point to Laska Cove (Figure 19). Thirteen foxes were marked with ear tags, color dyed and released, six foxes were recaptured.

Using the weighted mean Peterson Index we calculated an existing fox density of 23 foxes for the trapped area (8.8km of shoreline) or 2.6 foxes per kilometer of shoreline. Extrapolating this estimate for the entire island based on total usable shoreline (1.2 km; Figure 20), the total fox population for the island was estimated to be 108 foxes. Because of

Figure 20. Beach strand area suitable for foraging Arctic fox on Kagalaska Island.

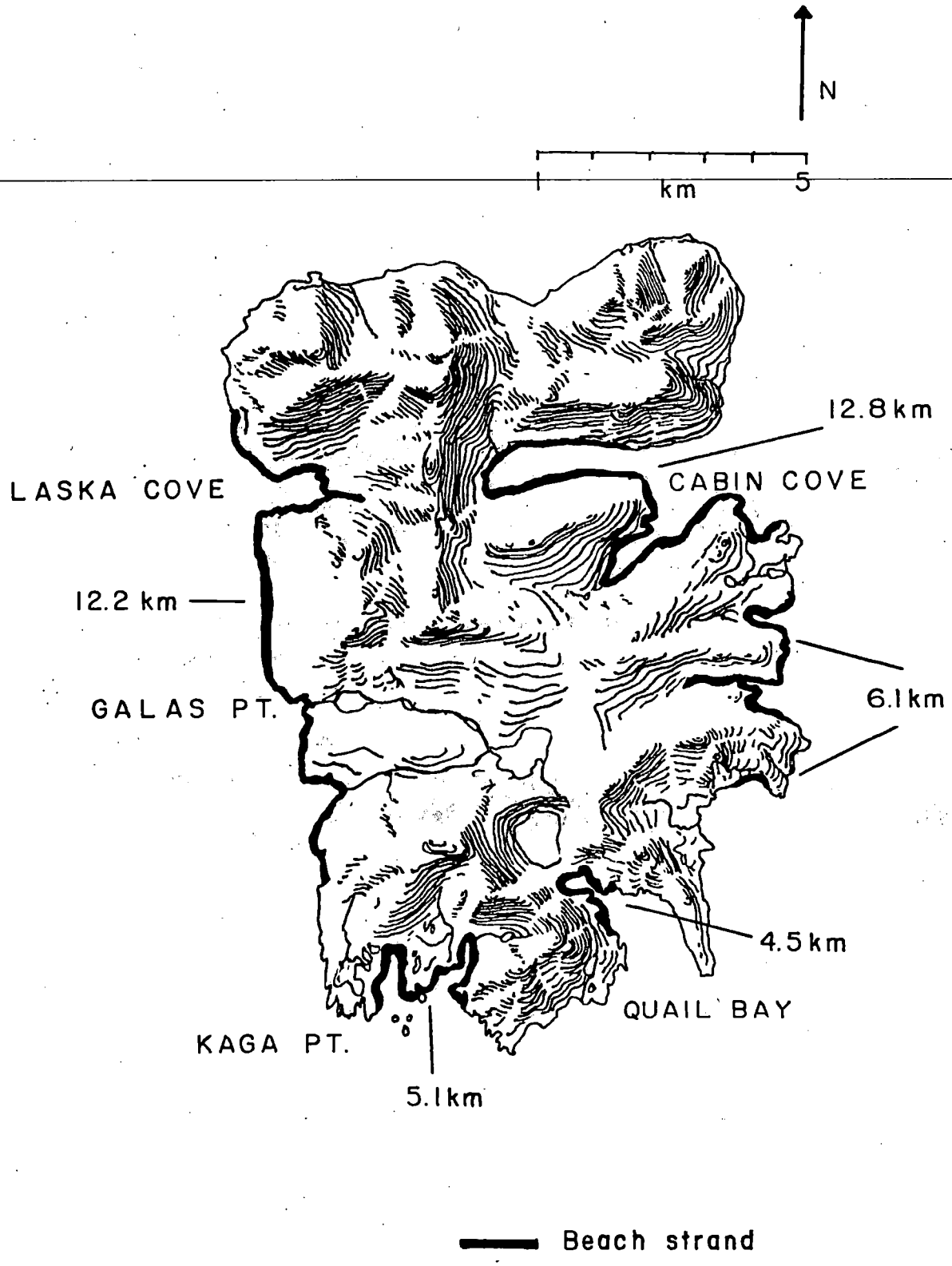
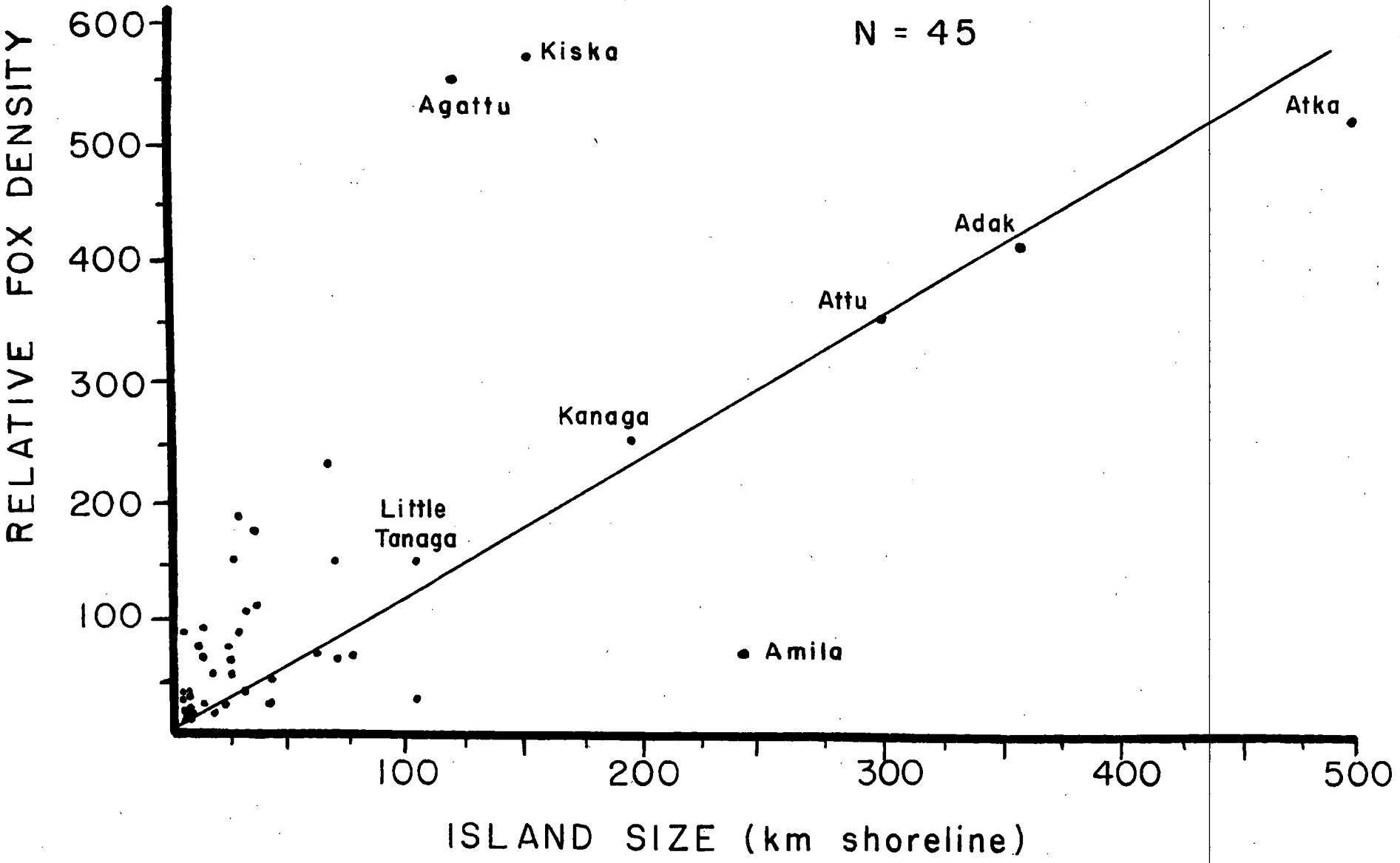

N
km
5
12.8km
LASKA COVE
CABIN COVE
12.2 km
GALAS PT.
6.1km
4.5km
QUAIL BAY
KAGA PT.
5.1km
Beach strand

Figure 21. Fox density relative to island size. Data points show maximum number of pelts taken annually from the islands from 1920-1936 (from Aleutian Island trapping records on file AIU-AMNWR, Adak, Alaska).


N = 45
RELATIVE FOX DENSITY
600
500
400
300
200
100
Kiska
Agattu
Atka
Adak
Attu
Kanaga
Little
Tanaga
Amila
100
200
300
400
500
ISLAND SIZE (km shoreline)

the small sample size, the variance is high. We believe however, that our estimate is reasonable. During 1930-1939 trappers working on Kagalaska Island estimated the total number of foxes to range from 60 to 120 ($\bar{X} \pm$ S.D. = 87 ± 26, N = 8). Our estimate falls easily within this range and is not significantly different from the calculated mean ($t = 0.76$, $P > 0.2$, d.f. = 7). Henry (1977) calculated an average density of foxes on Kanaga Island to be 2.29- 3.78 foxes/km of shoreline. Our density estimate for Kagalaska Island also falls within this range.

Island Carrying Capacity

The carrying capacity of an island environment (the total number of foxes in a stable population) is primarily dependent upon the resource requirements of individual foxes and the availability of these resources. Between islands within the Aleutian chain these resources are highly variable and dependent on island topography. Islands that are mountainous frequently support large colonies of birds which provide easily accessible food for foxes. Those islands which are comparatively flat often have extensive beach areas with large beach invertebrate populations as food sources.

In general, larger islands support more foxes (Figure 21). Islands of equal size however, may be significantly different in the fox carrying capacities. A reasonable first approximation of island carrying capacity would be 2-3 foxes per kilometer of useable beach area. This value will be higher of course, on islands with large bird colonies.

SUMMARY

The arctic fox is morphologically well adapted to surviving on the Aleutian Islands. The thick pelage provides more than adequate insulation for maintaining normal body temperatures all year. Regional heterothermy and countercurrent heat exchange also facilitate body heat conservation.

Two color phases, blue and white, are found on the islands. The blue phase predominates. On Kagalaska Island an apparent increase in the proportion of white phase foxes suggests that a high incidence of inbreeding has occurred.

Mating occurs from March through April and gestation lasts approximately 52 days. For island populations the mean primary reproductive rate is 7.8 embryos/litter. This potential litter size is lower, though not significantly different, from the mainland population rate of 9.2 embryos/litter. The mean litter size on the islands (4.74 pups/litter) is also lower than for mainland litters (6.8 pups per litter). The difference in parental reproductive success may be due to environmentally induced reabsorbtion of embryos or abortion. Postnatal mortality may be a result of sibling aggression or eagle predation.

Activity periods occur throughout the day and night when the weather

is favorable. Home range size for foxes on Kagalaska is estimated to be 2.8 km^2. Population size is estimated to be approximately 108 foxes for the entire island. Territorial behavior is likely to occur during the breeding season but it appears to break down after the foxes disperse from the den site. Dispersal occurs in mid to late summer. During the fall and winter foxes apparently roam freely about the island in search of food. Activities at this time are primarily confined to the beach strand areas. Diets of the fox consist mainly of beach invertebrates, birds, and carrion. Beach invertebrates and carrion provide a nutritional buffer to sustain the foxes throughout winter food shortages.

The carrying capacities of different islands are expected to be highly variable due to topographic differences although fox densities generally increase with island size. A first approximation estimate of the carrying capacity on any island is 2:3 foxes per kilometer of beach suitable for foraging.

BIOLOGICAL POTENTIAL FOR THE COMPETITIVE EXCLUSION OF ARCTIC FOX BY RED FOX

INTRODUCTION

Competition will occur when two species use the same critical resource(s) that is (are) in limited supply (Ayala 1970). Competition between two species may be realized by one, or both of two processes- exploitation or interference (Park 1954). Exploitation occurs when both species use the same limited resources but do not come in direct contact with one another. Interference occurs when individuals of the same, or different species interact directly and thereby reduce the efficiency of using the resource under contention. Competitive interactions between arctic and red fox in areas of sympatry apparently include both processes.

The extent to which competition will occur will be proportional to the degree to which resource requirements overlap. If the overlap is complete, coexistence is not possible and over time the less fit species will die out or be excluded from the range of sympatry. This ecological relationship is commonly referred to as the competitive exclusion principle (Hardin 1960). If the resource overlap is minimal, competition may be reduced sufficiently to permit indefinite coexistence. Temporary coexistence is possible for intermediate degrees of overlap.

In order to properly assess the biological potential for using the

red fox as control agents to exclude the arctic fox from the Aleutian Islands, the pattern of use, and degree of overlap of similarities in, resource requirements between both species must be determined. It should then be possible to make reasonable predictions about the outcome of competitive interactions between the two species. In this section we endeavor to establish an empirical basis for making these predictions by presenting a detailed analysis of resource utilization patterns. Our analyses show that red fox may possibly be effectively used as control agents although the number of red foxes required will be high.

NATURAL ASSOCIATIONS BETWEEN ARCTIC AND RED FOXES

Arctic foxes are found throughout the tundra regions of Alaska, Canada, Greenland, Norway, Sweden, and Russia (MacPherson 1964, Shilyaeva 1967, Bannikov 1970, Braestrup 1941, Chesemore 1975). Red fox zoogeographic patterns and field observations of red fox activity over the last fifty years suggest that in some areas the red fox has extended its range northward and is displacing the arctic fox (Marsh 1938, Skrobov 1959, MacPherson 1964). In Russia, Skrobov (1960) noted that the red fox replaced the arctic fox wherever their ranges overlapped. In Canada, Marsh (1938) observed a marked influx of red fox into the region of Churchill, Manitoba. In Norway, Ostybe et al. (1978) reported that red fox had displaced arctic foxes from 50% of their denning areas on Hardangervidda. Similar observations were made by Chirkova (1967) in Russia.

The reasons for the range extensions by the red fox are not clear although several hypotheses have been proposed. Chirkova (1967) believed that a general warming trend may have allowed the red fox to move farther northward. Garrot (pers. comm. in Rudzinski 1980) suggested that the range extensions are only apparent, and may be an artifact of fluctuating population cycles, in particular when movement patterns are studied over a short period of time. Rudzinski (1980) speculated that the red fox may be expanding their ranges in response to increased human activity in the arctic region. This activity, he suggests, may provide an artificially high food source in the form of refuse and direct feeding by field workers. Klein (1973), Hanson and L. Eberhardt (1977) and W. Eberhardt (1977) report that red and arctic foxes were attracted to oil pipeline construction camps in Alaska where food is readily available as handouts or in garbage dumps.

The mechanisms by which the red fox have displaced the arctic fox are also uncertain although competitive exclusion from denning sites is a possibility (Ostbye et al. 1978, Rudzinski 1980). Direct observations of confrontations between arctic and red foxes are few. Early Alaskan trappers considered the red fox to be one of the main predators of arctic foxes (Chesemore 1975). Marsh (1938) found that red foxes often attacked and killed trapped arctic foxes. Underwood (1980) observed that red foxes harass arctic foxes in areas of sympatry.

In contrast, Eberhardt (1977) found arctic and red foxes living sympatrically on the North Slope in Alaska. No direct interspecific competiton was observed but denning areas were spatially segregated; arctic fox dens were found in pingos, low ridges, dunes and river terraces on the tundra plain. Red fox dens were located primarily in river banks and in river terraces in the foothills of riverine habitat. The habitat segregation however, may indicate competitive displacement has already occurred. Following the breeding season, individuals of both species dispersed into each others denning areas. Eberhardt (1977) noted from scat analysis that diets of both species were similar and he suggested that during the fall and winter some competition for prey may exist in the areas of home range overlap.

The above data suggest that red fox may be expanding its range naturally, and that in areas of sympatry with the arctic fox, the arctic fox is displaced. These observations lend support to the premise that if red foxes were placed on islands inhabited by arctic fox, in numbers sufficient to monopolize critical limiting resources, the arctic fox would be eliminated. It is therefore possible that a biological control program using red fox as control agents could work providing suitable numbers of red foxes were used. This report provides an analysis of the ecological factors which would determine this number and discusses the practical feasibility of developing a management program based on this relatively unique type of biological control.

LIMITING SIMILARITIES BETWEEN ARCTIC AND RED FOXES

Energetics

Most resource requirements of homothermic animals (food, water, shelter) are directly related to energy requirements. Food and water are needed for metabolic heat production which is necessary to maintain a constant body temperature. Shelter is required for efficient behavioral thermo-regulation.

Red fox have greater overall energy requirements than do arctic fox (Table 12). Because of their larger mass, red foxes have a higher total metabolism. Contrary to normal trends where the smaller animal has the higher weight-based metabolism (Kleiber 1961) red foxes also show a greater mass specific metabolism. This is most likely due to higher energy requirements necessary to offset a greater conductive heat loss (Table 12). Arctic fox are more efficient in retaining body heat because of better insulation afforded by a thicker pelage (Figure 14).

The relatively small difference between summer and winter energy requirements for each species (Table 12) is due to the growth of thick fur coats during the winter (Hart 1960, Underwood 1971, Casey et al. 1979). The addition of this fur insulation results in an adaptive shift in lower critical temperatures (Figure 19). As the daily ambient temperatures decrease the lower critical temperature also decreases thereby increasing the critical gradients (the difference between body

temperature and ambient temperature). The energetic consequences of such a pelage change is that the foxes maintain a relatively constant metabolism despite large seasonal changes in environmental temperatures (Hart 1956, Underwood 1971, Casey et al. 1979).

Food Requirements

Both arctic and red foxes are opportunistic scavengers. They will eat almost any food item that is available. Red fox readily consume beach invertebrates, carrion and fish (Table 13), but prefer, as do arctic fox, birds and small mammals if available. Murie (1959) recorded observations of red fox feeding habits made by Beals and Longworth (Field Report 1941) on Unmak Island. They noted that the red foxes were concentrated on the beaches where they fed heavily on sandfleas. Red foxes introduced onto islands devoid of rodents would undoubtedly develop diets very similar to arctic foxes on the islands (Tables 6, 7, 8). Food resource use overlap should therefore be very high.

In a comparative analysis of food requirements of arctic and red foxes (Vaughn et al 1979); arctic foxes averaged higher food consumption per kilogram of body weight than red foxes during winter, spring and summer (Table 14). During the fall however, food consumption by the arctic fox dropped markedly below that of the red fox. Extrapolating these data to estimate total food consumed we multiplied each value by the approximate weight of each species. The results show arctic fox consumed

Table 12. Body mass, energy metabolism, total metabolism, and thermal conductance of Arctic and Red fox in summer and winter.

Species	Mass (kg)		Metabolism ($W\ Kg^{-1}$)		Total Metabolism (W)		Conductance ($W\ Kg^{-1}{}^{o}C^{-1}$)	
	S	W	S	W	S	W	S	W
Arctic fox	3.71	3.71	2.06	2.11	7.64	7.83	0.047	0.026
Red fox	4.44	5.10	3.07	2.78	13.63	13.92	0.100	0.053

All data are converted to S.I. Units (Mechtley, 1973). Conversion factor of 4.8 cal/ml O_2 is used. 1 Watt/Kg = 1.163 cal/g/hr. Adapted from Casey et al 1979.

Table 13. Food items used by red foxes on Dolgoi Island (from Murie 1959).

Item	Number	Percent
Microtus	38	52
Bird	16	21.9
Beach fleas (Crustacea)	6*	8.2
Sea urchin (Strongylocentrotus drobachiensis)	4*	5.4
Mussel (Mytilus sp.)	2*	2.7
Heavy cloth	2	2.7
Brown paper	2	2.7
Hair seal (Phoca sp.)	1	1.3
Small fish	1	1.3
Large bone	1	1.3

* Such forms are listed as times occurring, rather than as actual number of individuals.

more food during the spring and summer, less in the fall and approximately equal amounts during the winter.

Den Site Requirements

Both arctic fox and red fox have similar den site requirements (Eberhardt 1977, Ostybe et al. 1978). In an analysis of den characteristics on the north slope in Alaska, Eberhardt (1977) found arctic foxes used dens in pingos, low ridges, dunes and river terraces on the tundra plain. Red foxes denned primarily in river banks and in river terraces on the foothills of riverine habitat. All structural characteristics of these dens were similar except the den entrances were larger for the red fox. This was undoubtedly due to the larger size of the red fox.

On Hardangervidda, Norway, Ostybe et al. (1978) found that red foxes were occupying 50% of the dens formerly used by arctic foxes. The arctic fox had been relegated to den sites largely in bedrock, and in hollows too small for the red fox to enter. These observations strongly suggest that the preferred den site requirements of both arctic and red foxes are nearly identical. Wherever both species occur together red foxes are apparently able to monopolize the prime denning habitat.

Territoriality and Home Range

Like arctic fox, red fox show a variety of behavioral patterns with regard to territoriality and home range size. Many studies show that

Table 14. Food consumption by arctic and red foxes during various seasons of the year at Pt. Barrow, Alaska. (After Vaughan et al 1979).

	Amount of Food Consumed			
	Arctic foxes[1]		Red foxes[2]	
Season	kg/kg body wt.	Total	kg/kg body wt.	Total
Winter	0.9	3.42	0.86	3.53
Spring	0.87	3.31	0.59	2.42
Summer	1.14	4.33	0.96	3.94
Fall	0.52	1.98	0.85	3.84
$\bar{X}$	0.86	3.26	0.81	3.34
S.D.	0.26	0.97	0.16	0.65

1 N=5; estimated mean weight= 3.8kg (Table this report).
2 N=3; estimated weight= 4.1 (Underwood 1971).

adult red foxes are territorial, at least in the breeding season (Scott 1943, Ables 1969, 1975, Sargeant 1972, Montgomery 1974, Storm and Montgomery 1975, Niewold 1980, Storm et al. 1976, Johnson and Sargeant 1977, MacDonald 1977, 1980. Maurel 1980). Other studies show conspicuous overlapping of home ranges and nonexclusive use, except in the vicinity of active dens with cubs (Lloyd 1977, Browne 1978, Harris 1980). The degree to which foxes are territorial appears to depend on food resource availability and defensibility. When food is plentiful, there is little need to defend the resources (Horn 1968, see Harris 1980). However, if food is sparsely distributed, adult foxes are likely to defend their home ranges to guarantee exclusive access to its resources (Storm et al. 1976, MacDonald 1977, 1980, Neiwold 1976, 1980).

Home range size for red foxes also appears to be highly variable. Niewold (1980) reports red fox home ranges in the Netherlands vary from 1.54km^2 to 10km^2 in size. The home ranges of females were, on the average, larger than those for males (2.2km^2 for males and 3.0km^2 for females. Sargeant (1972) measured home ranges from 6.4km^2 to 8.6km^2. Maurel (1980) determined the total area required for foxes during the breeding season was 5.0km^2 (range = 4.9 - 6.0km^2). These values are comparable with the home range estimates for arctic foxes (Table 11).

Reproduction

The primary reproductive rate of red foxes ($\bar{X} \pm S.D. = 5.47 \pm 0.73$) (Table 15) is significantly less than that for arctic fox on the Aleutian Islands (Table 4) ($t = 3.21$, $P < 0.01$, d.f. = 47). MacPherson (1969) proposed that the larger litters of the arctic fox are an adaptive response to greater seasonal variability in food resources and consequent higher winter mortality. In the arctic food supplies are plentiful in the spring and summer. Foxes have no difficulty supplying their needs (Speller 1972). Winters are periods of food scarcity and mortality is high due to starvation. Under these circumstances the best reproductive strategy for the arctic fox would be to produce large litters while food is available (Lack 1954). The larger the litter, the better the chances are that some pups will survive to breed the following spring.

In contrast, a good portion of the distributional range of the red fox is below the arctic region. Here winters are less severe and the seasonal food supply more constant. There is also a smaller food supply in the summer, of that over the needs of the breeding population for the rearing of young. Under these conditions the best reproductive strategy would be to raise fewer young which, because of a more constant yearly food supply, would not be as susceptible to starvation and could more easily survive the lean periods.

Table 15. Mean potential litter size for red fox as indicated by number of fetuses or placental scars (MacPherson 1969).

Litter size	Reference
5.5	Schofield (1958)
5.4	Sheldon (1949)
5.4	Layne and McKeon (1956)
5.1	Richards and Hine (1953)
4.6	Shofield (1958)
6.8	Hoffman and Kirkpatrick (1959)

AN EXPERIMENTAL ANALYSIS OF ARCTIC AND RED FOX INTERACTIONS

In an effort to gain insight into behavioral relationships which may occur between arctic and red foxes in the wild, Rudzinski (1980) studied the interactions between pairs of both species in captivity. In a carefully controlled experiment, various combinations of single or paired red foxes were introduced into a 4.05 hectare enclosure containing acclimated pairs of arctic fox. All consequential agonistic interactions and dominance-subordinance relationships were recorded.

In summary Rudzinski found that the red foxes consistently forced the arctic foxes to use the less preferred sections of the enclosure. While there were no actual fights observed, threats and chases were common. Threats were mostly defensive in nature and usually preceded, or followed, a chase. The arctic foxes threatened the red foxes more than the converse, but the red foxes chased the arctics more. When in pairs, the male red fox generally took the role of the aggressor. The female red fox was often intimidating enough alone, to displace the arctics, but displacement occurred faster with her mate.

These data suggest that the red fox are behaviorally dominant to the arctic fox. How representative these results are of natural encounters between the two species however, is uncertain. Rudzinski observed that the arctic fox may be the superior overall competitor in tundra areas

even though the red foxes may be physically superior in direct competition. This situation could occur, he states, if the arctic foxes were better adapted to using available densities and the highly seasonal food resources characteristic of the northland habitat.

DISCUSSION

The preceding analysis of resource use patterns in arctic and red fox show substantial overlap in food, home range, and denning requirements. It would be reasonable to predict therefore that strong competition would occur between the two species should red foxes be introduced onto islands supporting arctic fox populations. The success of the proposed biological control program, however, will depend to a large extent on three factors: 1) the number of red foxes introduced, 2) the spatial and temporal heterogeneity of food resource abundance on the islands, and 3) the timing of red fox introductions.

The Number of Red Fox

A fundamental premise of competitive exclusion theory is that one species must be able to completely monopolize a limiting resource critical to the survival of its competitor. If resource requirements are similar, as they appear to be in the arctic and red fox, resource monopolization can occur if the dominant species' population level is at a maximum carrying capacity for that species only on an island. If the population level is lower than carrying capacity, those resources

not being used will be available to the subordinate species and coexistence could occur between the two species.

The number of red foxes required to achieve the carrying capacity of course depends on the size of the island and the relative abundance of critical resources. A reasonable approximation of the number can be estimated by reference to the size of the endemic arctic fox populations and by comparison of resource requirements. The data on energy requirements (Table 12) show that the red fox uses approximately twice the metabolic energy as the arctic fox. If it is assumed that metabolic energy requirements are proportional to food requirements, the red fox should require double the amount of food required by the arctic fox. This relationship in turn, would suggest the home range size of the red fox would also be proportionally larger. A first approximation of island carrying capacity for red fox would be one-half the population size of the arctic fox.

The results from the food requirement study (Table 14) however, show that food requirements are highly seasonal. Arctic foxes consume greater amounts of food than the red fox in the spring and summer, less in the fall, and comparable amounts during the winter. Since carrying capacities are frequently equal to the maximum population level sustainable at the most critical time of the year (in this case, winter) these data suggest the carrying capacity for the red fox would be equal to that of the arctic fox.

The reasons for the disagreement between the metabolic energy requirements and the food requirements in predicting the comparable resource requirements for the two species is uncertain. It is possible that differences in digestion efficiency could account for this discrepancy. The close taxonomic affinity and strong similarities in morphology and physiology between the species suggest that this is not the case.

Nevertheless it would be reasonable to predict that the number of red foxes that would be required to displace the arctic fox would be within the range of a 1:1 to 1:2 red-to-arctic introduction ratio.

Earlier predictions that a smaller number of red fox could be expected to do the job, based on reports of a single red fox swimming to Chowiet Island and destroying all of the arctic foxes living there (Bailey, pers. comm.) appear to be unsubstantiated, and are not supported by current ecological understanding of fox biology.

It would be possible, however, for a breeding pair of red foxes to become established on an island and gradually displace the arctic foxes by behavioral dominance (Rudzinski 1980) and natural population growth. This process is most likely the biological reason for red fox range expansions on the mainland and for fur farmer observations that red foxes exterminated blue fox whenever placed on the same island.

The red foxes to be used in the proposed biological program will necessarily be neutered to insure against their becoming established on the islands. The procedure will preclude any possibility of intensifying competitive pressure by gradual population growth. The number of foxes introduced onto an island must therefore be high enough to maximize the competitive impact by immediate monopolization of the resources. At a minimum this would require a 1:2 red-to-arctic fox introduction ratio. More realistically a 1:1, or greater, ratio may be required.

Spatial and Temporal Heterogeneity and Abundance of Food

The distribution and abundance of food resources on the islands appear to be very important in determining local fox density and home range patterns. On an island whose food is widely dispersed and sparse (e.g., islands with scattered small beaches but without bird rookeries), fox densities would be low and home ranges large. In contrast, on islands where food is concentrated and plentiful (e.g., islands with extensive bird rookeries) foxes are likely to be found in high numbers and exhibit smaller home ranges. In terms of biological control the monopolization of resources by the red fox would be accomplished most easily on islands with concentrated food supplies. Rudzinski (1980) observed that red foxes in captivity were able to displace the arctic foxes from preferred foraging areas.

A possible scenario for the effect of exclusion of the arctic fox from critical food sources may be envisioned as follows. Under chronic

stress of food shortage, intraspecific aggression is likely to increase, mating frequencies will decline, vixens will reabsorb or abort embryos, and post natal mortality will increase due to starvation and sibling aggression. Also during the Fall, if the arctic foxes are unable to build up extra reserves by putting on fat, or by building large food caches, they are likely to starve during the Winter. Combined, these factors are likely to result in a rapid decline in the arctic fox population.

However, if the food resources are widely dispersed and renewable, (e.g., beach amphipods), it is possible they will not be defensible (Horn 1968). The arctic fox may then be able to attain temporary, or indefinite, coexistence with the red fox by temporal and spatial segregation of resource use. This possibility is an important consideration with respect to the potential success of the biological control program. If the arctic foxes are able to coexist for a period of time equal to the expected longevity of the neutered red foxes (3-4 years) their populations could rebound following the death of the red foxes, unless subsequent additional introductions of red fox were made. The initial introductions should be sufficient in number therefore to guarantee complete monopolization of the available resources by red fox.

The Timing of Red Fox Introductions

Assuming that the arctic foxes are at carrying capacity on the islands at the time of the red fox introductions, the resource availability will be reduced in proportion to the number of red foxes introduced.

If the food requirements are comparable as suggested by Table 14, an introduction of red foxes at a 1:1 ratio will effectively reduce the amount of food available to each individual to one-half. Competition for these resources, both interspecific as well as intraspecific, will occur. To minimize intraspecific competition between the red foxes introductions should be made at several localities around the island, or at periodic intervals, to allow for adequate time for dispersal. All introductions should be made within one season to maximize interspecific competition.

CONCLUSION

The proposed biological control program is based on the fundamental premise that red fox are competitively superior to the arctic fox. In this report we have shown that red foxes, if introduced in sufficient numbers onto islands supporting arctic fox populations, should effectively compete for food and other critical resources. Evidence was presented demonstrating that red foxes are behaviorally dominant to arctic foxes and may displace arctic foxes. It is not certain however, that the competitive interactions will be intense, or prolonged, enough to result in the complete eradication of the arctic fox. In nature, species tend to avoid competition by partitioning resources and habitats (Schoener 1974, Ostbye et al. 1978). It is unlikely that red foxes will usurp any more territory than is required to provide essential resources for survival and reproduction. Without the ability to reproduce, the red foxes cannot

sustain competitive pressure beyond their longevity period. If the resources on an island are strongly heterogeneous, spatially and temporally, arctic foxes may be able to coexist using suboptimal habitats.

Obviously if enough red foxes were introduced, any island could be supersaturated and the chance for complete eradication of the arctic fox would be increased. There are equally obvious economic restrictions in doing so, however. To introduce red foxes at a 1:1 ratio on an island as large as Kanaga for example, would mean introducing about 700 animals (Henry 1977). The cost and logistics involved in such a project would be great, and potentially prohibitive.

Before conclusive predictions can be made on the final outcome of the competitive interactions between the two species, more research has to be done to learn how spatial and temporal heterogeneity of island resources affects the intensity and duration of competition. Only then can a realistic management program for all of the Aleutian Islands be outlined.

RECOMMENDATIONS

1). Resume the study by implementation of Phases I and II.

2). Select a small test island easy to support logistically. Shemya may prove difficult to work on due to military restrictions.

3). Red foxes may be more easily collected on the eastern Aleutian Islands instead of near Fairbanks. These animals are plentiful (E.Bailey pers. comm.) and presumably they will not be trap shy. Box traps should be used to preclude foot damage or injury due to exposure. An advantage to using island foxes is that they should be adapted to the environment of the test island and thereby be more effective control agents.

4). The use of Stericin (Appendix 4) may be a cost effective alternative to surgical sterilization of the red foxes. It could be performed by a trained technician, or veterinarian, in the field which would eliminate the need for building extensive holding facilities required for housing the foxes during recovery from surgery.

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APPENDICES

Appendix 1. Abundance and status of Aleutian Island birds.

(From U.S.F.& W.S. 1974, White 1977)

Bird Species	Relative Abundance*	Resident Status**	Breeding Status***
Gaviiformes			
Common Loon	U	PR	+
Arctic Loon	U	WR	-
Red-throated Loon	U	PR	+
Podicepediformes			
Red-necked Grebe	U	WR	-
Horned Grebe	U	WR	-
Procellariiformes			
Black-footed Albatross	U	SR	-
Laysan Albatross	U	SR	-
Northern Fulmar	C	SR	+
Sooty Shearwater	U	SR	-
Short-tailed Shearwater	A	SR	-
Scaled Petrel	R	SR	-
Fork-tailed Petrel	A	SR	+
Leach's Storm Petrel	A	SR	+
Pelecaniformes			
Double-crested Cormorant	U	SR	+
Pelagic Cormorant	C	PR	+
Red-faced Cormorant	C	SR	+
Anseriformes			
Whooper Swan	U	WR	-
Whistling Swan	U	PR	+
Canada Goose			
Cackling	U	M	-
Taverner's	A	M	-
Aleutian	R	SR	+
Black Brant	A	M	-
Emperor Goose	A	WR	-
White-fronted Goose	R	M	-
Mallard	U	PR	+
Gadwall	O	SR	-
Pintail	U	PR	+
Green-winged Teal			
Aleutian	C	PR	+
North American	C	SR	+

Appendix 1. Cont'd.

Bird Species	Relative Abundance*	Resident Status**	Breeding Status***
Anseriformes, cont'd.			
European Widgeon	U	M	-
American Widgeon	O	M	-
Northern Shoveler	O	M	-
Canvasback	R	WR	-
Greater Scaup	U	SR	+
Tufted Duck	O	PR	-
Common Goldeneye	O	SR	-
Bufflehead	C	UR	-
Oldsquaw	R	SR	-
Harlequin	C	PR	-
Steller's Eider	C	WR	-
Common Eider	C	PR	+
King Eider	C	WR	-
White-winged Scoter	O	SR	-
Surf Scoter	R	V	-
Black Scoter	R	SR	-
Smew	R	M	-
Common Merganser	O	WR	-
Red-breasted Merganser	U	SR	+
Falconiformes			
Rough-legged Hawk	O	SR	+
Bald Eagle	C	PR	+
Marsh Hawk	R	V	-
Gyrfalcon	R	SR	+
Peregrine Falcon	C	PR	+
Merlin	R	V	-
Galliformes			
Willow Ptarmigan	C	PR	+
Rock Ptarmigan	C	PR	+
Gruiformes			
Sandhill Crane	O	M	-
Charadriiformes			
Black Oystercatcher	C	PR	+
Semipalmated Plover	V	SR	+
American Golden Plover	U	M	-
Black-bellied Plover	R	M	-
Ruddy Turnstone	C	M	-
Common Snipe	R	M	-
Whimbrel	R	M	-
Wood Sandpiper	R	SR	+

Appendix 1. Cont'd.

Bird Species	Relative Abundance*	Resident Status**	Breeding Status***
Charadriiformes, cont'd.			
Wandering Tattler	U	M	-
Lesser Yellowlegs	R	V	-
Rock Sandpiper	C	PR	+
Sharptailed Sandpiper	O	M	-
Pectoral Sandpiper	O	M	-
Baird's Sandpiper	R	M	-
Least Sandpiper	U	SR	+
Dunlin	R	WR	-
Western Sandpiper	C	M	-
Bar-tailed Godwit	U	M	-
Sanderling	U	WR	-
Red Phalarope	C	M	-
Northern Phalarope	U	SR	+
Pomarine Jaeger	U	SR	-
Parasitic Jaeger	C	SR	+
Long-tained Jaeger	R	M	-
Glaucous Gull	O	WR	-
Galucous-winged Gull	C	PR	+
Slaty-backed Gull	R	V	-
Herring Gull	R	WR	-
Mew Gull	O	WR	-
Black-headed Gull	R	M	-
Black-legged Kittiwake	C	SR	+
Red-legged Kittiwake	C	SR	+
Sabine's Gull	R	M	-
Arctic Tern	C	SR	+
Aleutian Tern	U	SR	+
Common Murre	A	PR	+
Thick-billed Murre	A	PR	+
Pigeon Guillemot	A	PR	+
Marbled Murrelet	U	PR	-
Kittlitz's Murrelet	U	SR	+
Ancient Murrelet	C	SR	+
Cassin's Auklet	R	SR	+
Parakeet Auklet	C	SR	+
Crested Auklet	A	SR	+
Least Auklet	A	SR	+
Whiskered Auklet	C	SR	+
Horned Puffin	C	SR	+
Tufted Puffin	A	SR	+
Strigiformes			
Snowy Owl	R	WR	+
Short-eared Owl	U	SR	+

Appendix 1. Cont'd.

Bird Species	Relative Abundance*	Resident Status**	Breeding Status***
Coraciiformes			
Belted Kingfisher	R	V	-
Passeriformes			
Bank Swallow	V	SR	+
Black-billed Magpie	R	V	-
Common Raven	C	PR	+
Dipper	V	PR	+
Winter Wren	C	PR	+
Hermit Thrush	R	SR	-
Water Pipit	U	SR	+
Northern Shrike	R	V	-
Yellow Warbler	U	SR	+
Wilson's Warbler	R	SR	-
Gray-crowned Rosy Finch	A	A	+
Common Redpoll	C	SR	+
Savannah Sparrow	A	SR	+
Golden-crowned Sparrow	R	SR	-
Fox Sparrow	O	SR	+
Song Sparrow	C	PR	+
Lapland Longspur	A	SR	+
Snow Bunting	C	PR	+
McKay's Bunting	R	WR	-

* A- Abundant, C- Common, U- Uncommon, O- Occasional, R- Rare

** M- Migrant, PR- Permanent Resident, SR- Summer Resident, WR- Winter Resident, V- Vagrant

*** + Known to breed in distribution area, - not known to breed in distribution area

Appendix 2. Construction, assembly and operation of an arctic fox box-trap

1) Construction

a) Trap is constructed from 1/2 inch plywood.

b) Latch hook is wrapped around bolt supporting door lock.

c) Back may be solid plywood or have a heavy welded wire screen window. (Foxes can tear out of light galvanized screening).

2) Assembly

a) All bolts are fitted through sides and loosely adjusted.

b) Bottom board is fitted into lower dado grooves in sides, and bolts are tightened.

c) Back is fitted into end dados of sides.

d) Top is fitted into top dados and all bolts are tightened.

e) Door lock is fitted into bolt holes.

3) Operation

a) Lift door lock, then lift door.

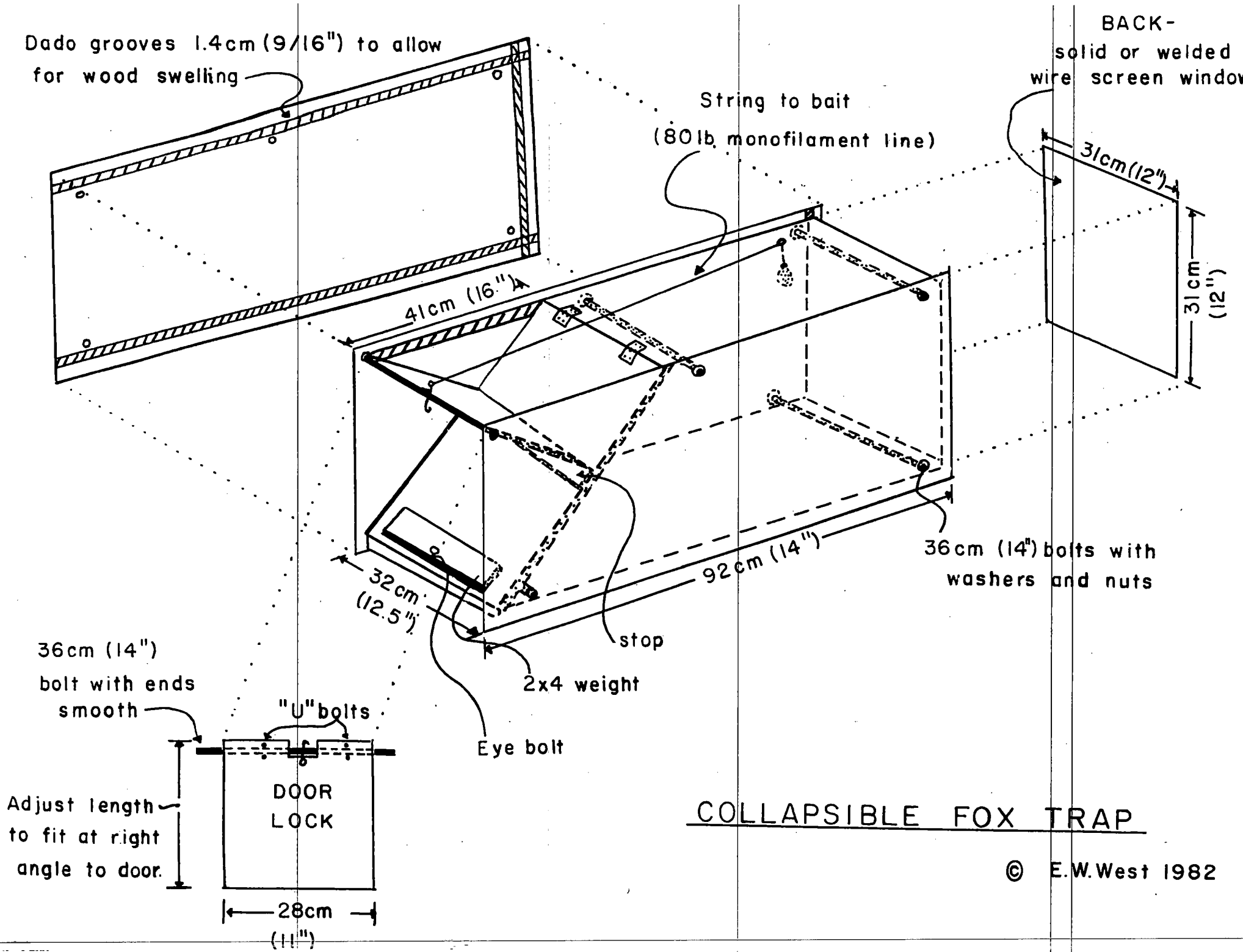
b) Hook latch hook into eye bolt.

c) Thread bait line through hole in top and tie securely to latch hook.

d) Adjust latch hook to most sensitive position.

e) Scatter extra bait around trap.

NOTE: Do not spread bait scent on top of trap or on bait line. Foxes will trip trap while investigating smell.



COLLAPSIBLE FOX TRAP

Appendix 3. Food items in blue-fox droppings, Aleutian Islands, 1936 and 1937

("Percent of Total" means percent of total number of occurrences of each species). From Murie 1959.

	Attu (72 droppings)		Agattu (156 droppings)		Semichi (39 droppings)		Kiska (171 droppings)		Segula (24 droppings)		Little Sitkin (33 droppings)		Rat (87 droppings)		Semisopochnoi (206 droppings)		Amchitka (48 droppings)		Gareloi (218 droppings)		Amatignak (21 droppings)	
	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total
Amphipods	15	19	118	59.2	24	38	105	42.2			6	11.3	53	40.1			47	59.5	1	.4	10	36
Isopods	11	15	4	2	1	1.5	6	2.5	1	4.1	16	30.2	2	1.5			1	1.2			2	4
Crabs							1	.5														
Goose barnacles			1	.5			1	.5														
Sea urchins	2	2	6	3	6	9.5	37	14.5			3	5.4	8	6	2	.9	9	11.3	3	1.2	7	15
Mussels	2	2					1	.5									1	1.2				
Snails	3	4															4	5				
Clamworm (*Nereis* sp.)	3	4																				
Clam													1	.7								
Beetles	1	1	3	1.5			1	.5			2	3.6					3	3.8				
Diptera																	2	2.4				
Caterpillars (Noctuidae)							10	4														
Insects																			1	.4		
Fork-tailed petrel	9	14	36	18			13	5.2			3	5.4			8	3.8			35	15	5	13
Leach's petrel			6	3																		
Fulmar			2	1			2	1			1	1.9										
Shearwater											1	1.9										
Tufted puffin	1	1	3	1.5	1	1.6	1	.5			1	1.9			7	3.3			1	.4	1	2
Horned puffin					1	1.6					4	7.2			1	.4						
Murre			4	2	1	1.6	9	3.6							1	.4						
Least auklet	1	1	1	.5	1	1.6	6	2.4	19	70	10	18.8	3	2.2	152	72.7	1	1.2	86	36.9		
Whiskered auklet																			9	3.8		
Parakeet auklet			1	.5															38	16.3	1	2
Crested auklet			2	1	5	8			7	25.9	4	7.2	2	1.5	36	17.2	1	1.2	43	18.4	1	2
Cassin's auklet																						
Ancient murrelet																			3	1.2		
Pigeon guillemot																			3	1.2	1	2
Cormorant					1	1.6																
Glaucous-winged gull							1	.5			1	1.9							3	1.2		
Pacific kittiwake																						
Emperor goose							2	1					1	.7								
Harlequin duck																						
Scaup duck	1	1																				
European teal																						
Unidentified bird	1	1	4	2	7	11.1	24	9.6					4	4.4					1	.4	1	2
Black oystercatcher																						
Aleutian sandpiper	1	1	2	1			1	.5													1	2
Ptarmigan	3	4																				
Snow bunting	1	1																				
Aleutian song sparrow	2	2			1	1.6	1	.5											1	.4		
Aleutian rosy finch	4	5					1	.5											1	.4		
Alaska longspur																			1	.4		
Aleutian winter wren	1	1					1	.5											1	.4	1	2
Bird egg															2	.9						
Fish	13	18	4	2			4	2					11	8.3			8	10.1			2	4
Blue-fox hair					3	4.7	7	2.8			1	1.9	1	.7					1	.4		
Sea otter							1	.5									1	1.2				
Rat (*Rattus* sp.)													38	28.8								
Hair seal							3	1.4					1	.7								
Pebbles			tr.	.5	10	15.8	1	.5					3	2.2								
Sand													1	.7								
Mud							4	2					2	1.5								
Paper							1	.5														
Cloth																						
Gummy substance							1	.5														
Crowberry							3	1.4											1	.4	4	9
Cranberry	1	1																				
Grass			1	.5	1	1.6																
Kelp																	1	1.2				
Moss																					1	2
Human skin (mummy)																						

Appendix 3. Food items in blue-fox droppings, Aleutian Islands, 1936 and 1937- Cont'd.

From Murie 1959.

	Ilak (64 droppings)		Kanaga (15 droppings)		Bobrof (220 droppings)		Adak —		Unak —		Kasatochi (46 droppings)		Amukta (114 droppings)		Herbert (25 droppings)		Carlisle (12 droppings)		Kagamil (103 droppings)		Ulaga (132 droppings)	
	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total	Number of Occurrences	Percent of Total
Amphipods	48	41					24	24	8	17	2	3	1	.6	8	19	7	23	20	10	4	2.3
Isopods	11	9.5			4	1	7	7			12	10			7	17	2	7	52	26		
Crabs					2	tr.	2	2														
Goose barnacles																						
Sea urchins	11	9.5	6	17	1	tr.	14	14	6	13	1	1	24	14.5	10	23	8	27	22	11	11	6.4
Mussels							7	7														
Snails	1	.8					2	2	1	2	3	2	3	1.8					1	.5		
Clamworm (*Nereis* sp.)																						
Clam																						
Beetles																						
Diptera																						
Caterpillars (Noctuidae)																						
Insects					2	tr.	5	5			15	13									12	7
Fork-tailed petrel					134	48	2	2	3	6	1	1	95	57.2	6	14	1	3	15	7	23	13.4
Leach's petrel																						
Fulmar																			1	.5		
Shearwater																			2	1		
Tufted puffin	2	1.7			12	4	1	1			2	2			1	2	1	3	4	2	98	57.3
Horned puffin					5	2	1	1	1	2							3	10	4	2	1	.6
Murre																						
Least auklet	20	17			25	9	1	1	7	14	32	27					2	7	7	3	1	.6
Whiskered auklet					5	2					1	1			3	7			5	2	1	.6
Parakeet auklet					5	2	1	1			4	3	1	.6	1	2			4	2		
Crested auklet					19	7	1	1	1	2	13	11			2	4			6	3	1	.6
Cassin's auklet	3	2.5																	2	1		
Ancient murrelet					2	tr.	2	2			2	2							2	1	2	1.2
Pigeon guillemot					10	3			1	2									2	1		
Cormorant					2	tr.							1	.6								
Glaucous-winged gull			3	9	1	tr.													1	.5		
Pacific kittiwake					1	tr.	1	1											1	.5		
Emperor goose			1	3																		
Harlequin duck			1	3															3	1		
Scaup duck																						
European teal			2	6																		
Unidentified bird	8	6.8	6	18	5	2	2	2	1	2	1	1	4	2.4	1	2	1	3	9	5	3	1.7
Black oystercatcher					1	tr.																
Aleutian sandpiper															1	2						
Ptarmigan			1	3																		
Snow bunting					1	tr.	3	3														
Aleutian song sparrow			1	3	2	tr.			7	14			1	.6					1	.5		
Aleutian rosy finch					4	1	2	2					1	.6					3	1		
Alaska longspur					2	tr.							1	.6								
Aleutian winter wren			2	6	2	tr.	1	1	3	6			1	.6					1	.5	2	1.2
Bird egg					27	10			1	2	24	20			1	2			4	2		
Fish	5	4.2	2	6	1	tr.	9	9	2	4	2	2	1	.6							6	3.5
Blue-fox hair	6	5.1	1	3	2	tr.									2	4	5	16	8	4		
Sea otter																			1	.5		
Rat (*Rattus* sp.)																						
Hair seal	1	.8																				
Pebbles																						
Sand																						
Mud	1	.8																				
Paper							2	2														
Cloth																						
Gummy substance													2	1.2								
Crowberry			4	11			4	4			1	1	26	15.7					4	2	3	1.7
Cranberry																						
Grass			2	6	2	tr.	4	4	5	10					1	2			10	5	3	1.7
Kelp											1	1	1	.6								
Moss			2	6																		
Human skin (mummy)																			2	1		

Appendix 3. Summary: Food items in blue-fox droppings, Aleutian Islands, 1936 and 1937. From Murie 1959.

Food item	Occurrences	
	Number	Percent of total
Invertebrates:		
Crustaceans	653	26.1
Sea urchins	53	2.1
Mollusks	30	1.1
Annelid worms (*Nereis* sp.)	3	.1
Insects	45	1.75
Total	784	31.3
Birds:		
Petrels	396	15.8
Fulmars and shearwaters	9	.35
Puffins	158	6.3
Murres	15	.6
Ancient murrelet	13	.5
Pigeon guillemot	17	.7
Auklets	604	24.1
Cormorants	4	.1
Gulls and kittiwakes	12	.4
Emperor goose	4	.1
Ducks	7	.2
Shorebirds	7	.2
Ptarmigan	4	.1
Small land birds	56	2.2
Bird eggs	59	2.3
Unidentified birds	83	3.3
Total	1,448	57.8
Fish	70	2.7
Mammals:		
Blue fox	37	1.4
Sea otter	3	.1
Rat	38	1.5
Hair seal	5	.2
Human skin (mummy)	2	.08
Total	85	3.3
Vegetation	86	3.4
Miscellaneous (mud, pebbles, paper)	28	1.1
Grand total	2,501	100

APPENDIX 4.

Investigator's Manual for Use of Stericin.

BIORESEARCH LABORATORIES

STERICIN™ INJECTABLE

(Chlorhexidine Digluconate)

Investigator's Manual

Table of Contents

I. GENERAL INFORMATION

Name and Address of Sponsor:

RMI, Inc.
3154 Worthington Drive
Fort Collins, Colorado 80526

Sponsor Contact:

James H. Schafer, D.V.M.
Douglas I. Hepler, Ph.D.

Generic Name of Drug:

Chlorhexidine digluconate

Trade Name of Drug:

STERICIN™ INJECTABLE

II. INDICATION FOR USE:

STERICIN™ is exclusively intended for the humane sterilization of male dogs without the need of surgical techniques or facilities.

III. DOSAGE FORM:

Form and Concentration: Solution, 4.5% chlorhexidine digluconate

Route of Administration: Injection, subcutaneous

Recommended Dosage: The maturity and body weight of the dog play an important part in the development of the testes and epididymides and the veterinarian should use his professional judgment in selecting an appropriate dose. The following schedule should be used as a guide:

Dog Body Weight	Suggested Dosage
under 30 lbs.	approximately 0.25 ml STERICIN™/ epididymis
over 30 lbs.	approximately 0.5 ml STERICIN™/ epididymis

IV. ANIMAL EFFICACY AND SAFETY:

Chlorhexidine digluconate (CHDG) has been studied extensively for its safety and effectiveness for various applications in both man and animals. These applications include: skin infection, wounds, burns, throat infection, obstetrics, bladder irrigation, instrument sterilization, dentistry, esophagitis, and use as a general disinfectant, and the company provided several studies from the scientific literature and an extensive bibliography attesting to the use of chlorhexidine digluconate in these applications. There is a large difference in the LD_{50} determination between oral and intravenous administration, in that the oral LD_{50} is 1800 mg/kg and intravenous LD_{50} is 22 mg/kg in mice. This pattern was also repeated in rabbits

and calves, demonstrating the relatively low absorption characteristic of chlorhexidine digluconate. During these studies it was determined that chlorhexidine digluconate appeared to be performing the function required of a sclerosing agent.

In studies reported in literature by Dr. M. H. Pineda, it was shown that chemical vasectomy in dogs could be obtained by injecting a proper sclerosing agent into the tail of the epididymis; irritation of the tubular and intertubular tissues is thereby established. This leads to the sclerosis of these tissues and provides an effective obstruction to the passage of sperm from the epididymis to the vasa defferentia, resulting in an azoospermic ejaculate in the male dog. Other injection sites proved to be not as effective.

In an extension of the work performed by Dr. Pineda, RMI, Inc. requested and received approval of an Investigation New Animal Drug Application from the Bureau of Veterinary Medicine. These studies were conducted by Elars Bioresearch Laboratories, Inc., 225 Commerce Drive, Ft. Collins, Colorado 80524. Investigators for the studies were: Douglas I. Hepler, Ph.D., Director of Toxicology; William H. Halliwell, D.V.M., Ph.D., ACVP, Pathologist; Kenneth A. Larson, D.V.M., Ph.D., President; David L. Heimbichner, Research Associate; Julie A. Schlegel, B.S., Administrative Assistant. During these well-controlled studies, including field trials with the drug, there have been over 700 male dogs treated. The studies were designed to demonstrate the safety and effectiveness of a chemical vasectomy procedure in all sizes, ages and breeds of male dogs, including long-term studies to show the drug will produce results which maintain the sterile status of male dogs.

Investigation concerning the safety of chlorhexidine digluconate treatment was conducted with 12 male dogs. Six dogs received injections of 3 times the recommended concentration (3x 4.5% CHDG, or 13.5%, 1 ml/epididymis) and 6 dogs received injections of sterile water as a control (1 ml/epididymis). It had been shown in other studies that with proper injection technique it is virtually impossible to overdose an

animal by injecting an excessive amount of drug, due to the fact that the epididymis fills with the drug, causing excess liquid to be expelled by hydrostatic pressure back out through the needle track. Therefore it was determined that the safety study would be based on a higher than required concentration. The dogs were observed and ejaculates collected for sperm count through day 42. Blood and urine samples were obtained through day 35 for clinical pathology determination. All animals were necropsied for gross and histologic examination within a few days after the 42 day post-treatment ejaculate collection.

No untoward effects other than transient scrotal swelling were observed. Clinical pathology evaluations revealed no treatment related trend in either principal group. Localized necrotic change, anticipated from the action of the drug and limited to the site of injection, was identified grossly and microscopically, with the 3x group exhibiting a more diffuse area of histologic alteration than the control group. Non-target organs examined were not affected by treatment.

Fifteen miniature breed or mid-size dogs (under 30 lbs) were treated with doses less than those used in the larger breed dogs (0.4 or 0.6 ml/epididymis rather than 1 ml/epididymis). Semen evaluation indicated treatment results were no different in any way than those obtained from larger dogs, with clinical infertility achieved in 3-4 weeks following treatment.

An additional controlled clinical trial in another laboratory was conducted on 29 dogs to demonstrate that the product and procedure could be adequately handled by personnel other than those responsible for the study at Elars. In addition to this information, the effects of a smaller injection were studied. This study was performed at Dellen Laboratories, Inc., Omaha, Nebraska. Investigators were: L. M. Wilkins, D.V.M., and L. E. McClaughry, D.V.M. This study demonstrated the lower

doses were not as effective in the larger dogs as in smaller dogs. All results were highly comparable to those recorded in other investigations with regard to reduction of sperm count and time to achieve sterility.

Thirteen Stericin™-treated dogs (1 ml/epididymis) have been placed under study for long-term semen evaluation along with one dog that had been injected with dimethyl sulfoxide (DMSO) to act as a control. Results indicate all dogs receiving a proper injection of chlorhexidine digluconate maintained their sterile status. The dog treated with DMSO retained a high sperm count throughout the study. Two of the treated dogs were also subjected to breeding studies using proven dams, there were no conceptions resulting from this test. Several of the animals also underwent unilateral castration during the course of the study to evaluate the extent of histologic alterations. There were no unexpected untoward effects noted in the microscopic examinations. The changes in the epididymis and testicle were largely of a coagulative necrosis type and localized at the injection site.

In field trials conducted at 6 animal shelters in the Los Angeles area, various sizes and breeds of dogs have been treated (1 mg 4.5% CHDG/epididymis) and placed in homes, and several follow-up semen evaluations have been conducted. Ninety-three percent of the dogs treated that have been available for follow-up were considered infertile on the basis of a zero sperm count, low count of viable sperm or an ejaculate in which only non-viable sperm cells were present. The remaining 7% were considered possibly fertile as evidenced by sperm counts approaching a level that is considered fertile. Of these 7%, one dog was allowed to be thoroughly examined and it was determined that one of the epididymides was inadvertently not injected. The dog was retreated and evaluated again in 6 months, at which time the sperm count was reduced to zero. The data from the field trials closely reflect treatment response obtained in the laboratory and clinical trials.

Subsequent laboratory investigation has revealed that less scrotal swelling occurs with smaller doses (< 1 ml/epididymis). The purpose of presently-conducted clinical trials in the field is to determine the efficacy of reduced dose sizes of Stericin™. It is anticipated that doses of 0.25-0.5 ml/epididymis will be easier to administer, result in less scrotal swelling, and still effect clinical sterilization.

INSTRUCTIONS FOR USE

ANATOMY:

In normal position the long axis of the testis runs dorso-caudally. The epididymis adheres to the dorso-lateral surface of the testis, with the tail at the caudal end and the head at the cranial end (Fig. 2). The head of the epididymis is on the medial surface of the testis, but twists slightly to run along the lateral side. The ductus deferens runs from the tail of the epididymis along the dorsal medial border of the testis, ascends and enters the abdominal cavity through the inguinal canal (Fig. 1).

DRUG METHOD OF ACTION:

Chlorhexidine digluconate is a sclerosing agent. Injected into the tail of the epididymis it causes necrosis of the intratubular epididymal tissue resulting in a scarring reaction. This reaction occurs only in the epididymal region; no qualitative changes occur in the seminiferous tubules and interstitial tissue. Sperm granulomas will be found in the epididymides, being more abundant in the tail region. After injection, palpation indicates a distinct enlargement of the epididymal tails; the enlargement gradually subsides leaving the tails firm. There occurs also an enlargement of the scrotum which will gradually decrease by 14-21 days post injection. The enlargement of the scrotum is generally not accompanied by pain as evidenced by testicular palpation.

METHOD OF INJECTION:

I. Equipment
   - A. 26-gauge 3/8 inch needles
   - B. 1 cc syringes
   - C. Rompun® for sedation

II. Dosage
   - A. Over 30 lbs*
     1. 0.5 ml/epididymis
   - B. Under 30 lbs*
     2. 0.25 ml/epididymis

* judgment may be needed to allow for anatomical size

III. Injection

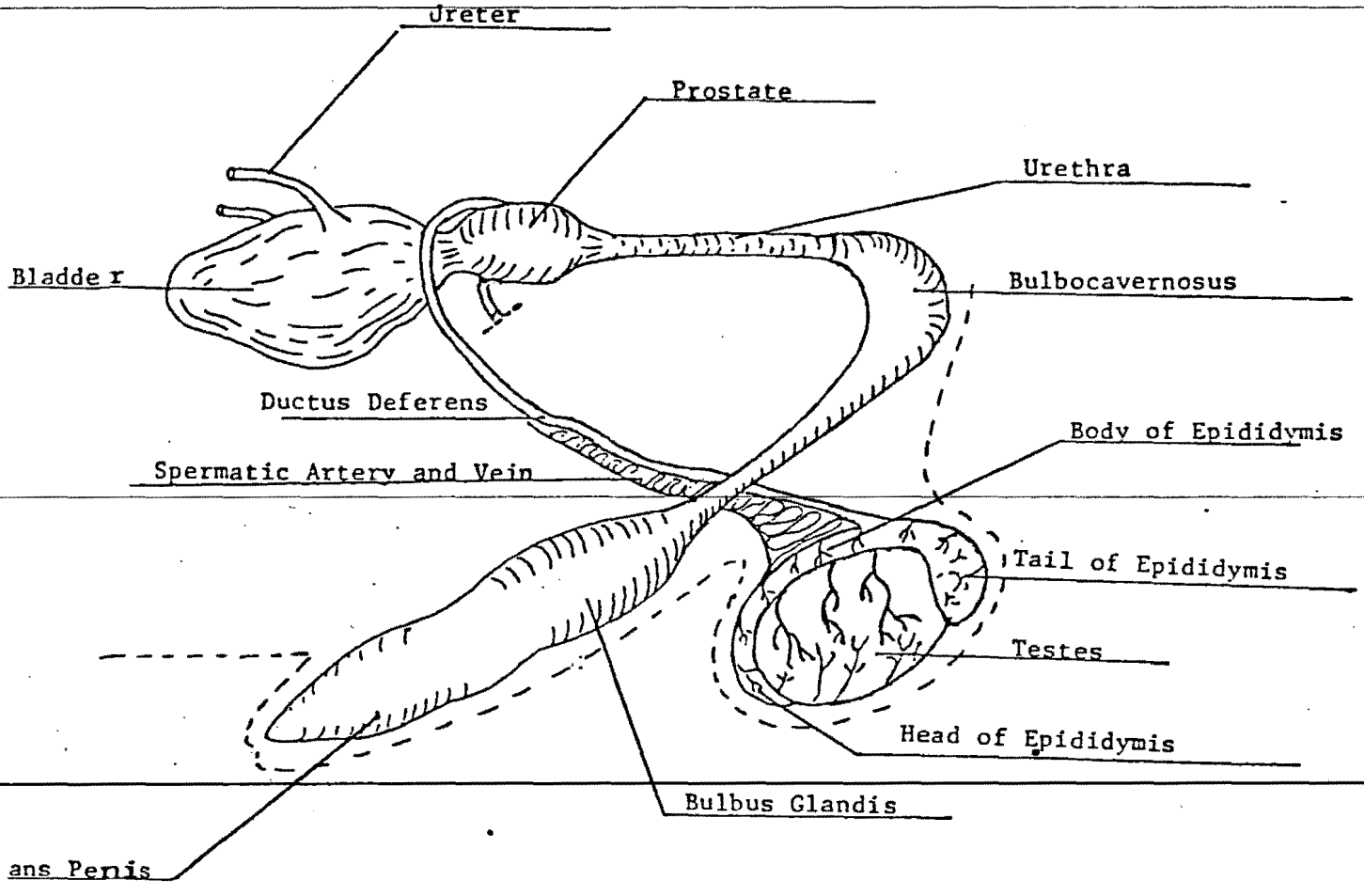
A. Lateral pressure should be applied to the testicle to be injected first, until the tail of the epididymis can be easily seen and palpated. The syringe should be held as shown in Figure 2, and the injection completed. The procedure is repeated for the other testicle and epididymis. Figure 2 also indicates the incorrect positioning of the needle and syringe, which can easily be pushed directly into the testicle defeating the purpose of the drug.

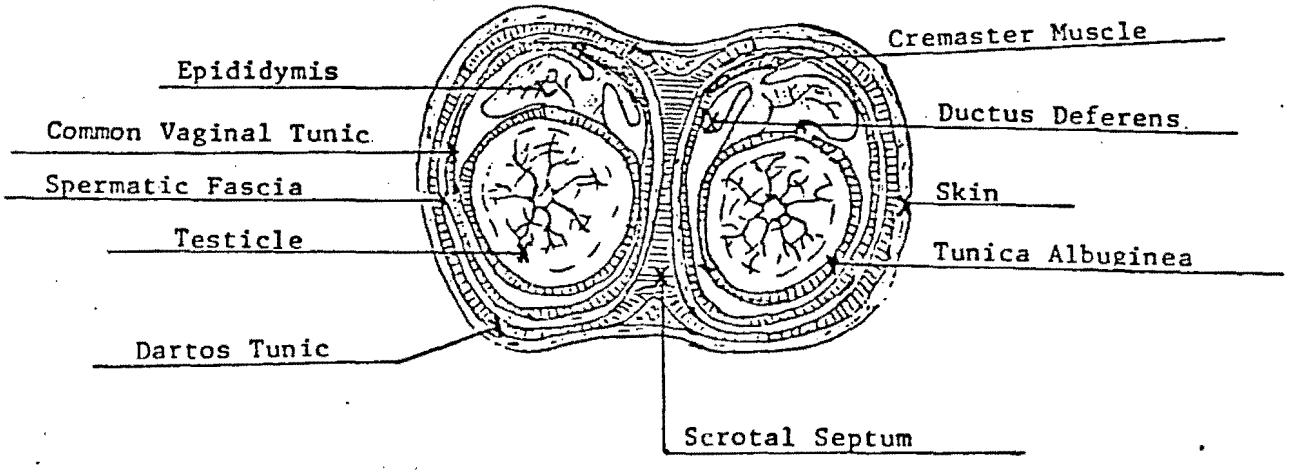
COMMENTS:

When the injection is completed properly, spermatozoa can no longer pass from the tail of the epididymis into the ductus deferens to complete fertilization. The testis will not be affected by the injection, and hormonal balance will remain normal.

Figure 1

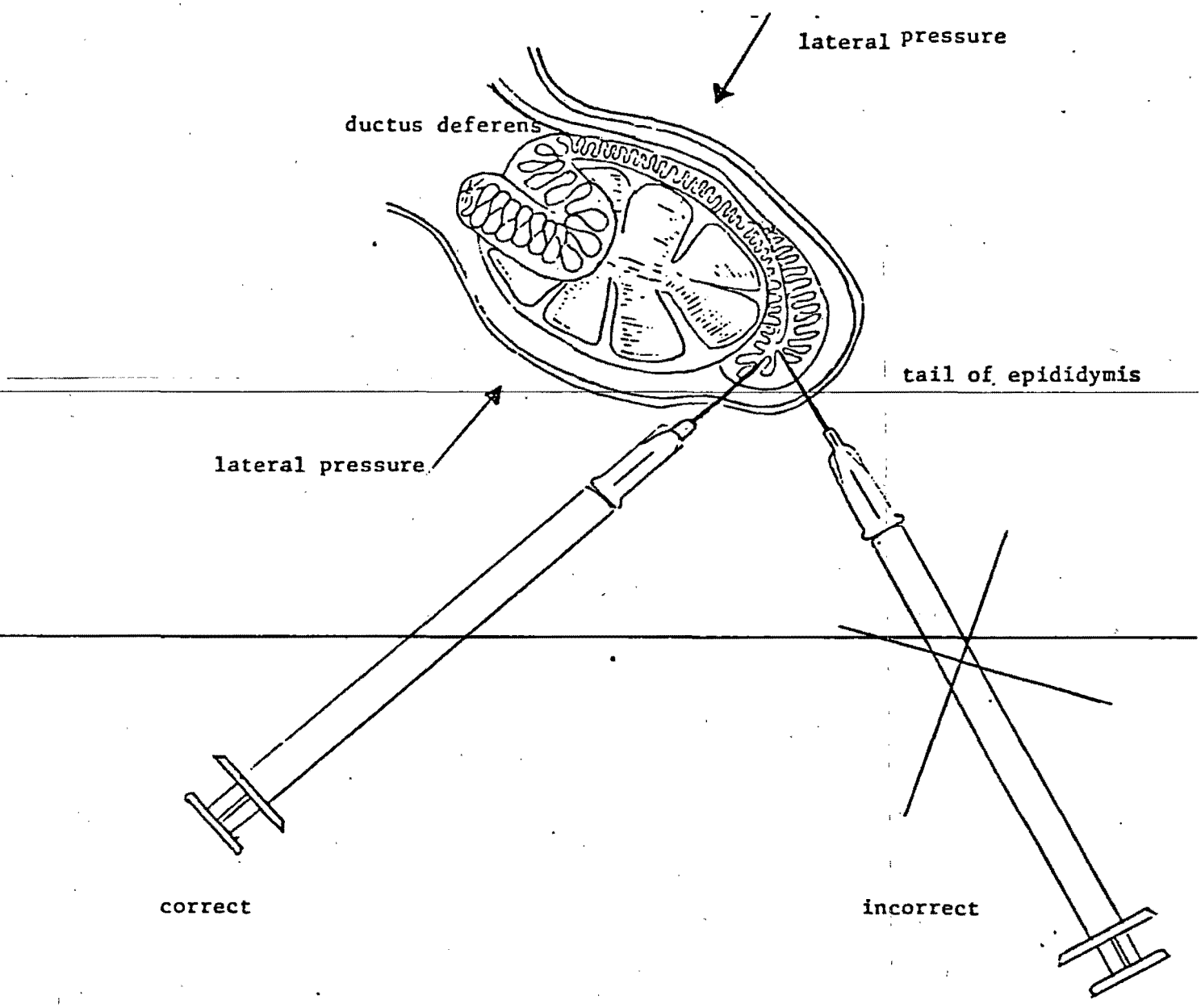
CANINE REPRODUCTIVE TRACT





CROSS SECTION SCROTUM AND TESTES

Figure 2


lateral pressure
ductus deferens
tail of epididymis
lateral pressure
correct
incorrect

SEMEN EVALUATION IN THE DOG

Refer: Collection, Storage and Insemination of Canine Semen. Lab An. Sci. Vol. 22:No. 2, pp. 177-182. Seager and Fletcher

I. Technique - refer to other handout

II. Evaluation

A. Volume

1. Time

Fraction	Volume	Time
1st	0.25 - 2.0 ml	30 - 50 sec
2nd	0.50 - 4.0 ml	50 - 80 sec
3rd	3.0 -25.0 ml	3 - 30 min
Total	3.75 -31.0 ml	4 - 32 min

2. Evaluation of Volume

a. Graduated centrifuge tube

b. Pipettes

3. Average volume of ejaculated semen - 2.19 ml

Range = 0.5 - 6.5 ml

B. Motility

1. Evaluation must be made immediately following collection

2. All materials should be kept at 38°C

- Temperature controlled incubator
- Slides
- Coverslips
- Warming stage
- Water bath

3. Mix sample collected, place small drop from applicator stick onto warm slide and examine under high power (430 X)

   a. Slight movement of head and tail

   b. Regular jerking movement of head and/or tail but no progressive motility

   c. Progressive motility

   d. Rapid progressive motility

4. With the same slide, determine the % of motile sperm in several high power fields and record to nearest 5%

5. Average % motile is 93.2% with a range of 75-99%

C. Color

- normal semen is gray to milky white
- urine - contamination may give a yellowish tinge
- genital exudates or hemorrhage could alter the normal color

D. Sperm counts

- mix specimen thoroughly but gently
- use a Unopette[B] white blood cell dilutent
- fill capillary tube with semen, express into dilutent and let sit a few minutes
- fill hemocytomer chamber with the diluted sample (discard first few drops)
- count one primary square and add six zeros. THis gives the number of cells per cc.
- WBC dilution factor is 1:100 so if you use some other method, check the dilution factor
- average canine sperm count on the first and second fraction is 564.4 million sperm cells per cc. The range is 103-708 million per cc.

- Secondary Abnormalities
  - Loose heads
  - Bent tails, coiled tails
  - Detached acrosome

3. Brucella canis (L.E. Carmichael, Therio, Vol 6; p. 105)

Post-infection weeks 2 and 5

- 30 - 80% abnormal sperm cells
- types of abnormalities
  - bent tails
  - swollen midpieces
  - double tails
  - heads lacking tails
  - distal cytoplasmic droplets

Post-infection weeks 20 and more

- 90% abnormal sperm cells
- severe reduction in motility
- neutrophils and moncytes commonly present
- head to head sperm agglutination

IgG humoral spermaglutinins

- sperm agglutinins aggluinated normal sperm and immobilized living sperm in the presence of complement. Low levels could be detected for as long as 27 months after infection.

E. pH

- average pH was 6.0 with a range of 5.5 - 6.5 Seager did not state if this included the third fraction

F. Live/dead counts

- Eosin-nigrosin stain can be used (5% aqueous eosin bluish and 10% nigrosin)
- Place one drop of 10% nigrosin at one end of the slide. Place 1 drop of semen and 1 drop of 5% eosin in the middle of the slide
- With a wooden applicator stick, gently mix the eosin and semen drops together and then mix with the nigrosin drop (30 seconds total)
- Obtain a small amount of the mixture on the end of another slide and spread it acr[illegible]s a third slide as if makking a blood smear
- Examine under oil immersion (970 X) or high power (430 X)
- Count 100 or 200 cells and classify as dead (pink) or alive (unstained)
- Normal canine semen usually has an average of 84% live cells with a range of 61-99%.

G. Morphology

1. Can again do a 100 or 200 cell differential count
2. Characterize abnormalities
   - Primary abnormalities can indicate testicular abnormalities in other animals
     - All head anomalies
     - Coiled tails
     - Double forms
     - Abaxial middle piece
     - Proximal protoplasmic droplets

Azoospermia in Dogs Induced by Injection of Sclerosing Agents into the Caudae of the Epididymides

M. H. Pineda, DVM, PhD; T. J. Reimers, PhD; L. C. Faulkner, DVM, PhD; M. L. Hopwood, PhD; G. E. Seidel, Jr., PhD

SUMMARY

Injections of sclerosing agents into the caudae of the epididymides of adult and prepubertal dogs induced a long-lasting and probably irreversible azoospermia. The technique is easy to do and inexpensive, does not seem to cause undesirable side effects, and appears suitable for large-scale sterilization programs in male dogs.

The increasing population of dogs is creating an intolerable nuisance due to public exposure to zoonotic diseases,[1] bites,[2,11] pollution of parks and recreation areas,[3,6] and damage to livestock, wildlife, and property.[6] Unwanted dogs and cats and uncontrolled pets are primary sources of ecologic problems and are a burden to society.[4] The cost of capturing and disposing of free-roaming pets, plus the associated indirect costs to society amount to approximately $450 million annually.[8] It is ironic and sad that while most states have laws punishing cruelty to animals, they are forced to use mass euthanasia in a losing battle with burgeoning numbers of pets.

The female cat and dog are widely perceived as the logical targets for reproductive control, whereas the male cat and dog are readily overlooked as effective targets. However, pregnancy to be successful obviously requires the participation of both sexes. Each intact male is potentially capable, year around, of siring a number of litters. Sterilization of large numbers of male dogs may well decrease the number of pregnant bitches to the point of affecting population growth. Moreover, if dominant males are rendered sterile without affecting their libido and social dominance, they might prevent matings of intact subordinates.

Received for publication Aug 23, 1976.

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Supported in part by the Ohio Animal Health Foundation, and by the Humane Society of the United States.

The authors thank Dr. E. R. Mutiga for his participation during the initial phases of this study. Dr. Mutiga's present address is the Department of Clinical Studies, Faculty of Veterinary Medicine, University of Nairobi, Kabete, Kenya.

[1] Beck, A. M., at the Conference on the Ecology of the Surplus Dog and Cat Problem, Chicago, Ill, May 21-23, 1974.

Currently, the only widely available means of contraception for pets are confinement and surgical sterilization. However, it is obvious that neither of these means have been widely embraced as a limitation to reproduction, and the acute need for the development of suitable alternatives to surgical sterilization is recognized.[4]

Injections of chemical agents into the vasa deferentia via laparotomy in rats,[9] and through surgical exposure of the vas or percutaneously in dogs[9] and monkeys[10] caused obstruction of the vasa. Dogs which were given intravasal injection of 10% silver nitrate or 3.6% formalin had lumens of the vasa occluded with scar tissue by 2 months after injection.[9] Sclerosing agents injected into the caudae of the epididymides induced azoospermia in bulls[3,7] and boars.[8]

The purpose of the present study was to examine the possibility of inducing sterility by injecting chemical agents percutaneously into the caudae of the epididymides of dogs. It was anticipated that the chemical agent would cause tissue irritation and sclerosis. Sclerosis would prevent the passage of spermatozoa from the epididymides to the vasa deferentia, causing the ejaculate to be azoospermic.

Materials and Methods

Experiment 1—Eight Beagle dogs, 18 to 23 months of age, were selected on the basis of their ejaculatory response to digital manipulation and were randomly assigned to 2 groups of 4 dogs each. Before treatment, the dogs were given an intramuscular injection of a sedative.[b] The scrotal area was washed and a disinfectant solution was applied. Two-tenths milliliter of 3.3% solution of formalin in 0.05 *M* phosphate-buffered saline solution (PBSS) was injected percutaneously through a 22-gauge ½-inch needle in the cauda of each epididymis of the 4 treated dogs (Fig 1). Dogs used as controls were given intraepididymal injections of PBSS.

Semen was collected from each dog by digital manipulation[10] on day 0, immediately before treatment, and on days 5, 7, 14, 21, and 28 after treatment (Table 1). The volume of each ejaculate was recorded (Table 2). Total number of spermatozoa per ejaculate was determined with a hemacytometer after diluting the ejaculate 1:100 with 0.9% saline solution in a red blood cell pipette. Smears of undiluted ejaculate were made for each treated dog if spermatozoa were not found in any of the 25 ruled squares of the chamber of the hemacytometer. Fewer than 10 spermatozoa in 10 fields (each field = 0.13 mm^3) of the smears at a magnification of 450 was recorded as azoospermic. Testicular diameter was estimated at time of seminal collection (by measuring the widest transscrotal diameter with calipers).

[b] Rompun, Chemagro, Division of Baychem Corporation, Shawnee Mission, Ks.

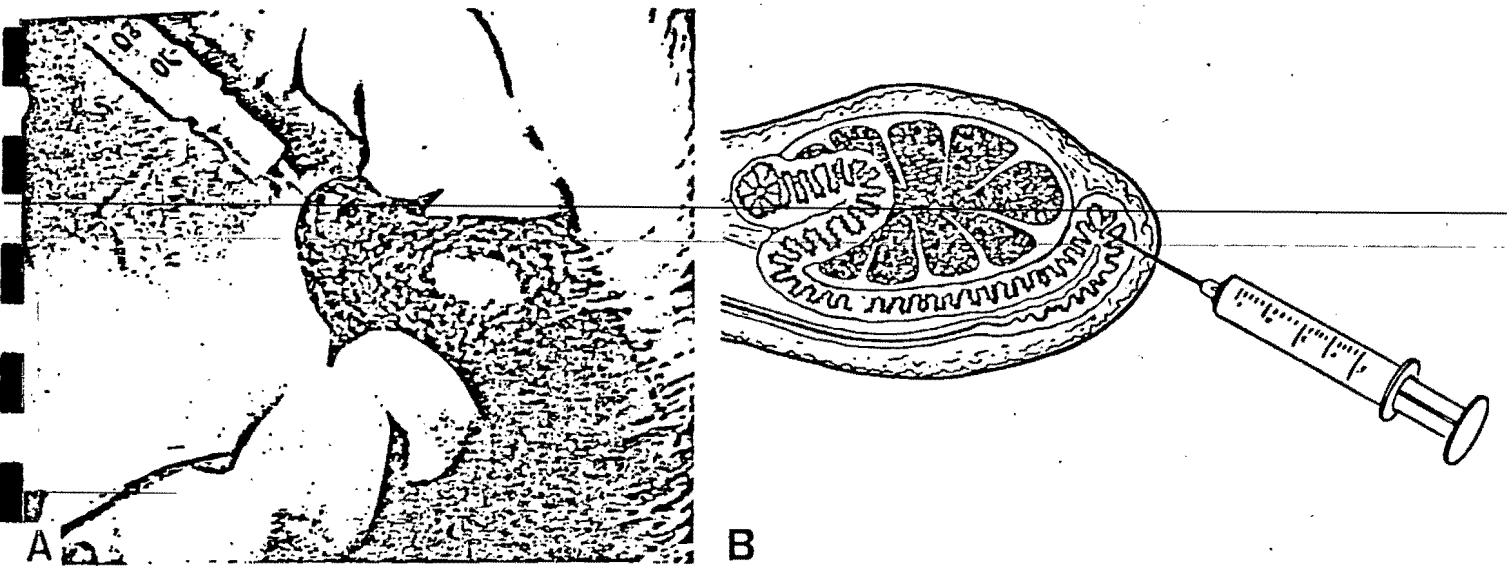

Fig 1—Actual (A) and schematic representation (B) of intraepididymal injection in the dog.

TABLE 1—Total Number of Spermatozoa/Ejaculate (10^6) of Control Dogs and of Dogs Given Intraepididymal Injections of Formalin: Experiment 1

	Control dogs				Treated dogs			
Day	1	13	14	25	9	10	11	12
0	480	432	980	720	240	1,680	702	2,106
5	150	396	540	17	585	240	357	31
7	51	285	240	39	120	0	88	98
14	81	220	660	504	185	46	0	0
21	388	846	1,495	525	169	0	196	0
28	540	693	1,824	455	584	180	68	17

TABLE 2—Volume of Ejaculate and Testicular Diameter of Control Dogs and of Dogs Given Intraepididymal Injections of Formalin: Experiment 1

	Volume of ejaculate (ml)		Testicular diameter (cm)	
Day	Control	Treated	Control	Treated
0	9.2 ± 0.9	9.4 ± 2.9	5.0 ± 0.7	4.8 ± 0.4
5	7.4 ± 3.5	10.8 ± 3.1	4.9 ± 0.7	5.5 ± 0.3*
7	9.9 ± 1.7	9.5 ± 2.5	4.7 ± 0.7	5.4 ± 0.2*
14	6.7 ± 3.7	10.5 ± 2.2	4.5 ± 0.8	4.9 ± 0.3
21	11.0 ± 1.5	9.8 ± 1.9	4.4 ± 0.6	4.7 ± 0.2
28	9.9 ± 2.9	7.7 ± 3.5	4.3 ± 0.5	4.5 ± 0.1

Data are expressed as mean ± standard deviation.
* Significantly different from the corresponding control value ($P < 0.05$).

Experiment 2—Several chemical agents were tested for their ability to induce azoospermia. Six Beagle dogs, 12 to 26 months of age, were given intraepididymal injections as described in experiment 1. Dogs 9, 10, 11, 12, and 25 were used in experiment 1 and had recovered (Tables 1 and 3). Number of dogs, chemical agents, and volume of each intraepididymal injection are shown (Table 3).

Testicular diameter and volume of ejaculates were measured as in experiment 1 on day 0, before treatment, and on days 1, 4, and 7, and once each week thereafter until day 56. Total number of spermatozoa per ejaculate was determined as in experiment 1. Fewer than 5 spermatozoa in 10 fields of the smears of undiluted ejaculate at a magnification of 450, was considered as azoospermia. Oligospermic ejaculate containing more than 5 spermatozoa in smears of undiluted ejaculates were centrifuged at 1,000 × g. The seminal pellet was resuspended in a known volume of 0.9% saline solution and counted in the hemacytometer.

Experiment 3—Eight Beagle dogs, 9.5 to 16.5 months of age, were randomly assigned to a control group of 3 dogs and a treated group of 5 dogs. Each treated dog was given bilateral intraepididymal injections of 0.6 ml of 1.5% chlorhexidine gluconate in 50% dimethyl sulfoxide (DMSO). Intraepididymal injections were given as described in experiment 1, except that the injection was given through a 27-gauge, ½-inch needle, and the chemical agent was injected while slowly withdrawing the needle. Control dogs were given bilateral intraepididymal injections of 0.9% saline solution.

Volume of ejaculate, testicular diameter, and total number of spermatozoa per ejaculate were determined on days −7, −2, and 0, immediately before treatment, on days 1, 2, 4, and 7 after treatment, and once each week thereafter until day 357. Body weight was determined on day 0, before treatment, and once each week thereafter. Total number of spermatozoa per ejaculate was determined with a hemacytometer, as described in experiment 1. Total number of spermatozoa in oligospermic ejaculates was determined in undiluted samples, using both chambers of the hemacytometer. Spermatozoa were counted in the 25 large, ruled squares of each chamber, and the total number was divided by 2. Since the volume of each chamber of the hemacytometer is 0.1 µl, 1 spermatozoon in each of the 2 chambers of the hemacytometer represented a concenrtation of 1×10^4 spermatozoa/ml. If spermatozoa were not found in any of the 50 squares of the hemacytometer, the ejaculate was considered to be azoospermic. Occasionally, ejaculates from treated dogs were centrifuged at 1,000 × g; the seminal pellet was resuspended in 0.9% saline solution and examined with a microscope.

All treated dogs and one randomly selected control dog were euthanatized on day 358. Testes, epididymides, and proximal segments of the vasa deferentia were dissected free and fixed in Bouin's solution for histologic examination.

Experiment 4—Three Beagle dogs, 17 to 23 months of age, were given bilateral intraepididymal injections of 0.6 ml of 1.5% chlorhexidine gluconate in 50% DMSO on day 0 and again on day 7.

Testicular diameter, volume of ejaculates, total number of spermatozoa per ejaculate, and body weight were determined as described in experiment 3 on day 0, before treat-

TABLE 3—Total Number of Spermatozoa/Ejaculate (10⁶)—Experiment 2

	Treatment*					
	1.5% Chlorhexidine gluconate; 0.5 ml**		1.5% Chlorhexidine gluconate in 50% dimethyl sulfoxide (DMSO); 0.5 ml**		1.0% Ethylcellusolve in 50% DMSO and 10% formalin; 0.6 ml**	4.0% Chlorhexidine diacetate in 1.0% ethylcellusolve; 0.6 ml**
Day	Dog 9	Dog 12	Dog 10	Dog 11	Dog 25	Dog 35
0	920	540	517	550	221	960
1	270	152	0	205	63	37
4	270	240	0	0	0	0
7	391	87	0	0	0	0
14	0	65	0	0	0	0
21	0	41	0	0	0	5
28	0	0	0	0	0	0
35	0	0	0	0	3	0
42	34	0	0	0	0	0
49	5	0	0	0	0	0
56	0	0	0	0	0	0

* In aqueous solution, provided by Fort Dodge Laboratories, Fort Dodge, Ia. ** Injected into each epididymis.

TABLE 4—Volume of Ejaculate and Testicular Diameter of Adult Dogs Given Intraepididymal Injections of Chemical Agents: Experiment 2

	Treatment							
	Chlorhexidine (n = 2 dogs)		Chlorhexidine in DMSO (n = 2 dogs)		Ethylcellusolve in DMSO and formalin (n = 1 dog)		Chlorhexidine in ethylcellulose (n = 1 dog)	
Day	Volume of ejaculate (ml, $\bar{x}$)	Testicular diameter (cm, $\bar{x}$)	Volume of ejaculate (ml, $\bar{x}$)	Testicular diameter (cm, $\bar{x}$)	Volume of ejaculate (ml)	Testicular diameter (cm)	Volume of ejaculate (ml)	Testicular diameter (cm)
0	12.5	4.5	6.9	4.7	6.3	3.8	12.0	3.8
1	11.1	5.3	7.7	5.1	12.6	4.0	7.3	4.2
4	9.5	5.1	11.1	5.0	6.5	3.9	2.5	4.4
7	9.9	5.0	8.9	4.8	12.0	3.8	8.5	5.1
14	13.2	4.9	8.5	4.9	10.8	4.3	7.4	4.5
21	11.1	4.8	7.7	4.5	13.5	3.7	4.9	4.9
28	11.9	4.7	9.0	4.6	9.5	4.0	5.2	3.9
35	10.4	4.8	9.5	4.6	3.9	3.8	6.3	3.6
42	10.5	4.7	12.4	4.6	5.5	4.2	5.8	3.6
49	9.0	4.7	5.7	4.9	13.0	3.9	4.5	3.7
56	10.1	4.4	5.3	4.6	9.1	3.8	3.3	3.8

TABLE 5—Total Number of Spermatozoa/Ejaculate, Volume of Ejaculate, Testicular Diameter, and Body Weight of Adult Control Dogs and of Adult Dogs Given Intraepididymal Injections of 1.5% Chlorhexidine Gloconate in 50% DMSO: Experiment 3

	Total No. of spermatozoa/ejaculate (10⁶)*		Volume of ejaculate (ml)		Testicular diameter (cm)		Body weight (kg)	
Day	Controls	Treated	Controls	Treated	Controls	Treated	Controls	Treated
−7	287 ± 198	125 ± 64	4.2 ± 3.9	4.3 ± 2.2	3.8 ± 0.1	3.7 ± 0.3	ND	ND
−2	559 ± 500	361 ± 253	5.2 ± 3.7	6.3 ± 2.5	3.7 ± 0.2	3.7 ± 0.3	ND	ND
0	471 ± 364	479 ± 312	5.7 ± 4.8	7.1 ± 2.8	3.8 ± 0.3	3.9 ± 0.2	10.4 ± 1.0	10.8 ± 0.9
1	275 ± 251	16 ± 20	7.0 ± 5.8	5.4 ± 4.0	3.8 ± 0.2	4.1 ± 0.3	ND	ND
2	48 ± 44	0.1 ± 0.2	6.5 ± 4.5	5.8 ± 3.7	3.9 ± 0.4	4.2 ± 0.4	ND	ND
4	215 ± 130	6.5 ± 7.2	6.0 ± 4.4	6.7 ± 3.5	3.7 ± 0.0	4.3 ± 0.2	ND	ND
7 to 28*	434 ± 190	0.5 ± 0.9	7.6 ± 3.7	8.0 ± 2.7	3.6 ± 0.2	3.9 ± 0.2	9.9 ± 1.1	10.5 ± 1.0
35 to 56*	579 ± 274	0.1 ± 0.2	8.9 ± 2.7	8.0 ± 3.3	3.6 ± 0.1	3.7 ± 0.2	10.7 ± 0.9	11.0 ± 1.0
63 to 84*	785 ± 218	0.4 ± 1.4	11.3 ± 1.5	9.6 ± 2.8	3.7 ± 0.1	3.8 ± 0.1	10.6 ± 0.5	11.3 ± 0.9
91 to 357**	546 ± 250	0	9.4 ± 2.3	8.5 ± 2.9	3.7 ± 0.2	3.8 ± 0.1	10.9 ± 0.6	11.4 ± 0.8
PROBABILITIES								
Treatment effect	ND		NS		NS		NS	
Time effect	ND		< 0.01		< 0.01		< 0.01	
Interaction	ND		NS		NS		NS	

Data are expressed as mean ± standard deviation.
* Averages of 4 collections or measurements once each week. ** Averages of 39 collections or measurements once each week.
ND = Not determined; NS = not significant ($P > 0.05$).

ment, and once each week thereafter until day 42. Tissues were collected and processed for histologic examination as described in experiment 3.

Experiment 5—Four prepubertal, littermate Beagle dogs, 5 months of age, were randomly assigned to a treated or control group of 2 dogs each. Treated dogs were given bilateral intraepididymal injections of 0.6 ml of 1.5% chlorhexidine gluconate in 50% DMSO as in experiment 3. Controls were given bilateral intraepididymal injections of 0.9% saline solution.

Testicular diameter, volume of ejaculates, total number of spermatozoa per ejaculate, and body weight were determined as described in experiment 3.

Both treated dogs and one of the control dogs were euthanatized on day 358. Tissues were collected and processed for histologic examination as described in experiment 3.

TABLE 6—Total Number of Spermatozoa, Volume of Ejaculate, Testicular Diameter, and Body Weight of Dogs Given a Series of 2 Intraepididymal Injections of 1.5% Chlorhexidine Gluconate in 50% MSO: Experiment 4

Day	Total No. of spermatozoa/ ejaculate (10^9)*	Volume of ejaculate (ml)	Testicular diameter (cm)	Body weight (kg)
−7	686 ± 82	9.0 ± 0.4	3.8 ± 0.1	11.8 ± 0.0
0	542 ± 133	9.2 ± 1.1	3.8 ± 0.2	11.4 ± 0.0
7	48 ± 26	9.5 ± 0.5	4.2 ± 0.3**	11.2 ± 0.3
14	20± 17	9.1 ± 1.0	4.2 ± 0.2**	11.7 ± 0.2
21	0.12 ± 0.09	9.2 ± 2.5	3.9 ± 0.1	11.4 ± 0.0
28	0.03 ± 0.03	9.5 ± 1.7	3.9 ± 0.1	11.1 ± 0.3
35	0	9.9 ± 2.1	3.8 ± 0.1	11.0 ± 0.7
42	0	10.3 ± 2.3	3.8 ± 0.2	11.4 ± 0.6

Data are expressed as mean ± standard deviation.
* Statistical analysis was not applied to data on total number of spermatozoa/ejaculate. ** Significantly different from values in the same column ($P < 0.05$).

Statistical Analyses—Data were analyzed by analysis of variance,[9] using the "conservative" F value[10] for establishing significance. Tuckey's w-procedure[11] was used to test differences between means of end points for which the analysis of variance indicated a significant F ratio. Statistical analyses were not done on any of the data collected in experiment 2, due to the small number of animals, nor on data for total number of spermatozoa per ejaculate in any of the experiments.

Results

Experiment 1—Treatment with formalin induced temporary azoospermia or oligospermia in all treated dogs (Table 1). Injections of buffer alone in the control dogs induced temporary oligospermia only. Volume of ejaculate was not affected by treatment (Table 2). Testicular diameter increased significantly ($P < 0.05$) in the formalin-treated dogs on days 5 and 7 after treatment (Table 2).

Experiment 2—All dogs readily ejaculated semen or prostatic fluid as early as 24 hours after treatment (Tables 3 and 4). The 2 dogs (10 and 11) treated with 1.5% chlorhexidine gluconate in 50% DMSO became azoospermic for the duration of the study. Signs of discomfort were not observed at any time following injections; however, there was an apparent temporary increase in testicular diameter as early as 24 hours after injection of all treatments (Table 4).

Experiment 3—Treatment induced oligospermia from the 1st day after injection (Table 5). Treated dogs became azoospermic by day 70. One of the treated dogs had spermatozoa in his ejaculates on days 77 and 84 and became azoospermic again by day 91. By day 91, all treated dogs were azoospermic and remained azoospermic for the duration of the study (Table 5). Control dogs were oligospermic for about 24 hours after injection of the saline solution, but they rapidly recovered. Volume of ejaculate, body weight, and testicular diameter were not affected by treatment ($P > 0.05$), but there was a significant time ($P < 0.01$) effect. A slight swelling of the scrotum was observed on the first 7 days after treatment, but signs of discomfort were not observed. Moreover, the dogs readily ejaculated as early as 24 hours after injection.

Palpation of the testes, performed periodically after treatment, revealed a distinct and firm enlargement of the caudae of the epididymides about 1 month after treatment. Lesions were not palpable in the control dogs. The enlargement subsided and was less prominent but the caudae of the epididymides remained firm. At necropsy, gross examination of the epididymides of the treated dogs revealed enlargement, and the epididymal tubule was distended and visible through the albuginea of the epididymis. Three of the 5 treated dogs had prominent lesions at the surface of the corpus and cauda of the epididymides. When sectioned, these lesions contained a milky fluid under pressure, suggesting focal rupture and extravasation of epididymal sperm and fluid.

Qualitative changes were not observed in the seminiferous tubules and interstitial tissue from the dogs given intraepididymal injections of sclerosing agents. All dogs had apparently normal germinal epithelium and active spermatogenesis (Fig 2A, E).

Lumens of epididymal tubules of the control dog were lined by tall, columnar cells with abundant cytoplasm (Fig 2B to D). Sperm granulomas were found microscopically in the epididymides of all treated dogs, and in 3 dogs there were large, cystic granulomas (Fig 3). The granulomas seemed to be more abundant in the corpus and cauda than in the caput of the epididymides. Epididymal tubules of treated dogs showed changes that varied from animal to animal and from right to left side within the same animal. Magnitude of the changes seemed to be associated with the presence of large, cystic type of granulomas. Epididymal tubules of treated dogs, in which we did not observe large granulomas, had dilated tubules with dense masses of spermatozoa accumulated in the lumens. Cells of the epithelium lining tubules were flattened, with little cytoplasm. These changes were more striking in the corpora and caudae of the epididymides than in the capita (Fig 2F to H). Epididymal tubules of treated dogs in which we found large, cystic granulomas were mildly distended or not distended at all (Fig 4A, B). Cells of the epithelium lining the tubules were tall and had abundant cytoplasm. The content of apparently intact tubules adjacent to a large granuloma varied from animal to animal. Some tubules had few spermatozoa, and others were empty (but apparently normal) or were folded and had disrupted epithelium (Fig 5A, B).

Necrosis of the intertubular epididymal tissue, with scarring reaction, accumulation of spermatozoa, and infiltration of macrophages were observed in the caudae of the epididymides in some of the treated dogs.

The vasa deferentia of the control dog had spermatozoa in their lumens, whereas those in treated dogs did not have spermatozoa and the lumens appeared reduced in diameter.

Experiment 4—All 3 dogs became azoospermic by 35 days after the 1st of 2 intraepididymal injections (Table 6). Volume of ejaculate and body weight were not affected by treatment ($P > 0.05$). Testicular diameter was significantly increased ($P < 0.05$) on days 7 and 14 after the 1st intraepididymal injection. Scrotal swelling was observed between days 7 and 14, but did not interfere with ambulation or produce detectable discomfort to the dogs.

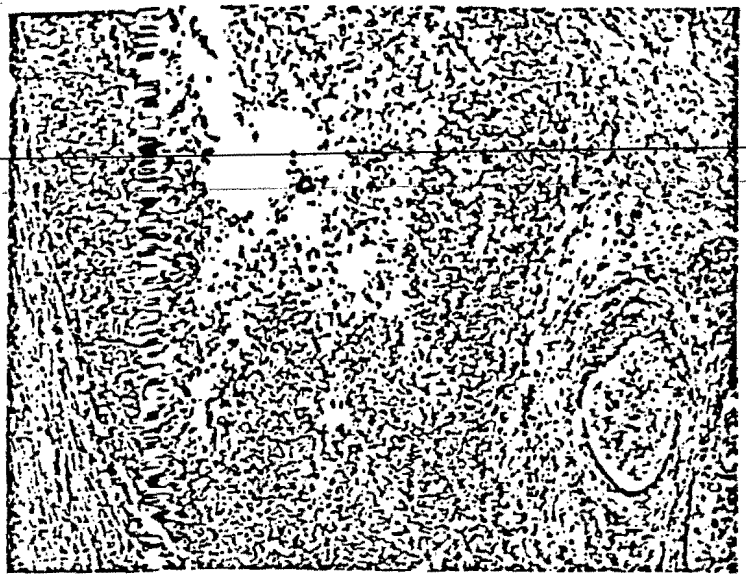

Fig 3—Large, cystic granuloma in the corpus of the right epididymis of treated dog 47. H&E stain; × 83.

Qualitative changes were not observed in the testes. Epididymal changes were not as marked as those described for the dogs given 1 intraepididymal injection of sclerosing agents in experiment 3. Epididymal tubules showed a mild dilation and some flattening of the epithelium lining the tubules. The caudae of the epididymides had large, cystic granulomas, with spermatozoa extravasated into the intertubular tissue.

Experiment 5—One of the control dogs began to ejaculate by day 28 after treatment; the other control dog ejaculated on day 35 after treatment (Table 7). The 2 treated dogs began to ejaculate by day 28. Volume of ejaculate was not affected by treatment ($P > 0.05$) and gradually increased in control and treated dogs. Spermatozoa were present in the 1st ejaculates from control dogs, and total number of spermatozoa per ejaculate increased progressively from the 1st ejaculate. Spermatozoa were not found in ejaculates of the treated dogs.

Body weight and testicular diameter were not af-

Fig 4—Apparently normal tubule in the caput of the right epididymis (A, × 83) of treated dog 47 which had a large, cystic granuloma in the corpus of the same side (B, × 35). H&E stain.

TABLE 7—Total Number of Spermatozoa, Volume of Ejaculate, Testicular Diameter, and Body Weight of Prepubertal Control and Treated Dogs Given Intraepididymal Injections of 1.5% Chlorhexidine Gluconate in 50% DMSO: Experiment 5

Day	Total No. of spermatozoa/ejaculate (10^9)		Volume of ejaculate (ml)		Testicular diameter (cm)		Body weight (kg)	
	Controls	Treated	Controls	Treated	Controls	Treated	Controls	Treated
−7	...	...	...	...	2.9 ± 0.4	2.7 ± 0.6	9.0 ± 0.0	9.5 ± 0.5
−2	...	...	...	...	3.1 ± 0.4	2.9 ± 0.7	ND	ND
0	...	...	...	...	3.2 ± 0.5	3.0 ± 0.4	9.3 ± 0.3	9.5 ± 0.6
1	...	...	...	...	3.4 ± 0.5	3.3 ± 0.3	ND	ND
2	...	...	...	...	3.4 ± 0.4	3.5 ± 0.7	ND	ND
4	...	...	...	...	3.1 ± 0.6	3.5 ± 0.4	ND	ND
7–21*	...	...	...	...	3.4 ± 0.3	3.4 ± 0.5	9.2 ± 0.7	8.9 ± 0.7
28–357**	457 ± 191	0	7.7 ± 1.8	8.3 ± 2.2	3.8 ± 0.1	3.8 ± 0.2	11.4 ± 0.8	11.5 ± 0.5
PROBABILITIES								
Treatment effect	ND		NS		NS		NS	
Time effect	ND		< 0.01		< 0.01		< 0.01	
Interaction	ND		NS		NS		NS	

Data are expressed as mean ± standard deviation.
* Averages of 3 collections or measurements once each week. ** Averages of 48 collections or measurements once each week.
... = Dogs did not ejaculate. ND = Not determined; NS = not significant ($P > 0.05$).

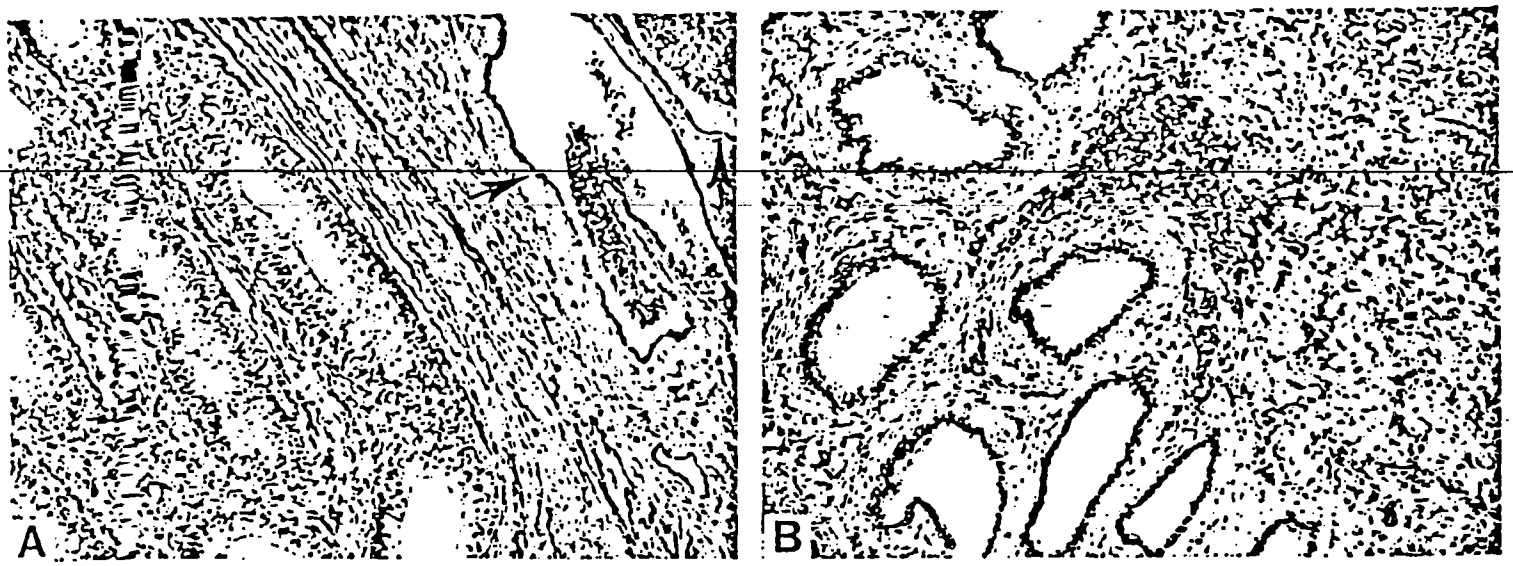

Fig 5—Apparently normal portion of the epididymal tubule adjacent to a disrupted portion (arrows) in the right cauda of the epididymis (A, dog 34); folded portion of the epididymal tubule adjacent to a granuloma in the right cauda of the epididymis (B, dog 39). H&E stain; × 83.

fected by treatment ($P > 0.05$), but there was a significant time effect ($P < 0.01$). Signs of swelling of the scrotum or discomfort to the dogs were not observed.

Macroscopic appearance of the epididymides of the treated dogs was similar to that described in experiment 3.

The histologic changes of testes, epididymides, and vasa deferentia of treated dogs were similar to those described for experiment 3.

Discussion

Results of this study indicate that a long-lasting azoospermia can be induced in dogs by injecting sclerosing agents into the caudae of the epididymides.

Treatment with a 3.3% solution of formalin in PBSS induced temporary azoospermia or oligospermia. Intraepididymal injections of PBSS alone did not induce azoospermia, indicating that the azoospermia was not due solely to the traumatic effect of the injection. The lack of effect of treatment on the volume of ejaculate was anticipated because most of the ejaculatory volume is contributed by the prostate gland. The increased testicular diameter in the formalin-treated dogs was attributed to inflammatory swelling caused by treatment.

The 2 dogs treated with 1.5% chlorhexidine gluconate in 50% DMSO in experiment 2 became azoospermic for the duration of the study. On this basis, this mixture was selected for further studies. The criteria we used to characterize an ejaculate as azoospermic was progressively more demanding.

Adult dogs given bilateral intraepididymal injections of 1.5% chlorhexidine gluconate in 50% DMSO showed a consistent decline in the number of spermatozoa in each successive ejaculate after treatment. In vasectomized dogs, the total number of spermatozoa decreased progressively with each ejaculate after vasectomy, and ejaculates were azoospermic by 21 days after vasectomy.[18] Ejaculated spermatozoa in the dog originate from the epididymides and from spermatozoa stored in the vasa deferentia. The decrease in number of spermatozoa in the ejaculates of adult dogs injected intraepididymally with sclerosing agents could result from a gradual establishment of obturating tissue reaction at the site of injection and from a gradual emptying of vasal spermatozoa.

Although fertility of ejaculates that were oligospermic immediately after treatment was not tested, it seems unlikely that pregnancy would result from matings during the transitional period until the dogs became azoospermic. The time required to establish the obturating tissue reaction might be dose dependent. Adult dogs given 2 bilateral intraepididymal injections of chlorhexidine gluconate in DMSO became azoospermic by 35 days after treatment, whereas adult dogs given only 1 bilateral intraepididymal injection of the sclerosing agent became azoospermic by 91 days after treatment. Larger volumes or higher concentrations of these or other sclerosing agents in one bilateral intraepididymal injection might shorten the time to obtain azoospermic ejaculates.

Prepubertal dogs given bilateral intraepididymal injections of chlorhexidine gluconate in DMSO began to ejaculate seminal fluid at approximately the same time as the control dogs, but never had spermatozoa in their ejaculates.

Hydrostatic pressure in the caudae of the epididymides was elevated in the hamster[13] and guinea pig[14] after long-term vasectomy, as a result of the accumulation of sperm and fluid. The capita and caudae of the epididymides were dilated after vasectomy in several species.[1,12,14] The distended epididymides tended to rupture, leaking spermatozoa and epididymal fluid into the surrounding tissues.[1,12] To obtain azoospermic ejaculates in adult dogs, the tissue reaction to the sclerosing agent may have to overcome the increasing epididymal pressure until obturation of the epididymal tubule is completed. In prepubertally treated dogs, the obturating tissue reaction might be completed before epididymal pressure is present or increases. From this point of view, treatment with intraepididymal injections of sclerosing agents before puberty seems desirable.

The lack of testicular changes in dogs treated with intraepididymal injections of sclerosing agents was anticipated, in view of previous reports on the effects of long-term vasectomy in dogs. Vasectomy resulted in degenerative changes and atrophy of the seminiferous tubules and in suppression of spermatogenesis by about 4 months after surgery.[5,15,21] However, impairment of spermatogenesis was temporary and was followed by gradual recovery by the 6th month after vasectomy.[5,17,21]

Increased intraluminal pressure[13,14] and probably deficient reabsorption of fluid are likely to be the cause of tubular dilation and epididymal stasis or rupture.[12] Conceivably, the accumulation of sperm and fluid may have increased intraepididymal pressure to such a point as to induce tubular rupture and extravasation of fluid and spermatozoa into the tubular tissue. The type of tissue reaction and tubular impairment varied from animal to animal, probably as a function of time elapsing since the formation of the lesions.

Granulomas and associated tissue reaction were consistently found in all dogs. The formation of granulomas in the epididymides and vasa deferentia is a common result of vasectomy in man[19] and other species.[1,12,22] Distention of the epididymides and formation of cysts in the caudae of the epididymides in long-term vasectomized dogs have been reported.[21] The large, cystic granulomas and the necrosis found in the caudae of the epididymides of dogs given intraepididymal injections of sclerosing agents are likely to be a consequence of the trauma caused by the hypodermic needle at the time of injection, the leakage of spermatozoa and fluid from the lumen of the epididymal tubule, and the injury caused by the chemical agent itself.

The apparently decreased diameter of the lumen of the vasa in treated dogs could be ascribed to the lack of content and pressure due to the obstruction. However, this finding was not anticipated and needs corroboration since serial sections were not performed.

Treatment of young adult or prepubertal dogs with chlorhexidine gluconate and DMSO did not affect volume of ejaculate, testicular diameter, or body weight, but there was significant effect of time on these measurements. The effect of time was interpreted as a reflection of growth and attainment of mature functional capability as the dogs became older. The lack of a significant treatment versus time interaction provides convincing evidence that changes induced by time were independent of treatment.

The procedure described in this study is effective, easy to apply, and apparently safe for the sterilization of male dogs. Undesirable clinical side effects other than a transient swelling of the scrotum were not observed.

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CANINE PRACTICE — REPRODUCTION

A new method for the nonsurgical sterilization of male dogs is being developed at Colorado State University. Long-lasting azoospermia has been induced in adult and prepubertally treated dogs by intraepididymal injections of sclerosing agents. This method of sterilization has consistently resulted in azoospermia and appears suitable for large-scale programs of sterilization for dogs.

Chemical Vasectomy in Dogs

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Practitioners are well aware of client objections, silent and voiced, to the surgical sterilization techniques commonly recommended for control of reproduction in male dogs. The introduction of this chemical vasectomy procedure suggests an apparently safe and effective nonsurgical sterilization method which may prove highly acceptable to clients for their pets. Increasing demands for reproduction control methods for pets warrant continued research into such alternative sterilization techniques. *The Editors*

The increasing population of dogs and the problems associated with unwanted and uncontrolled dogs are of serious concern to city and state governments and humane associations. The bitch and the female cat are generally perceived as the ultimate targets in the control of canine and feline populations. The male dog and cat are readily overlooked as effective targets in spite of the contribution of the male to the overpopulation of pets. In a survey of pet ownership conducted in Yolo County, California, in 1970 (1), it was found that 67% of bitches and 96% of the male dogs were reproductively intact. Assuming these figures to be representative of the national population of dogs, a simple, effective and inexpensive method for the sterilization of male dogs would certainly contribute to the control of the population. After all, bitches do not get pregnant by immaculate conception and each intact male is capable of siring a multitude of litters.

Objections to Orchiectomy and Vasectomy

Currently, the only proven methods for sterilizing male dogs and cats are orchiectomy and vasectomy. Both methods require surgical procedures and facilities. Obviously, neither of the two methods has been widely used to limit the growth of the dog population. Pet owners have raised a number of real

ducing the acceptability of this procedure, In spite of the fact that castration in the adult dog not only blocks reproduction but also reduces roaming, urine marking and fighting with other dogs (2). Desirable as these effects of castration might be to control the dog population, many owners object to the use of the procedure in their own pets. Vasectomy, on the other hand, is a procedure seldom used for the sterilization of dogs probably because, like orchiectomy, it requires anesthesia and surgical facilities and does not have the advantages of orchiectomy in relation to desirable behavioral changes.

Psychological attitudes of pet owners toward their pets have a direct relation to social attitudes toward pet control and methods to be used for controlling the population of pets. It is now clear that surgical sterilization is not a popular solution to the overpopulation of dogs and the acute need for the development of suitable alternatives to surgical sterilization is recognized (3).

This paper reports our current findings in the development of a nonsurgical method for the sterilization of dogs.

Development of a Nonsurgical Sterilization Technique

Obstruction of the vas deferens in dogs by injection of sclerosing agents into the lumen of the vas was reported (4). The injection was made percutaneously without exposure of the vas. This procedure offered a number of advantages over vasectomy because it did not require surgical facilities or postoperative care. However, the injection of the sclerosing agents in the lumen of the vas deferens presented difficulties. Penetrating the lumen of the vas consistently was not achieved easily, if my own experience is any indication, and this problem would certainly hinder the successful application of the procedure to a large number of dogs.

ANATOMY OF THE EPIDIDYMIS

The epididymis is an important functional component of the excurrent tract, connecting the seminiferous tubules of the testes with the vas deferens. The epididymis is closely attached to the surface of the testis along its major axis (Fig. 1). The epididymis consists of the epididymal tubule and of intertubular tissue. The epididymal tubule is a very long, highly coiled tubule that begins in the efferent ducts and ends in the vas or ductus deferens. Three anatomic parts are recognized in the epididymis: head or caput, body or corpus, and tail or cauda (Fig. 1). The tail of the epididymis in the dog is an easily palpable and recognizable structure since its contour is visible through the scrotum.

RATIONALE FOR EPIDIDYMAL SITE OF INJECTION

Since the epididymal tubule is still coiled at the tail of the epididymis, where it gradually merges with the vas deferens, we endeavored to develop an even simpler method of inducing occlusion of the excurrent duct by injecting sclerosing agents, percutaneously, into the cauda of the epididymis. We anticipated that the chemicals deposited in the cauda of the epididymis would cause irritation of the tubular and intertubular tissue and subsequently lead to sclerosis of these tissues. The sclerosis induced in this manner would occlude the epididymal duct and, thus, prevent the passage of sperm from the epididymides to the vasa deferentia, inducing a chemical vasectomy-like effect and causing the ejaculates to be azoospermic.

EFFECTIVE CHEMICAL AGENT SELECTION

This hypothesis was tested in a number of experiments, using both adult and prepubertal dogs. A series of different chemicals were tested for their ability to induce azoospermia when injected into the cauda of the epididymides. The results of those experiments were recently reported (5). From the results of preliminary experiments, we selected for further studies a preparation containing 1.5% chlorhexidine gluconate in 50% dimethylsulfoxide (DMSO) in aqueous solution (provided by Fort Dodge Laboratories). Adult and prepubertally-treated Beagle dogs given a single, bilateral intraepididymal injection of 0.6ml of 1.5% chlorhexidine

gluconate in 50% DMSO developed a long-lasting and probably irreversible azoospermia. There were no clinically apparent undesirable side effects other than a transient swelling of the scrotum (5).

TABLE 1

Total Number of Spermatozoa/Ejaculate (10^6)* and Volume of Ejaculate (ml)* of Prepubertal Control and Treated Dogs Given Intraepididymal Injections of 1.5% Chlorhexidine Solution

Day	Total Number of Spermatozoa Controls	Treated	Volume of Ejaculate (ml) Controls	Treated
-7 to 21**	—	—	—	—
28 to 357 +	457 ± 191	0	7.7 ± 1.8	8.3 ± 2.2

* Values given as mean ± standard deviation.

** Seminal collections were attempted on Days -7, -2 and 0, prior to treatment; on Days 1, 2 and 4 after treatment, and weekly thereafter. One of the control dogs began to ejaculate on Day 28 after treatment, the other control ejaculated on Day 35 after treatment. Two treated dogs ejaculated on Day 28 after treatment.

+ Averages of 48 seminal collections performed once a week.

TABLE 2

Total Number of Spermatozoa/Ejaculate (10^6)* and Volume of Ejaculate (ml)* of Adult Dogs Given Intraepididymal Injections of 1.5% Chlorhexidine Solution

Day	Total Number of Spermatozoa Controls	Treated	Volume of Ejaculate (ml) Controls	Treated
-7	287 ± 198	125.0 ± 64.0	4.2 ± 3.9	4.3 ± 2.2
-2	559 ± 500	361.0 ± 253.0	5.2 ± 3.7	6.3 ± 2.5
0	471 ± 364	479.0 ± 312.0	5.7 ± 4.8	7.1 ± 2.8
1	275 ± 251	16.0 ± 20.0	7.0 ± 5.8	5.4 ± 4.0
2	48 ± 44	0.1 ± 0.2	6.5 ± 4.5	5.8 ± 3.7
4	215 ± 130	6.5 ± 7.2	6.0 ± 4.4	6.7 ± 3.5
7-28**	434 ± 190	0.5 ± 0.9	7.6 ± 3.7	8.0 ± 2.7
35-56**	579 ± 274	0.1 ± 0.2	8.9 ± 2.7	8.0 ± 3.3
63-84**	785 ± 218	0.4 ± 1.4	11.3 ± 1.5	9.6 ± 2.8
91-357 +	546 ± 250	0	9.4 ± 2.3	8.5 ± 2.9

* Values given as mean ± standard deviation.

** Averages of four seminal collections performed once a week.

* Averages of 30 [illegible] performed once a week.

All prepubertal dogs given an intraepididymal injection of 0.6ml of the solution containing 1.5% chlorhexidine gluconate in 50% DMSO into each epididymis began to ejaculate seminal fluid at approximately the same age as the controls but spermatozoa were never found in their ejaculates (Table 1). All adult dogs given intraepididymal injections of the sclerosing agents showed a consistent decline in the number of spermatozoa in each successive ejaculate after treatment and became azoospermic by Day 91 after treatment (Table 2). The ejaculates of adult and prepubertally treated dogs were still azoospermic on Day 357 after treatment, when the study was terminated (Tables 1 & 2).

Adult dogs given two successive, bilateral intraepididymal injections of 0.6ml 1.5% chlorhexidine gluconate in 50% DMSO on Day 0 and again on Day 7 became azoospermic by 35 days after the first of the two intraepididymal injections (Ref. 5, Table 3). These results suggested that the time required to establish the obturating tissue reaction might be dependent on the volume of the solution of sclerosing agent or on its concentration in the solution.

HIGHER CONCENTRATION MAY BE MORE RAPIDLY EFFECTIVE

The hypothesis that a higher concentration of chlorhexidine gluconate in 50% DMSO and larger volumes of the solution of the agents given in a bilateral intraepididymal injection would shorten the time to azoospermic ejaculation was tested in an experiment still in progress. In this experiment, eight adult male Beagle dogs were assigned to two groups of four dogs each. Each dog in Group 1 was given an injection of 0.5ml of 3.0% chlorhexidine gluconate in 50% DMSO into each epididymis. Each dog in Group 2 received a bilateral intraepididymal injection of 1.0ml of 3.0% chlorhexidine gluconate in 50% DMSO. One control dog received a bilateral intraepididymal injection of 1.0ml of 50% DMSO.

All dogs in Group 1 became azoospermic by 42 days after treatment (Table 4). One of

TABLE 3

Total Number of Spermatozoa/Ejaculate (10^6)* and Volume of Ejaculate (ml)* of Dogs Given Two Sequential Intraepididymal Injections of 1.5% Chlorhexidine Solution

Day	Spermatozoa	Ejaculate (ml)
-7	686.00 ± 82.0	9.0 ± 0.4
0	542.00 ± 133.0	9.2 ± 1.1
7	48.00 ± 26.0	9.5 ± 0.5
14	20.00 ± 17.0	9.1 ± 1.0
21	0.12 ± 0.09	9.2 ± 2.5
28	0.03 ± 0.03	9.5 ± 1.7
35	0	9.9 ± 2.1
42	0	10.3 ± 2.3

* Values given as mean ± standard deviation.

the treated dogs (Dog No.2, Table 4) had spermatozoa in his ejaculate on Day 56 and again on Day 70 after treatment. By Day 77, all treated dogs receiving bilateral intraepididymal injections of 0.5ml of the 3.0% solution were azoospermic and have remained azoospermic to date.

All dogs from Group 2 that were given bilateral intraepididymal injections of 1.0ml of the 3.0% solution became azoospermic by Day 35 after treatment (Table 5). Intraepididymal injections of a solution of 50% DMSO alone in the control dog induced a temporary decrease in the total number of spermatozoa but rapidly recovered. The significance of the decrease has not been established.

CONCLUSION

We have previously shown that ejaculated spermatozoa in the dog originate from the

TABLE 4

Total Number of Spermatozoa/Ejaculate (10^6) of Dogs Given Bilateral Intraepididymal Injections of 0.5ml of 3.0% Chlorhexidine Solution(Experiment in progress)

Day	Control Dog	Treated Dogs #1	#2	#3	#4	Mean	Standard Deviation
-7	480	660	513	950	440	641	226
0	725	496	684	360	627	542	145
7	105	15.70	11.34	3.84	1.58	8.10	6.60
14	120	4.10	0.54	0.11	0.12	1.22	1.90
21	257	0.13	0.22	0	0	0.09	0.10
28	225	0	1.08	0.06	0.06	0.30	0.50
35	426	0	0.09	0	0	0.02	0.05
42	553	0	0	0	0	0	—
49	428	0	0	0	0	0	—
56	441	0	0.08	0	0	0.02	0.04
63	549	0	0	0	0	0	—
70	550	0	0	0	0	0	—
77	630	0	0.04	0	0	0.01	0.02
84	658	0	0	0	0	0	—
91	390	0	0	0	0	0	—
98	747	0	0	0	0	0	—
105	950	0	0	0	0	0	—
112	540	0	0	0	0	0	—
119	720	0	0	0	0	0	—

Cont page

TABLE 5
Total Number of Spermatozoa/Ejaculate (10^6) of a Control Dog and of Treated Dogs Given Bilateral Intraepididymal Injections of 1.0ml of 3.0% Chlorhexidine Gluconate in 50% DMSO (Experiment in progress)

Day	Control Dog	Treated Dogs #5	#6	#7	#8	Mean	Standard Deviation
-7	480	1080	810	904	452	812	265
0	725	847	891	810	504	763	176
7	105	0.32	1.24	1.13	0	0.7	0.6
14	120	0	0.55	0.11	0	0.2	0.3
21	257	0.11	0.08	0	0	0.05	0.06
28	225	0.03	0.08	0	0	0.03	0.04
35	426	0	0	0	0	0	—
42	553	0	0	0	0	0	—
49	428	0	0	0	0	0	—
56	441	0	0	0	0	0	—
63	549	0	0	0	0	0	—
70	550	0	0	0	0	0	—
77	630	0	0	0	0	0	—
84	658	0	0	0	0	0	—
91	390	0	0	0	0	0	—
98	747	0	0	0	0	0	—
105	950	0	0	0	0	0	—
112	540	0	0	0	0	0	—
119	720	0	0	0	0	0	—

epididymides and vasa deferentia. Surgically vasectomized dogs had their ejaculates cleared of spermatozoa by 21 days after vasectomy (6). We postulated (5) that the consistent decline in numbers of spermatozoa in the ejaculates of dogs given bilateral intraepididymal injections of sclerosing agents was the result of a gradual establishment of obturating tissue reaction at the site of deposition of the sclerosing solution and a gradual emptying of the spermatozoa from the vas deferens. By giving two successive bilateral intraepididymal injections of 1.5% chlorhexidine gluconate in 50% DMSO or by increasing the concentration of the solution of chlorhexidine gluconate from 1.5% to 3.0% in 50% DMSO we shortened the time to azoospermic ejaculation in adult dogs from of "chemical vasectomy" we are developing seems comparable to, and as effective as, surgical vasectomy (Table 6).

Chemical Vasectomy Technique

We recommend the use of a sedative prior to treatment. We use a sedative that is also an analgesic (Rompun®:Haver-Lockhart), given intramuscularly approximately 10 minutes prior to the intraepididymal injections. The scrotal area is washed with soap and water and a disinfectant solution is then applied to the scrotum. Clipping of scrotal hair is not necessary in Beagle dogs but it might be necessary in other breeds. The solution of

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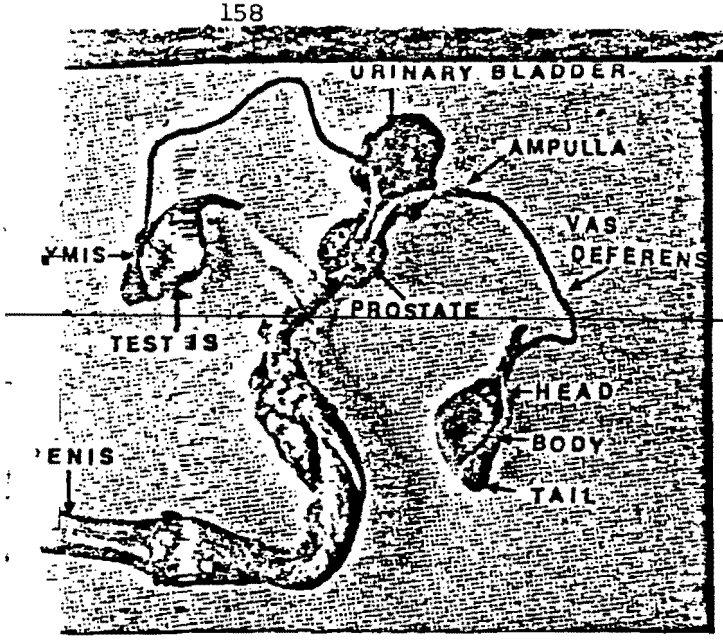


Fig. 1 — Reproductive tract of the dog; specimen trimmed after fixation in formalin. The epididymis is closely attached to the surface of the testis along its major axis and consists of a very long, highly coiled epididymal tubule and of intertubular tissue.

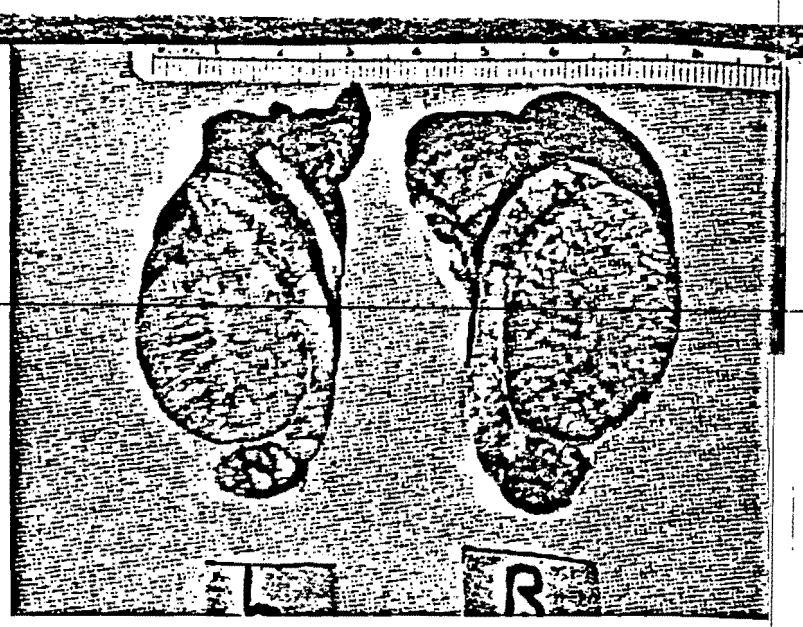


Fig. 2 — Area of diffusion 24 hours after intraepididymal injection in a dog. L = Left tail injected with a mixture of 0.5ml physiologic saline and 0.1ml of India ink. R = Right tail injected with 0.5ml of 1.5% chlorhexidine gluconate in 50% DMSO and 0.1ml of India ink.

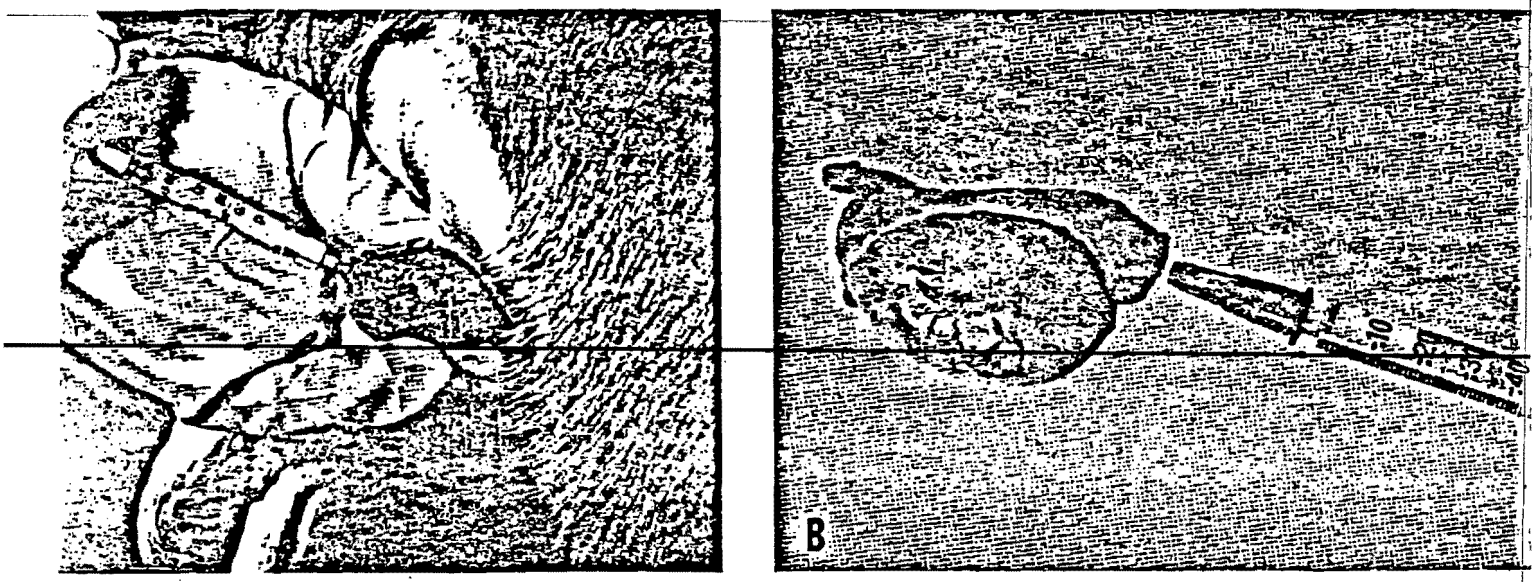


Fig. 3 — Intraepididymal injection in the dog: (A) actual and (B) injection in a specimen fixed in formalin.

Fig. 4 — Dilated epididymal tubule in the left tail of the epididymis, with dense masses of spermatozoa accumulated in the lumen of treated dog No. 39. Hematoxylin and eosin (X83).

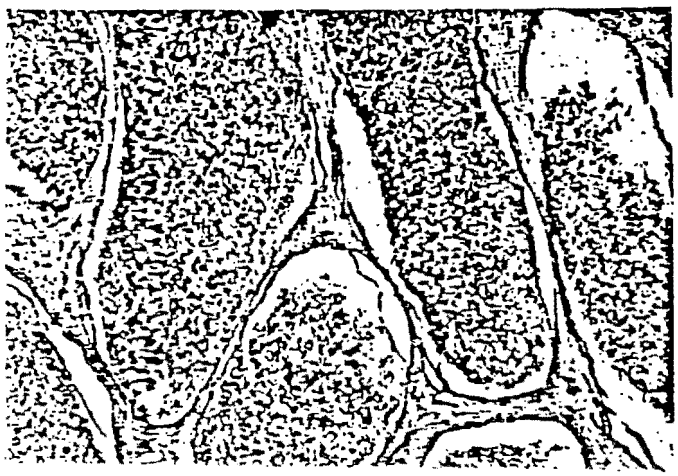
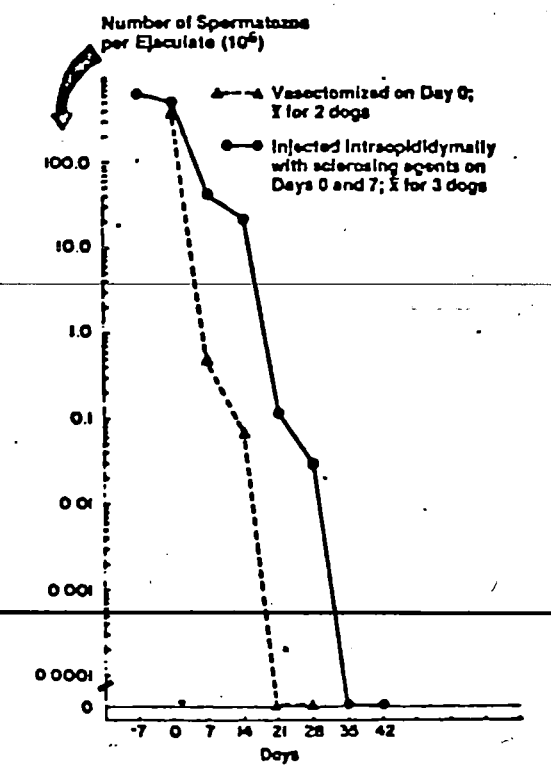


Fig. 5 — Large granuloma in the tail of the right epididymis of treated dog No. 39. Hematoxylin and eosin (X83). Sperm granulomas were found microscopically in all treated dogs.

TABLE 6
Effectiveness of Chemical Vasectomy



sclerosing agents is then injected percutaneously through a 26 gauge, 3/8 or ½-inch long needle into the cauda of each epididymis, while slowly withdrawing the needle. The area of injection in the cauda of the epididymides is shown in Fig. 2. The intraepididymal injection is easy to do in the dog (Figs. 3A & B). After the dog has been sedated we routinely perform the bilateral intraepididymal injection within 60 to 70 seconds.

OPTIONAL INJECTION METHOD

In my hands, this method of injection has produced consistent results. However, in some cases, I have used a slight modification of the technique by injecting half of the total volume of the solution of sclerosing agents while slowly withdrawing the needle up to about ⅔ of its length, and then re-introducing the needle at a different angle and injecting the remainder of the solution. Both approaches for the intraepididymal injections appear to be equally effective, although critical experiments to ascertain the advantages of one over the other hasn't been performed.

For adult Beagle dogs, volumes of 0.5ml and 1.0ml of the solution of 3.0% chlorhexidine gluconate injected into each epididymis were effective in inducing azoospermia. However, the minimal effective volume of the solution of chlorhexidine gluconate in DMSO has not yet been critically determined. The volume of the solution for intraepididymal injections in dogs of breeds other than the Beagle needs to be determined. Age and body size are probably the main factors to be considered for selecting the appropriate volume of the intraepididymal injections.

Treatment Results

Macroscopically, the epididymides of dogs treated with the 1.5% solution were enlarged and the epididymal tubule was distended; microscopically, the epididymal tubules of the treated dogs were dilated (Fig. 4). Sperm granulomas were found microscopically in all treated dogs (Fig. 5) and they seemed more abundant in the body and tail of the epididymides than in the head. With the exception of the necrotic area and scarring at the site of injection in the tail, the histological changes observed in dogs given bilateral, intraepididymal injections of sclerosing agents were similar to the epididymal changes reported in the literature for long-term vasectomized animals, including the dog. A more detailed description of the epididymal histology in dogs given intraepididymal injections of sclerosing agents is given in reference No. 5 of this report.

The azoospermia induced by intraepididymal injections of sclerosing agents was not associated under our experimental conditions with undesirable clinical side effects other than a transient swelling of the scrotum. The swelling of the scrotum lasted for

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about 7 days, did not interfere with ambulation and did not seem to bother the dogs in any observable way.

Volumes of ejaculates and body weights were not affected by treatment in adult dogs or in dogs treated prepubertally with bilateral intraepididymal injections of 1.5% chlorhexidine gluconate in 50% DMSO (5). Data on volume of ejaculates and body weights for the dog given bilateral intraepididymal injections of 3.0% chlorhexidine gluconate in 50% DMSO has not yet been analyzed statistically as the experiment is still in progress.

NO ADVERSE REACTIONS OBSERVED

The acute and chronic toxicity of the chlorhexidine gluconate in DMSO needs to be studied critically in appropriate experiments, including blood chemistry and hematology. However, none of the experiments performed so far provided any clinical indication of toxic effects in any of the treated dogs. Moreover, two adult male Beagle dogs were given an intravenous injection in the jugular vein of 6.0ml of 1.5% chlorhexidine gluconate in 50% DMSO. This dose was five times the total volume of the bilateral intraepididymal injection (0.6ml, volume of each intraepididymal injection, times two epididymides, times five). I did not observe any adverse clinical reaction to the drug during 3 months of daily observation.

Discussion

The intraepididymal injection of sclerosing agents has consistently induced azoospermia in all treated Beagle dogs. However, the percentage of success of the procedure under a variety of conditions and with different individuals giving the intraepididymal injections needs to be established in dogs of different breeds, ages and health conditions.

I believe that the method of inducing occlusion of the epididymal duct by injecting sclerosing agents percutaneously into the tail of the epididymides is a significant step forward toward a practical, nonsurgical method

I also believe that the effects of sterilization of male dogs on population growth have been unwarrantedly belittled. If contraception in either sex was equally consumptive of resources, then the female would be the target sex for population control. However, if a large number of males could be sterilized expeditiously and inexpensively, then the impact of male sterilization becomes an important factor in the control of dog population.

In our studies, we did not observe qualitative changes in the histology of the seminiferous tubules and interstitial tissue, and judging by the ejaculatory response to digital manipulation of the penis, treatment did not effect libido (5). Thus, the method of sterilizing males by intraepididymal injections of sclerosing agents might be more readily accepted by pet owners than neutering on the basis of cost and eliminating the need for postoperative care. Moreover, many owners fear or dislike surgery and object to the behavioral changes associated with orchiectomy. The simplicity of the procedure for intraepididymal injection makes this approach particularly well suited for application by paramedical personnel under veterinary supervision and ideal for large-scale sterilization programs. □

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