University of Montana

ScholarWorks at University of Montana

Graduate Student Theses, Dissertations, & Professional Papers

Graduate School

1972

Status of prairie falcons in western Montana: special emphasis on possible effects of chlorinated hydrocarbon insecticides

Robert Raymond Leedy
The University of Montana

Follow this and additional works at: https://scholarworks.umt.edu/etd

Let us know how access to this document benefits you.

Recommended Citation

Leedy, Robert Raymond, "Status of prairie falcons in western Montana: special emphasis on possible effects of chlorinated hydrocarbon insecticides" (1972). *Graduate Student Theses, Dissertations, & Professional Papers*. 6534.
https://scholarworks.umt.edu/etd/6534

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.

THE STATUS OF PRAIRIE FALCONS IN WESTERN MONTANA: SPECIAL EMPHASIS ON POSSIBLE EFFECTS OF CHLORINATED HYDROCARBON INSECTICIDES

By

Robert R. Leedy

B. S., Cornell University, 1969

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1972

Approved by:

John J. Craighead
Chairman, Board of Examiners

Dean, Graduate School

June 20, 1972
Date

UMI Number: EP37335

All rights reserved

INFORMATION TO ALL USERS
The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript
and there are missing pages, these will be noted. Also, if material had to be removed,
a note will indicate the deletion.

UMI
Dissertation Publishing

UMI EP37335

Published by ProQuest LLC (2013). Copyright in the Dissertation held by the Author.

Microform Edition © ProQuest LLC.
All rights reserved. This work is protected against
unauthorized copying under Title 17, United States Code

ProQuest

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

6-21-72

PROJECT FINANCING

Financial support for this project was supplied by Bureau of Sport Fisheries and Wildlife Contract No. 14-16-0008-1041 to John J. Craighead, and by the Montana Cooperative Wildlife Research Unit: Bureau of Sport Fisheries and Wildlife, University of Montana, Montana State Fish and Game Department, and Wildlife Management Institute cooperating.

Please Note: This dissertation is not a publication, and no portion herein may be quoted without express permission of the author and the Montana Cooperative Wildlife Research Unit.

ACKNOWLEDGEMENTS

I owe sincere thanks to Dr. John Craighead, Leader of the Montana Cooperative Wildlife Research Unit, for his guidance and valuable aid throughout this study. I am also indebted to Dr. Bart O'Gara for his time and advice during all phases of the study.

Thanks to the other members of my committee, Drs. Lee Metzgar and Bob Ream, for their suggestions and review of this manuscript.

Dave Ellis, Pete Widener, Gerald Geiger, Jay Sumner, and Harry Reynolds divulged locations of prairie falcon eyries known to them. Rand Bradley, Jeff Hart, and Chris Servheen provided assistance and companionship in the field. Thanks are due to all of these friends and associates.

Mrs. Mabel Koskela typed the final manuscript, and my mother, Mrs. Barbara Leedy, typed my many rough drafts. Thanks, also, for the help, friendship, and understanding of many other people not mentioned above.

TABLE OF CONTENTS

Page

LIST OF TABLES iv

LIST OF FIGURES vi

CHAPTER I INTRODUCTION 1

CHAPTER II STUDY AREAS 5

Locations 5

Topography 5

Climate 6

Vegetation 9

Land Use 10

CHAPTER III NESTING SITES 11

Methods and Techniques 11

Results and Discussion 14

CHAPTER IV POPULATION STATUS 22

Methods and Techniques 22

Breeding Population 22

Productivity 24

CHAPTER V SURVEY OF CHLORINATED HYDROCARBONS 34

Methods and Techniques 34

Residues in Study Areas 35

Residues in Eggs 36

Thicknesses of Eggshells 41

Chlorinated Hydrocarbons and Nesting Success . . . 44

Page

CHAPTER VI SUMMARY 50

LITERATURE CITED 53

APPENDIX I. Pesticides and the birds of prey 56

APPENDIX II. Form for recording data at eyrie sites 93

APPENDIX III. Reproductive success of prairie falcons in Area C, 1970 94

APPENDIX IV. Methodology for analyses of chlorinated hydrocarbons 95

LIST OF TABLES

Table Page

1. Climatological summary, 1971 8

2. Number (and percentage) of prairie falcon nesting territories at various altitudes in western Montana 15

3. Exposures of occupied cliffs and eyries 16

4. Use of different types of eyries, and shelter from weather afforded by each type, 1970 and 1971 18

5. Reproductive success of prairie falcons in western Montana . . 25

6. Comparison of frequency distribution of clutch sizes of prairie falcons 26

7. Summary of reproductive success of prairie falcons in western Montana, 1970 and 1971 27

8. Comparison of reproductive success of prairie falcons in different areas 28

9. Hay crops sprayed or dusted in 1964 for insects and disease and in 1969 for insects 37

10. Residues of chlorinated hydrocarbons (ppm, wet weight) in eggs of prairie falcons, 1971 39

11. Mean residues of chlorinated hydrocarbons (ppm, wet weight) in eggs of prairie falcons 40

12. Thicknesses of eggshells of prairie falcons 42

13. Mean thicknesses of eggshells of prairie falcons in western Montana, 1970 and 1971 43

14. Ranking of eggshells of prairie falcons in western Montana by ascending thicknesses (mm), with indication of viable eggs, 1970 and 1971 45

15. Ranking of eggshells of prairie falcons in western Montana by ascending thicknesses (mm), with indication of eggs from completely unsuccessful eyries, 1970 and 1971 . . 45

Table Page

16. Summary of data related to chlorinated hydrocarbon insecticides and productivity of prairie falcons in western Montana, 1970 and 1971 46

17. Thicknesses of eggshells and residues of chlorinated hydrocarbons from eggs of prairie falcons in western Montana, 1971. 48

LIST OF FIGURES

Figure Page

1. Outline map of western Montana and study areas 6

2. Upper - Habitat of prairie falcons in Area B 13

Lower - Rapelling to a prairie falcon eyrie

3. Left - A clutch of prairie falcon eggs in an old nest of a golden eagle 30

Right - A two-week-old prairie falcon; a single chick hatched from a clutch of four eggs.

CHAPTER I

INTRODUCTION

Birds of prey have been persecuted by man for many years. Since World War II, raptors have been subjected to an insidious attack whose mechanisms have remained largely unknown. Populations of peregrine falcons (Falco peregrinus), stable for hundreds of years in Great Britain, have decreased drastically (Ratcliffe, 1967a), and peregrines (F. p. anatum) have been virtually eliminated as a breeding species in the eastern United States (Berger et al., 1965). Cade and Fyfe (1970) state that, if the present rate of decline continues, this once ubiquitous species could become extinct in North America during this decade. Similar reports of rapid declines have been made concerning other raptors, including bald eagles (Haliaeetus leucocephalus), ospreys (Pandion haliaetus), accipitrine hawks, and others (Cramp, 1963; Sprunt, 1965; Ames, 1966; Hickey, 1969).

Evidence indicates that declines have been caused by the use of chlorinated hydrocarbon insecticides and related substances whose residues accumulate in the tissues of the affected animals. The most influential effects of these persistent chemicals upon raptors and other predatory birds have not been directly toxic, but sublethally disruptive to normal physiology and behavior (Kupfer, 1967; Peakall, 1967; Wiemeyer and Porter, 1970). The generally accepted theory, at this time, is that high residue levels induce increased production of hepatic enzymes which, in turn, break down steroid hormones and result in reduction of eggshell thickness and accompanying reproductive failure.

At The International Peregrine Symposium held in Madison, Wisconsin, in August, 1965, Hickey and Roello commented that the decline of peregrines was not noted by ornithologists until several years after it had begun, and that many other species are involved in similar declines At the same conference, Glading and Cade stated, respectively, "... that the prairie falcon (*Falco mexicanus*) may well be a model species to study with regard to pesticide effects in the American west," and that "... a study of [prairie falcons] might be most profitable" (Hickey, 1969).

Although closely related to the peregrine and found over much of the latter's western American range, the prairie falcon does not seem to have suffered a marked population decline. By 1965, only 10-20 percent of all known peregrine eyries in the states of Washington, Oregon, Idaho, Utah, and western Montana and Wyoming were still occupied (Nelson, 1965). By 1969, only 20 percent of 50 eyries in Arizona, New Mexico, Colorado, Wyoming, and Montana held peregrines and only eight pairs produced young (Enderson, In Cade and Fyfe, 1970). In contrast, prairie falcons in these same states are thought to be common in suitable habitat and even abundant in a few areas (Beebe and Webster, 1964; Nelson, 1965). However, the status of the prairie falcon in western Montana was unknown at the inception of the present investigation. Studies of the golden eagle (*Aquila chrysaëtos*) demonstrated the need to establish ecologic baselines for raptors in Montana (McGahan, 1968; Reynolds, unpubl.).

Several associates of the Montana Cooperative Wildlife Research Unit and local falconers knew the locations of a number of prairie falcon eyries and had some data on reproduction, but little was known concerning the population as a whole or the reproductive success from more than a few eyries. In view of the increasing use of artificial elements in the environment, especially organochlorine compounds, the collection of meaningful descriptive data was considered imperative to judge better the effects of various disruptive elements upon the present and future welfare of these birds.

Knowledge of the present status of prairie falcons was considered vital for future comparisons when research indicated that low levels of chlorinated hydrocarbons were present in the tissues and eggs of red-tailed hawks (Buteo jamaicensis) (Seidensticker and Reynolds, 1971) and in the eggs and prey of golden eagles (Reynolds, unpubl.). Both of these species of raptors are sympatric with the prairie falcon. Additional research showed that the reproductive success of ospreys near Flathead Lake, Montana, was being adversely affected by chlorinated hydrocarbons (Koplin et al., unpubl.).

Because pesticides played such an important role in the origins of this study, the investigator has made a comprehensive review of the literature concerning the effects of pesticides, especially chlorinated hydrocarbons, upon birds of prey. A written summary of this review is presented in Appendix I.

The present study was devoted to finding as many eyries of prairie falcons as possible, determining clutch sizes and the fate of eggs, recording fledging success of all nesting pairs, and gathering addled eggs for analyses of pesticide residues. Thicknesses of shells of addled and hatched eggs were compared with thicknesses reported by Anderson and Hickey of eggshells taken in this region prior to widespread use of pesticides (In press). Data on nesting sites were collected and examined in an effort to find possible correlations between these and the status of the population.

CHAPTER II

STUDY AREAS

A general survey of prairie falcons was conducted in western Montana during the 1970 and 1971 breeding seasons. This survey was conducted in Montana west of the 110th meridian and south of the 48th parallel, an area of approximately 45,000 square miles. Because of the huge extent of this area and because much of it is not nesting habitat for prairie falcons, three study areas were selected for more intensive investigation. These study areas were designated A, B, and C. The general region surveyed and the relative locations of the study areas are illustrated in Figure 1.

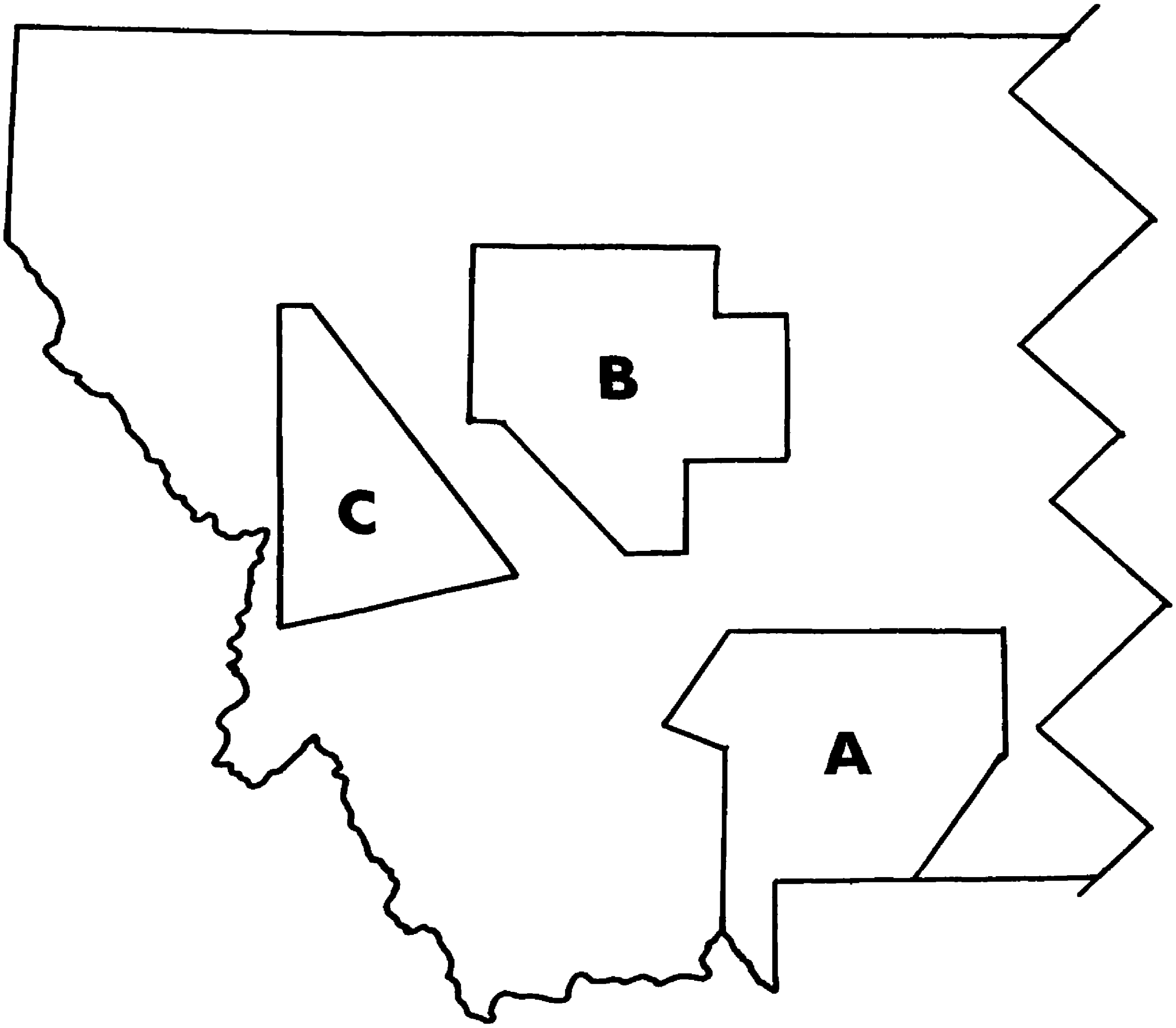
Locations

Study Area A comprises Park, Sweetgrass, and Gallatin Counties. Area B includes Cascade, Lewis and Clark, and Teton Counties. Area C comprises some of the intermontane valley within a 60-mile radius of the city of Missoula, and includes portions of Lake, Sanders, Missoula, Ravalli, Granite, and Powell Counties.

Topography

Elevations in Area A range from 4,000 feet along the flood plains of the Yellowstone, Madison, Gallatin, and Shields Rivers to over 10,000 feet in the surrounding Bridger, Gallatin, Crazy, and Absaroka Mountain Ranges. Features of the transitional foothills lying between river

Figure 1. Outline map of western Montana and study areas.



Study areas - **A ; B ; C**

bottoms and mountain slopes include buttes, ravines, and valleys marked by rock outcroppings and cliffs.

Area B varies in elevation from 3,000 to 8,000 feet. It is transected by the Missouri, Sun, Teton, and Dearborn Rivers. Gently rolling plains are characterized by numerous buttes and "reefs" formed by volcanic intrusions and erosion of sedimentary rocks (Figure 2, upper). In addition, steep, narrow canyons have been cut by rivers along the western and southern borders. Except where it meets the forested Rocky and Big Belt Mountains, at its western and southern edges, the area is surrounded completely by open plains.

Major rivers in Area C are the Clark Fork, Flathead, Bitterroot, and Blackfoot. The Bitterroot, Mission, and Garnet Mountain Ranges lie within the Area. Elevations range from less than 3,000 feet to more than 11,000 feet. The river valleys generally are narrow and escarpments are common.

Climate

On the east side of the Continental Divide, winters are harsher, precipitation is more seasonal, summers are warmer, and winds are stronger than on the west side. The west side is cloudier and slightly more humid during all seasons (Dightman, 1960). Climatological data for Livingston, Cascade, and Missoula during the 1971 study period are summarized in Table 1.

Table 1. Climatological summary, 1971[1].

Month	Air Temperature, °F			Precipitation, inches H_2O	
	Mean Max.	Mean Min.	Mean	Total	Greatest Day
Livingston					
March	39.8	21.7	30.8	0.62	0.14
April	52.1	30.7	41.4	3.21	1.04
May	63.2	38.0	50.6	2.68	0.62
June	71.9	45.1	58.5	2.80	1.33
July	80.5	47.6	64.1	0.63	0.60
Cascade					
March	44.9	24.0	34.5	0.64	0.33
April	58.7	31.7	45.2	0.85	0.31
May	68.5	39.5	54.0	3.49	0.83
June	74.3	47.0	60.7	1.29	0.56
July	84.6	45.5	65.1	0.33	0.23
Missoula					
March	45.2	25.7	35.5	0.78	0.15
April	58.9	30.6	44.8	2.09	0.56
May	68.4	40.5	54.5	1.35	0.44
June	72.4	44.2	58.3	1.75	0.66
July	85.8	48.3	67.1	0.53	0.15

[1] Data taken from records at the Livingston FAA Airport, 5 miles south of Cascade, and Missoula FAA Airport (U.S. Dept. Comm., Weather Bur., 1971).

Vegetation

Plant communities of Areas A and B are almost identical, and Area C differs primarily in that the slopes of its narrow mountain valleys are more heavily forested at somewhat lower elevations than is common east of the Continental Divide.

River bottomlands are characterized by cottonwood (*Populus* spp.)., willow (*Salix* spp.), and wild rose (*Rosa* spp.). Ponderosa pine (*Pinus ponderosa*), Engelmann spruce (*Picea engelmanni*), and alder (*Alnus* spp.) are prominent in some riparian communities, especially in the mountain valleys and foothills. Hay is commonly grown on floodplains and benchlands. Alfalfa (*Medicago* spp.), timothy (*Phleum pratensis*), clover (*Trifolium* spp.), and bluegrass (*Poa* spp.) are the most common crops of hay.

Grasses are the most prevalent plants on the plains and on the dry lower slopes of the foothills. The dominant species of the grassland communities are the wheatgrasses (*Agropyron* spp.), fescues (*Festuca* spp.), needlegrasses (*Stipa* spp.) and prairie junegrass (*Koeleria cristata*). Cheatgrass (*Bromus tectorum*) is common in overgrazed areas. In addition, wheat, barley, and other small grains are cultivated in many areas east of the Divide. Sagebrush (*Artemisia* spp.), juniper (*Juniperus* spp.) and limber pine (*Pinus flexilis*) often are associated with the prairie grasses and forbs.

The most abundant trees on lower mountain slopes are Ponderosa pine, Douglas fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*). The latter two species, along with Englemann spruce and alpine fir

(*Abies lasiocarpa*), continue up to timberline where grasses and other plants of low stature again become prevalent.

Land Use

Agriculture is the most conspicuous use of land in Areas A and B and in the intermontane valleys of Area C. According to the 1969 Census of Agriculture, there is a trend toward the consolidation of farms and ranches. Although there are fewer farms and ranches than in 1964, they are larger and more intensively managed (U. S. Dept. of Comm., Bur. of the Census, 1967 and 1971). The percentage of total land used for agriculture in Cascade County rose from 84.5 percent in 1964 to 88.8 percent in 1969. On the other hand, in Park County, land in agriculture diminished from 52.4 percent to 51.0 percent over the same period of time. Trends in Area C vary from county to county. Wheat, barley, and oats are the principal crops cultivated in Areas A and B, and hay is an important crop in all three areas. Cattle are the major livestock in all three areas, and sheep are important in Areas A and B.

CHAPTER III

NESTING SITES

Methods and Techniques

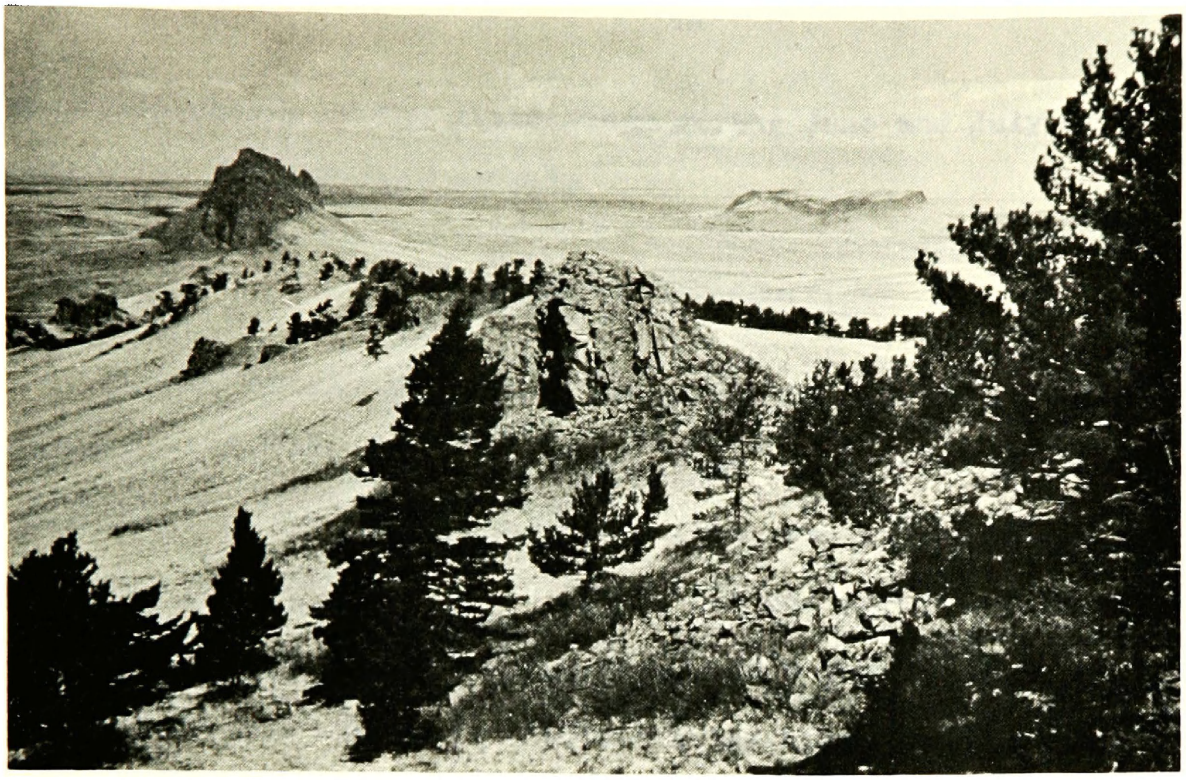
Locating prairie falcon eyries in western Montana is an arduous and time-consuming task. It is simplified only by the fact that these birds nest almost exclusively on escarpments with ledges or potholes suitable for the incubation of eggs and the rearing of young. There is one recorded instance of prairie falcons nesting in a tree (Goss, 1891, In Skinner, 1938). Prairie falcons most commonly nest on cliffs in or near open grasslands (Skinner, 1938; Beebe and Webster, 1964).

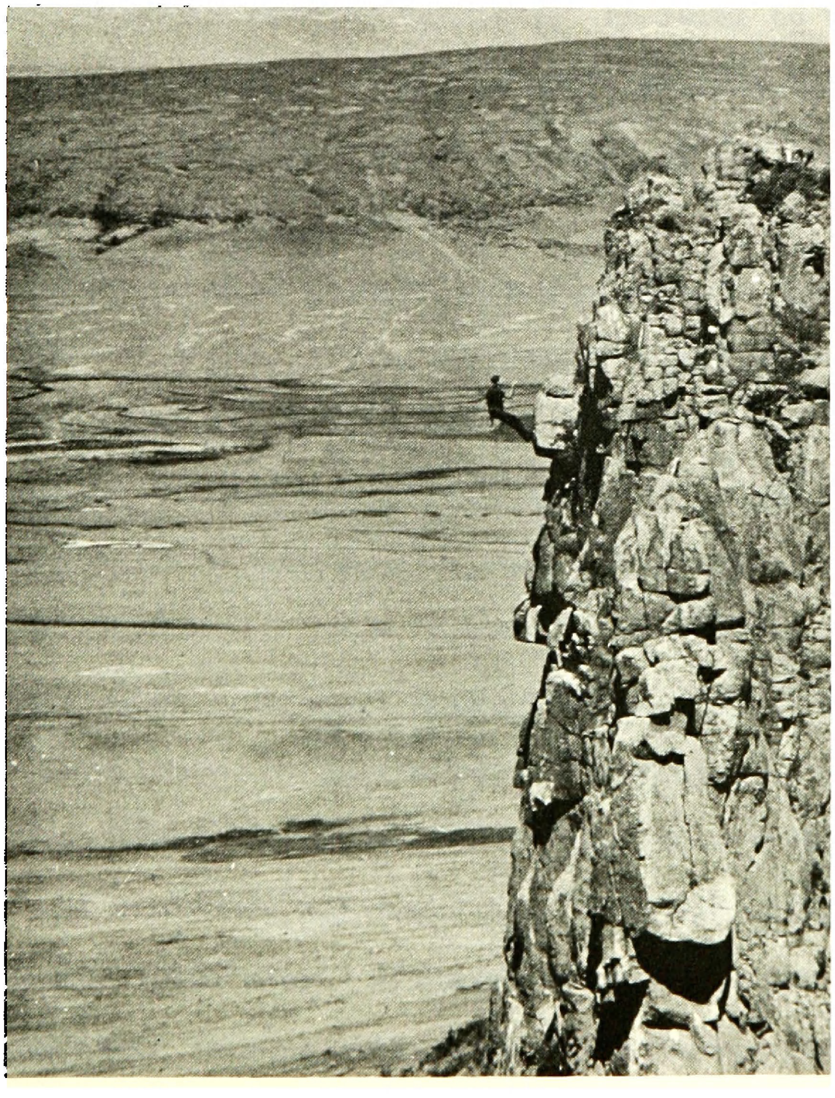
Most cliffs in Areas A and B were examined for nesting falcons several times, using the techniques described by Craighead and Craighead (1956). I checked cliffs of all exposures which had heights of over 10 feet; more time was spent examining those formations overlooking prairies as opposed to forested lands.

I used nylon climbing ropes and mechanical descending and ascending devices to reach all eyries which were studied (Figure 2, lower). Elevations were estimated by the use of topographic maps, and cliff and eyrie heights were approximated by using ropes of known lengths for comparison. Locations of nesting territories were recorded on maps for future reference. A copy of the form used for recording data obtained at eyrie sites is presented in Appendix II. At least one assistant aided

Figure 2. Upper - Habitat of prairie falcons in Area B.

Lower - Rapelling to a prairie falcon eyrie.





me in all phases of the field study during June and July of 1970 and from March through July of 1971.

Results and Discussion

Prairie falcons scrape out loose debris on ledges to form small depressions in which they lay their eggs. The exact location of these nest sites, or eyries, often varies from year-to-year (Webster, 1944; Enderson, 1964; Fyfe *et al*., 1969). I found eyries for most pairs of falcons which were under observation. In a few instances, eyries were never found even though the falcons using them fledged young. I will use the term "occupied nesting territory" to refer to "...any previously known territory occupied by a pair of adult prairie falcons or any cliff defended by one or two adult prairie falcons at any time during the breeding season" (Fyfe *et al*., 1969).

Fifty-seven occupied nesting territories were discovered during 1970 and 1971. Of these, 47, or 83 percent, were located between 4,000 and 6,000 feet above sea level (Table 2). The lowest river bottoms in most of the areas studied are between 3,500 and 4,500 feet. In western Montana, the extensive grasslands favored by prairie falcons extend upward to about 6,000 feet. Thus, ideal nesting habitat of prairie falcons in this region appears to range from approximately 4,000 to 6,000 feet in elevation, or the range in elevation most typified by prairie grasslands. Two eyries were located in clay banks bordering a river at less than 3,000 feet, and one eyrie was found on a mountain cliff above timberline at approximately 9,000 feet. Although prairie falcons usually inhabit foothills and broad valleys, they have nested above timberline at

Table 2. Number (and percentage) of prairie falcon nesting territories at various altitudes in western Montana.

Altitude (feet)	1970		1971		All territories[1]	
	N	(%)	N	(%)	N	(%)
2,000-3,000	0	(0)	2	(4)	2	(3)
3,000-4,000	0	(0)	3	(6)	3	(5)
4,000-5,000	13	(81)	29	(57)	34	(60)
5,000-6,000	2	(13)	12	(23)	13	(23)
6,000-7,000	1	(6)	4	(8)	4	(7)
7,000-8,000	0	(0)	0	(0)	0	(0)
8,000-9,000	0	(0)	1	(2)	1	(2)
Totals	16	(100)	51	(100)	57	(100)

[1] Territories occupied in both 1970 and 1971 counted only once.

elevations of 9,500 and 11,000 feet in Colorado and California, respectively (Beebe and Webster, 1964; Skinner, 1938). The four nesting territories I located between 6,000 and 7,000 feet were all at the mouths of large river canyons where mountain ranges met prairies.

Cliffs occupied by nesting prairie falcons ranged from 30 feet to over 300 feet, the average height being approximately 125 feet. Locations of eyries on the cliffs varied from 10 to 250 feet above the bases of the cliffs; mean height was 80 feet. All of the cliffs were nearly vertical, and most eyries appeared to be inaccessible to all but avian and human predators.

Skinner (1938) stated that prairie falcons select nesting sites in cliffs 50 to 500 feet in height, and that the sites chosen are generally at least 30 feet above the ground. Enderson (1964) reported that cliffs occupied by the prairie falcons he studied in Colorado and Wyoming ranged from approximately 25 to 125 feet and averaged about 50 feet high. The average nest was 36 feet above the base of the cliff. Data from my investigation tend to confirm Enderson's hypothesis that, given a protected eyrie site that overlooks some treeless country, outcroppings under 30 feet can be occupied by prairie falcons. In 1971, five young were fledged from an eyrie in Area B that was only 10 feet above the ground.

The investigator located 49 occupied eyries in 45 nesting territories during 1970 and 1971. Of these eyries, 8 percent faced north, 39 percent east, 33 percent south, and 20 percent west (Table 3).

Table 3. Exposures of occupied cliffs and eyries[1].

	Direction of exposure									
	North		East		South		West		Totals	
Year	N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Cliffs										
1970	0	(0)	7	(50)	4	(29)	3	(21)	14	(100)
1971	3	(8)	15	(38)	13	(32)	9	(22)	40	(100)
All cliffs[2]	3	(7)	18	(40)	14	(31)	10	(22)	45	(100)
Eyries										
1970	0	(0)	7	(50)	4	(29)	3	(21)	14	(100)
1971	4	(10)	14	(35)	14	(35)	8	(20)	40	(100)
All eyries[2]	4	(8)	19	(39)	16	(33)	10	(20)	49	(100)

[1] Only those cliffs with eyries of known location are included.
[2] Cliffs and eyries occupied in both 1970 and 1971 counted only once.

Skinner (1938) indicated that prairie falcons favor southern exposures. Of 36 sites studied by Enderson (1964), 61 percent faced south, 14 percent north, and 25 percent east or west.

Seventy-two percent of all eyries located in the present study faced south or east. The proportion of these nesting ledges facing east was much greater than expected. Falcons selecting these sites may be favored by warmth during the chill of mornings and shade during hot afternoons. An additional factor may be wind; the prevailing winds east of the Continental Divide are generally from the west. Although eyries on cliffs of particular exposures do not always have the same exposures as the cliffs, the data presented in Table 3 indicate that the overall differences are small.

McGahan (1968) suggested that southern exposures might be advantageous to Montana raptors nesting in cliffs during the early spring when below-freezing temperatures occur. That is, the sun's rays would tend to warm eggs and incubating adults during March and April. Nests with exposures to the east and south might be preferable even in summer; eyries facing east would be warmed by the morning sun and shaded during the heat of the day. Nelson (1965) contended that 1/2 hour of exposure to direct rays of the sun in temperatures over 90° F can kill young raptors. He has seen chicks of prairie falcons die this way.

Eyries were located in three situations: ledges in vertical cracks; horizontal shelves; and caves and potholes. Ledges in vertical cracks were particularly common in the columnar formations typical of many cliffs composed of igneous rock. Horizontal shelves were found most often in outcroppings of sedimentary or partially metamorphosed, sedimentary rock. Small caves, potholes, and larger caves were found in a variety of formations, but were seen most frequently in cliffs of limestone or sandstone which were high in calcium content. Ledges in vertical cracks and potholes were the most commonly used types of eyries (Table 4). Eyries ranged in size from one ledge so small that it could barely hold 4 nearly fledged falcons to one cave so large that a man could not touch its ceiling when standing on the nesting ledge.

Table 4. Use of different types of eyries and shelter from weather afforded by each type, 1970 and 1971.

		Shelter from weather			
		Protected		Unprotected	
Type of eyrie	Number of eyries of each type	N	(%)	N	(%)
Ledge in vertical crack	19	16	(84)	3	(16)
Horizontal shelf	10	4	(40	6	(60)
Pothole or cave	20	18	(90)	2	(10)
Totals	49	38	(78)	11	(22)

The typical prairie falcon eyrie is sheltered by an overhanging portion of the cliff (Skinner, 1938; Enderson, 1964). This usually affords some protection from the elements. Listed in Table 4 are eyries which I deemed as either having or not having shelter from weather. An eyrie was considered to be unprotected if eggs in the nesting scrape would be struck directly by precipitation or sunlight entering the eyrie at an angle of more than 45° above the horizontal. Horizontal shelves were the most unprotected sites, and, in several cases, this type of eyrie had no protective overhang. Ninety percent of the eyries in potholes or caves and 84 percent of those in vertical cracks were sheltered from weather. Only 40 percent of the eyries on horizontal shelves received similar protection. Seventy-eight percent of all eyries were sheltered, thus indicating that the nesting pairs usually chose protected sites.

Four prairie falcon eyries were located on large stick-nests abandoned by other species of birds (Figure 3). One of the nests was originally constructed by golden eagles and one was a recently-used nest of ravens (Corvus corax). The other two nests probably were built either by ravens or by red-tailed hawks. The eagle nest was built on a horizontal shelf, the raven nest was in a large cave, and the other two nests were in a pothole and on a horizontal shelf. Use of abandoned stick-nests by prairie falcons has been recorded by several observers, and the use of raven nests is common in some regions (Dawson, 1923; Decker and Bowles, 1930; and Sclater, 1912, and Tyler, 1923, In Skinner, 1938).

Webster (Beebe and Webster, 1964) has stated that bushytail woodrats (Neotoma cinerea) occasionally take over nesting ledges and build nests that prevent falcons from using those sites in future years. This undoubtedly occurs, but prairie falcons in the present study were observed nesting on top of both old and decayed, and small, recently abandoned woodrat nests.

Three prairie falcon eyries occupied in 1970 were taken over by other raptors in 1971. Two of these sites were occupied by kestrels (Falco sparverius), and one was used by great-horned owls (Bubo virginianus). At least 3 pairs of nesting prairie falcons used eyries abandoned by peregrine falcons from 1 to 10 years ago (Pete Widener, pers. comm.). This taking over of peregrine eyries by prairie falcons has been noted in the northwest United States since the mid-1940's (Hickey, 1969).

All but one of 57 nesting territories overlooked at least some grassland. Twenty-one territories were 1 mile or less from extensive forests, and 10 territories were 1 mile or closer to cultivated farmland. Twenty-four of the 57 territories were within 1 mile of rivers or large impoundments of water; nine more territories were within 1 mile of smaller creeks. Thirty-one territories were within 1 mile of unpaved county or paved roads. Three of these territories were within 200 yards of frequently-traveled United States highways; one directly overlooked a populous commercial area.

Quantitative estimates were not made of prey found at nest sites. No prey and few pellets were found at eyries until the young falcons were 2 to 3 weeks old. Fowler (1931) observed adult prairie falcons carrying prey from the nest and noted that remains of small birds "... disappear on the spot as if by magic." The selection of prey by individual prairie falcons probably depends upon the abundance and availability of the hunted species (Craighead and Craighead, 1956).

Richardson's ground squirrels (Citellus richardsonii) and horned larks (Eremophila alpestris) were the most common prey found at eyries, and western meadowlarks (Sturnella neglecta) were the third most frequently observed prey. Enderson (1964) reported similar findings for prairie falcons in Colorado. Other species of prey found in the present study included: vesper sparrows (Pooecetes gramineus); black-billed magpies (*Pica pica*); Brewer's blackbirds (*Euphagus cyanocephalus*); mourning doves (*Zenaidura macroura*); red-shafted flickers (*Colaptes cafer*); an eastern kingbird (*Tyrannus tyrannus*); and a mountain cottontail rabbit (*Sylvilagus nuttalli*). Falcons nesting near rivers appeared to prey more heavily upon birds than did falcons of drier prairies. Some of the falcons in arid habitat seemed to subsist almost entirely upon ground squirrels.

CHAPTER IV

POPULATION STATUS

Methods and Techniques

Comparative data on populations or reproduction of prairie falcons in western Montana have not been published. Because of this, my investigation consisted of initial surveys in widespread areas of suitable habitat. In addition to nesting territories I discovered, locations of other eyries were obtained by personal communication from Pete Widener, Gerald Geiger, and Jay Sumner, all falconers; David Ellis, a graduate student studying eagles in the vicinity of Area B; and others interested in falcons. The search for eyries continued throughout the 1970 and 1971 field seasons.

I used three criteria to determine productivity and nesting success: number of eggs laid; number of eggs hatched; and number of young fledged. I found that recording complete data from all occupied territories was not feasible because of the large area surveyed, the time spent locating eyries, and the late discovery or inaccessibility of some nesting sites. Furthermore, I considered fledging success to be the best indicator of productivity, and minimized my visits to eyries during incubation and soon after hatching to reduce disturbance.

Breeding Population

Enderson (1964) noted that prairie falcons in Colorado arrive at nesting cliffs by mid-March. This appears to be true also of birds in western Montana, although the present study indicates that many of the falcons are not associated in pairs until the beginning of April. The period from pair formation until incubation proved to be the best time to locate occupied nesting territories because the birds then were more visible, more vocal, and more defensive of their territories than at any other time except when investigators intruded.

All pairs of prairie falcons in the present study which were observed defending cliffs were considered to be potential breeders.

New nesting territories were discovered throughout all stages of the breeding cycle. The eyries of some pairs that failed to breed or which were deserted before or during incubation undoubtedly were not found. Therefore, the number of breeding pairs of prairie falcons reported for specific study areas may be low.

Only 16 eyries were found in 1970. Five sites were in Area A, 10 were in Area B, and one was not in a study area. In addition two groups of three falcons and two single birds were sighted in Area B before incubation commenced, but they disappeared from the area and apparently did not nest. Numbers of young fledged were observed at all occupied eyries. Fifty-two occupied territories were discovered during 1971 and counts of fledglings were made at 42 of these sites. Twelve eyries were studied in Area A, 12 in Area B, 8 in Area C, and 10 were not in study areas.

Several times, more than one pair of prairie falcons were found nesting on the same butte. A large butte of radiating volcanic dikes was occupied by 6 pairs of falcons. Two pairs had eyries less than 200 yards apart, These eyries faced each other, but were separated by a third dike that rose between them. Enderson (1964) studied several nesting sites that were less than 200 meters apart. These sites characteristically faced away from each other, and intraspecific strife was uncommonn. Peregrine falcons in areas of high breeding density behave similarly (Beebe, 1960). Craighead and Craighead (1956) stated that prairie falcons nesting closer together than usual maintain hunting ranges distinct from those of other nesting pairs.

Productivity

Dates of completion of clutches in the present study ranged from April 10th to May 14th. Hatching was observed from May 9th to June 12th, and fledging occurred from June 15th to July 21st. The peak of laying was during the last week of April, and most eggs hatched by the beginning of June. Fledging was more variable, but most young birds left their eyries during the first week of July. These dates correspond with the observations of Enderson (1964) in Colorado, but the dates of laying are generally earlier than the egg dates given by Skinner (1938).

Data accumulated on the reproductive success of prairie falcons in the western Montana study areas during 1970-71 are presented in Table 5. These data are summarized and discussed in detail in the following sections of this report. Numbers of eggs laid and young hatched were not observed in all nesting territories in which numbers of fledgings were observed. No eyries were discovered in Area C during 1970. Data on reproduction in this area during 1970 were obtained by personal communication from Gerald Geiger, a falconer living in Missoula (Appendix 3).

Table 5. Reproductive success of prairie falcons in western Montana[1].

Area	Sample sizes: Clutches observed	Sample sizes: Eyries with hatchlings	Sample sizes: Nesting territories	Reproductive success: Eggs laid	Reproductive success: Young hatched	Reproductive success: Young fledged
1970						
A	1	1	5	4	0	6
B	2	8	10	10	18	25(21)*
Other	-	-	1	-	-	4
Total	3	9	16	14	18	35(31)*
1971						
A	4	2	12	14	3	9
B	9	9	12	35	20	23
C	5	7	8	23	20	22(20)*
Other	-	-	10	-	-	21
Total	17	18	42	72	43	75(73)*
1970 and 1971						
A	5	3	17	18	3	15
B	10	17	22	45	38	48(44)*
C	5	7	8	23	20	22(20)*
Other	-	-	11	-	-	25
Total	20	27	58	86	61	110(104)*

[1] Numbers of eggs laid and young hatched were not observed in all nesting territories for which fledgling counts were obtained,

* Numbers in parentheses refer to numbers of young fledged after exploitation by humans.

Clutch size.

Twenty clutches were counted, 3 in 1970 and 17 in 1971. Twenty percent of those clutches consisted of 3 eggs, 30 percent of 4 eggs, and 50 percent of 5 eggs (Table 6). One clutch of one egg and one clutch of 2 eggs were found, but these may not have been complete. Clutches of 2 eggs have been noted by other observers (Skinner, 1938). Comparative data on clutch sizes in California, Oregon, and Washington tend to confirm Skinner's hypothesis that nests of "eastern" prairie falcons contain fewer eggs than those farther west (Table 6). Renesting was observed once in Area B when a clutch of 3 eggs was laid to replace 4 eggs that disappeared early in the season.

Table 6. Comparison of frequency distribution of clutch sizes of prairie falcons.

Area and source	Number of clutches in sample	Percent of different clutch sizes			
		3 eggs	4 eggs	5 eggs	6 eggs
California, Oregon, and Washington (Skinner, 1938)	100	7	21	70	2
Montana (Present study)	20	20	30	50	-

The mean number of eggs was 4.3 per observed clutch (Table 7). The average size of a clutch in Area A was 3.6, or approximately one egg less per clutch than was observed in Areas B or C. I do not know the reason for this difference. The average of 4.3 eggs per clutch in western Montana is only slightly less than the number of eggs laid by prairie

Table 7. Summary of reproductive success of prairie falcons in western Montana, 1970 and 1971[1].

Area	Mean eggs per clutch	Mean hatchlings per eyrie	Mean fledglings per territory[2]	Percentage of successful pairs	Mean fledglings per successful pair[2]
A	3.6(5)	1.0(3)	0.9(17)	35(6)	2.5(6)
B	4.5(10)	2.2(17)	2.2(22)	73(16)	3.0(16)
C	4.6(5)	2.9(7)	2.8(8)	88(7)	3.1(7)
Other	_ (0)	- (0)	2.3(11)	82(9)	2.8(9)
Total	4.3(20)	2.4(27)	1.9(58)	66(38)	2.9(38)

[1] Numbers in parentheses refer to sample sizes.

[2] Nearly fledged young taken from eyries by humans were considered fledged in this table.

falcons in most other regions of North America for which there is comparative data (Table 8). Figure 3, left, shows a clutch of 4 eggs.

Table 8. Comparison of reproductive success of prairie falcons in different areas[1].

Area and source	Eggs per clutch	Hatchlings per eyrie	Fledglings per terr.
Colorado, 1960-62 (Enderson, 1964)	4.5(55)	1.9(67)	1.2(67)
Colorado, 1967-68 (Enderson, Berger, 1969)[2]	4.6(35)	1.9(35)	1.6(35)
Saskatchewan, Alberta, 1968-69 (Fyfe, 1969)[2]	4.3(85)	2.5(85)	- (0)
Idaho, 1971 (Andy Ogden, p.c.)[3]	4.2(31)	- (0)	3.3(42)
California, 1969 (Herman, 1969)[2]	4.4(13)	- (0)	1.3*(13)
Calif., Ore., Wash., pre-1938 (Skinner, 1938)	4.7(100)	- (0)	- (0)
Montana, 1970-71 (Present study)	4.3(20)	2.4(27)	1.9(58)

[1] Numbers in parentheses refer to sample sizes.

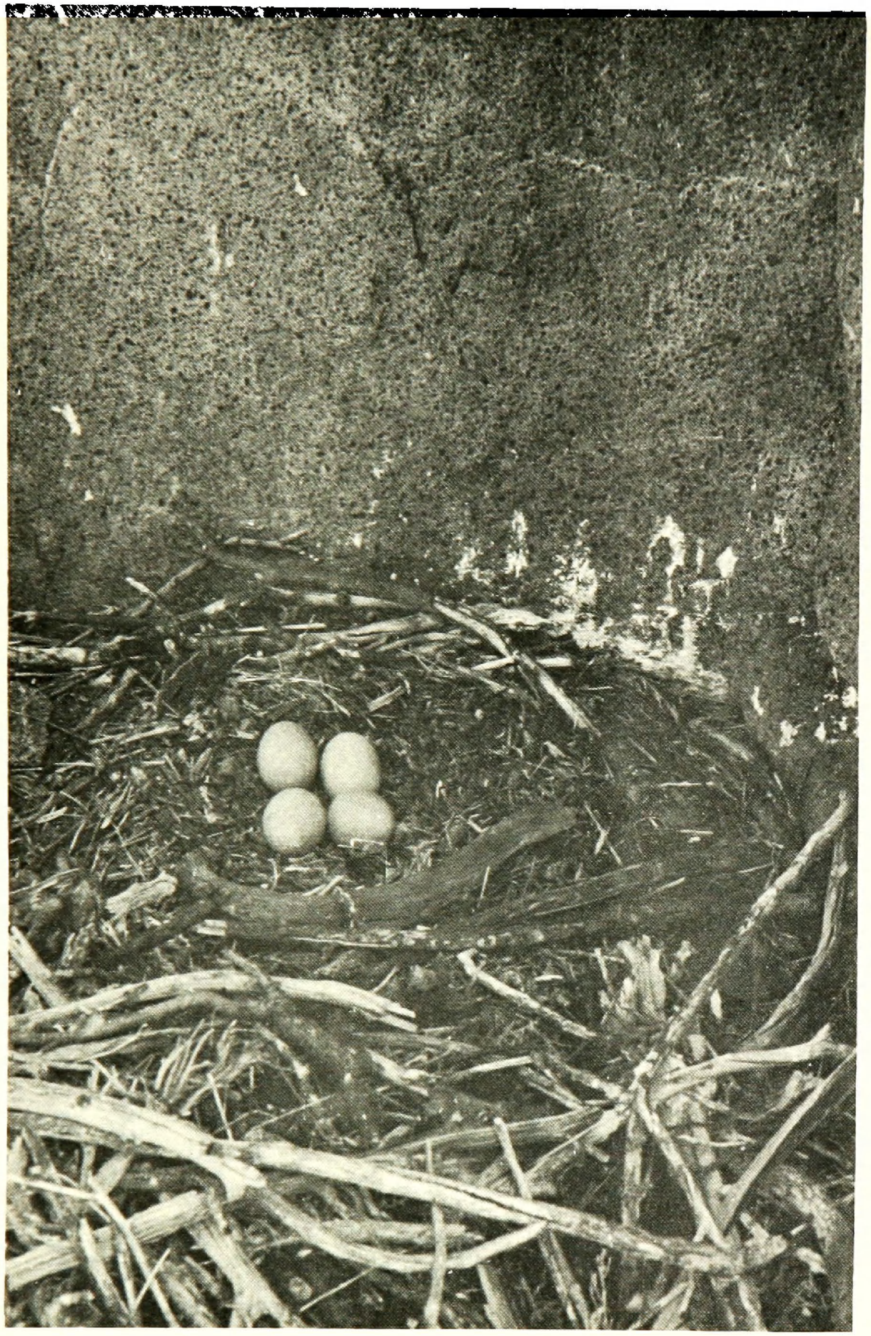
[2] Cited in the Research Planning Conference on Peregrine Falcons and Other Birds of Prey, held November 7-8, 1969, at Cornell University. Transactions were written by hand, unpublished.

[3] Personal communication, Idaho Cooperative Wildlife Research Unit.

*This number may have been copied incorrectly in the original conference transactions.

Figure 3. Left - A clutch of prairie falcon eggs in an old nest of a golden eagle.

Right - A two-week-old prairie falcon; a single chick hatched from a clutch of four eggs.



Hatching success

Young birds considered as hatchlings in this study were small, downy young less than 2 weeks old, with the darker feathers of their tails and wings not noticeable (Figure 3, right). Since it was not always possible to observe eyries immediately after eggs had hatched, some young falcons may have been lost before I could record them. The observed hatching success may be lower than was actually the case.

At least one hatchling per eyrie was produced in 20(74%) of 27 eyries throughout western Montana. This figure may be high because of the small sample size of less successful breeding pairs in Area A (Table 7). The mean number of hatchlings (range 0 to 5) was 2.4 per observed eyrie. At least two breeding efforts, one in Area A and one in Area C, were aborted after the birds were disturbed by people. In one case, the eggs were destroyed; in the other, a member of the breeding pair was trapped.

The mean number of young hatched is similar to comparative data from the Canadian prairies and higher than that from Colorado (Table 8). Hatching success in Colorado was lower partially because of intense harrassment by humans on some of the nesting escarpments studied by Enderson (1964).

Unhatched eggs were rarely recovered intact. Shell fragments of broken eggs were found occasionally, but, in most cases, both whole eggs and shell fragments disappeared. I believe that adult prairie falcons pick up shell fragments and carry them some distance from the eyrie in much the same manner as described by Fowler (1931) in which they clear the nesting ledge of remnants of food. Two sets of eggs, which had been broken and apparently eaten, could either have been destroyed by predators or eaten by the adult falcons. Two small chicks in the vicinity of Area B died of exposure and/or starvation after one of the parents disappeared. The cause of other nesting failures is unknown.

Fledging success

Young were considered fledged when they left the eyrie or were about to do so. Most of the eyries were located for the first time in 1971. Some territories that were deserted early were surely missed. The probability of missing early nesting failures introduces a bias toward higher productivity, and the observed fledging success may be above the actual rate.

One hundred and ten young prairie falcons were fledged from 58 territories in 1970 and 1971. Breeding pairs in only 38 (66%) of those territories were successful (Table 7). Successful pairs produced 2.9 (range 1-5) fledglings per eyrie. Fledging success per occupied territory is a more valid indication of reproductive success because it takes into account nesting failures. The number of young fledged per occupied territory averaged 1.9 (range 0-5) for all areas combined. This figure includes nearly fledged young known to have been taken from eyries by falconers. Four young falcons were taken from Area B in 1970, and 2 were removed from Area C in 1971 (Table 5). Additional falcons may have been exploited in this manner, but such data are not available.

Nesting success averaged more than two young fledged per occupied territory for Area B, Area C, and for eyries not in study areas during 1970 and 1971 (Table 7). In Area A, however, a mean of less than one young was fledged per nesting attempt. Area A produced 2.5 young per successful pair, or slightly less than the mean for all other areas, but breeding pairs in only six (35%) of 17 occupied territories fledged one or more young. The reasons for this high incidence of complete failure is not known, but possibilities will be discussed in Chapter V.

Fledging success of prairie falcons determined in the present study is compared in Table 8 with fledging success observed in other regions of North America. Although it is less than the 3.3 fledglings per eyrie observed by Andy Ogden (pers. comm.) in Idaho, the mean fledging success in western Montana is above the 1.2 young per eyrie reported by Enderson (1964) to be maintaining a stable population in Colorado.

Life tables based on North American band recoveries indicate that mortality rates for peregrine and prairie falcons are similar. Enderson (1965) calculated mortality rates of 70 percent for immature peregrines and 74 percent for immature prairies. Average rates of mortality for adults were 25 percent for both species. Although these figures are biased by several factors, and probably are above true, natural mortality, they indicate that the required breeding success of the two species must also be similar.

Estimates of the minimum productivity required to maintain stable populations of peregrine falcons are slightly over one fledged young per pair per year (Hickey, 1969; Cade, 1971). If this figure is true also for prairie falcons, the productivity of these birds in western Montana as a whole is more than enough to sustain a stable population. However, the average number of young fledged per nesting attempt (0.9) in Area A may be below the required minimum, and may indicate a decling population in that region of the State.

CHAPTER V

SURVEY OF CHLORINATED HYDROCARBONS

Methods and Techniques

I used three methods to determine the relationship of chlorinated hydrocarbons to the prairie falcon population. Nonviable eggs were analyzed for residues of organochlorine compounds, eggshell fragments were measured, and indirect estimates of chlorinated hydrocarbon insecticide applications in the study areas were made on the basis of percentage of land area of crops receiving pesticide treatments.

Nonviable eggs were collected, placed in glass jars, frozen, and held for later analyses of chlorinated hydrocarbons. I considered eggs viable if they hatched and nonviable if they remained unhatched beyond the normal incubation period of 29-30 days. Because prairie falcons frequently clean debris from their eyries, addled eggs rarely were found. Two eggs were collected in 1970, and 10 in 1971. Only 10 of the 12 samples were suitable for analyses.

Analyses were conducted for chlorinated hydrocarbons at the University of Montana, Missoula, Montana, using gas chromatography. (See Appendix IV for details.)

Decreases in thickness of eggshells of raptors and other birds suffering population declines due to contamination by chlorinated hydrocarbons are well documented (Ratcliffe, 1967b; Wiemeyer and Porter, 1970; Cade *et al.*, 1971; Anderson and Hickey, In press). All eggshells of prairie falcons found during the present study were collected, dried, and measured according to standard procedures using a Starrett 13 mm micrometer with a rounded anvil and 0.01 mm graduations. Five measurements, including the attached membrane, were taken around the girth of the shells, and a mean shell thickness was calculated for each egg (Hickey, pers. comm.). Thicknesses were estimated to the nearest 0.001 mm. Shell fragments without membranes or which were too small to enable determination of the girth of the egg were not measured.

Appendix I contains a detailed literature review of the effects of pesticides on the birds of prey.

Residues in Study Areas

The stability of chlorinated hydrocarbon insecticides insures that once they are applied they will remain in the environment for many years. They are used by private agriculturists, aerial spray companies, and local, state, and federal agencies. Levels of application in the past may be as important as levels being applied at present. Information from local informants often is unreliable (Reynolds, unpubl.). Because of the complexity of these factors, levels of organochlorine compounds applied in the study areas are not known.

Agricultural use of insecticides probably accounted for the major portion of chlorinated hydrocarbons applied in the study area. Wheat and alfalfa were the major crops cultivated in these areas. The U. S. Department of Agriculture reported that, in 1966 "... only about 5 percent of the cropland (not including pasture and rangeland) in the Mountain and Northern Plains regions was treated with insecticides, primarily because of the large acreage of wheat, which is seldom treated for insects or soil organisms" (U.S.D.A., 1968). Insecticides were used on 12 percent of the acreage of alfalfa cultivated in the Mountain region. While only 5,000 pounds of active ingredients were used on wheat, 1,265,000 pounds were used on alfalfa. Slightly less than half of all insecticides used on all crops in the Mountain region were chlorinated hydrocarbons (U.S.D.A., 1970).

Census of Agriculture statistics on the treating of hay crops for insects in 1964 and 1969 show that treatments for insects in Area A were more than twice as extensive as treatments in Area B (Table 9). Treatments for insects in Area C were relatively limited.

Analyses of prey of prairie falcons were not conducted during the present study, but analyses were performed on 10 Richardson's ground squirrels from Area A in 1967. Reynolds (unpubl.) found that the mean level of DDE was 0.038 ppm wet weight (range 0.020-0.061) and that total residues of organochlorine compounds averaged 0.075 ppm (range 0.040-0.112). These are low levels of concentration and are comparable to levels found in some small Arctic mammals (Cade, *et al.*, 1968; Enderson and Berger, 1968; Lincer, *et al.*, 1970). Many birds taken as prey would probably have higher residue levels.

Residues in Eggs

Production of DDT in the United States reached its peak in 1963 and has diminished steadily since then. It has been replaced in general agricultural usage by dieldrin, chlordane, lindane toxaphene, aldrin, and heptachlor (Woodwell *et al.*, 1971). The major chlorinated

Table 9. Hay crops sprayed or dusted in 1964 for insects and disease and in 1969 for insects.

		1964		1969	
Area/County	Land area of county[1] (Square Miles)	Square miles of hay treated[2]	(Percent of land area treated)	Square miles of hay treated[3]	(Percent of land area treated)
A					
Park	2,627	17.88	(0.68)	3.06	(0.12)
Sweetgrass	1,846	17.93	(0.97)	3.09	(0.17)
Gallatin	2,517	21.06	(0.84)	6.04	(0.24)
Total	6,990	56.87	(0.81)	12.19	(0.17)
B					
Cascade	2,659	12.91	(0.49)	2.92	(0.11)
Teton	2,294	16.04	(0.70)	4.00	(0.17)
Lewis & Clark	3,477	2.71	(0.08)	0.00	(0.00)
Total	8,430	31.66	(0.38)	6.92	(0.08)
C					
Lake	1,500	2.95	(0.20)	1.07	(0.07)
Missoula	2,613	0.47	(0.02)	0.00	(0.00)
Granite	1,783	0.08	-	0.00	(0.00)
Total	5,846	3.50	(0.06)	1.07	-

[1] U. S. Dept. of Comm., Bur. of the Census, 1940.
[2] U. S. Dept. of Comm., Bur. of the Census, 1967.
[3] U. S. Dept. of Comm., Bur. of the Census, 1971.

hydrocarbons used in Area A in the late 1960's were dieldrin and chlordane (Reynolds, unpubl.). Metabolites of insecticides which were found in eggs during the present study included: DDE from DDT; heptachlor epoxide from heptachlor and chlordane; lindane from lindane toxaphene; and dieldrin from dieldrin and aldrin. Trace amounts of PCB's also were detected.

Data on residues of organochlorine compounds found in individual prairie falcon eggs from each study area are presented in Table 10. All residues were measured as ppm wet weight of total egg contents, and all eggs were collected in 1971 unless otherwise noted. DDE levels ranged from 0.96 - 2.35 ppm, and total residues ranged from 1.24 - 3.33 ppm.

Mean total residues in eggs from all study areas were 2.15 ppm (Table 11). Total residues were highest in Area A (2.58 ppm, or 2.51 ppm excluding the 1967 sample) and lowest in Area C (1.63 ppm). Eggs from Area A contained measurable amounts of all insecticide metabolites which were found. Only trace amounts of dieldrin were found in Area B and Area C, and only trace amounts of lindane were detected in Area C. Comparisons of data from the three study areas are based on small sample sizes, but are presented because they indicate possible differences between areas.

DDE was the major residue in all eggs and heptachlor epoxide was the next most abundant contaminant. DDE frequently has constituted up to 95 percent of all residues of organochlorine compounds found in the eggs of raptors (Berger _et al_., 1970; Cade _et al_., 1971). About 73 percent of all residues found in the present study were DDE.

Table 10, Residues of chlorinated hydrocarbons (ppm, wet weight) in eggs of prairie falcons,

Area/Sample	Fertility	DDE	Heptachlor Epoxide	Lindane	Dieldrin	PCB	Total Residues
<u>A</u>							
1	no embryo	1,28	0,90	0,08	trace	trace	2.26
2	no embryo	0,96	0.59	0,09	0.70	trace	2.34
3	no embryo	2,19	0,25	trace	0	trace	2.44
4 (1967]*	no embryo	2.35	0,70	0	0.23	-	3.33
<u>B</u>							
5 (1970)	unknown	1.16	0.74	0	0	0	1.90
6	embryo	1.17	0.70	trace	0	trace	1.87
7	embryo	1.88	0.79	0.39	trace	trace	3.05
<u>C</u>							
8	embryo	1.91	0	trace	trace	0	1.91
9	no embryo	1.51	trace	trace	trace	0	1.51
10	embryo	1.24	0	trace	trace	0	1.24
11	unknown	1.71	0.14	trace	0	trace	1.85

*(Reynolds, unpubl, The analysis also showed TDE at 0.010 ppm and DDT at 0.040 ppm.)

Table 11. Mean residues of chlorinated hydrocarbons (ppm, wet weight) in eggs of prairie falcons.

Area	Number of samples	DDE	Heptachlor epoxide	Lindane	Dieldrin	PCB	Total Residues
A	4	1.70	0.61	0.04	0.23	trace	2.58*
B	3	1.40	0.74	0.13	trace	trace	2.27
C	4	1.59	0.04	trace	trace	trace	1.63
Total	11	1.58	0.44	0.05	0.09	trace	2.15

*Excluding the 1967 sample (Reynolds, unpubl.), mean total residues for Area A were 2.51 ppm.

Enderson and Berger (1970) reported that a mean of 24 ppm DDE on a dry weight basis was found in 70 eggs of prairie falcons in Colorado. This is about 5 ppm on a wet weight basis at 80 percent egg moisture content, or slightly more than three times the mean residues of DDE (1.58 ppm) found in the present study. Residues of DDE found in 34 eggs of prairie falcons from Saskatchewan and Alberta averaged about 4.5 ppm (Fyfe et al., 1969). These data indicate that the level of DDE residues in western Montana as a whole is low and below levels known to be causing thinning of eggshells of prairie falcons in Colorado and Canada.

Thicknesses of Eggshells

Strong correlations have been found between geographical variations in degree of chlorinated hydrocarbon contamination, amount of change in thickness of eggshells, and frequency of egg breakage in raptors and fish-eating birds (Hickey and Anderson, 1968; Ratcliffe, 1970; Cade et al., 1971). High levels of DDE in eggs, thin eggshells, decreased production, and declining populations of prairie falcons have been shown to be correlated events in portions of Alberta, Saskatchewan, and Colorado (Fyfe et al., 1969; Enderson and Berger, 1970).

Thicknesses of individual eggshells, viability of eggs measured, and success of eyries from which I obtained samples are presented in Table 12. The average thickness of 19 eggshells from all study areas was 0.306 mm (Table 13). Three shells taken from Area A averaged 0.266 mm in thickness. Mean thickness of 12 shells from Area B was 0.313 mm, and four shells from Area C averaged 0.316 mm.

Table 12. Thicknesses of eggshells of prairie falcons.

Area/Sample	Viability[1]	Success of eyrie[2]	Eggshell thickness (mm)
1970			
B			
1	V	S	0.328
2	V	S	0.316
3	V	S	0.315
4	N-V	U	0.280
5	N-V	S	0.345
Mean	-	-	0.317
1971			
A			
6	N-V	U	0.253
7	N-V	U	0.266
8	N-V	U	0.279
Mean	-	-	0.266
B			
9	V	S	0.333
10	N-V	U	0.281
11	N-V	S	0.334
12	N-V	S	0.318
13	N-V	S	0.331
14	N-V	S	0.278
15	V	S	0.293
Mean	-	-	0.310
C			
16	N-V	S	0.295
17	N-V	S	0.323
18	N-V	S	0.292
19	N-V	S	0.355
Mean	-	-	0.316

[1] V = viable; N-V = nonviable.

[2] S = successful; U = unsuccessful.

Table 13. Mean thicknesses of eggshells of prairie falcons in western Montana, 1970 and 1971.

Area	A	B	C	Total
Thickness (mm)	0.266	0.313	0.316	0.306
Sample size	3	12	4	19

One hundred and sixty-seven eggs of prairie falcons collected from western North American grasslands before 1947, prior to the widespread use of chlorinated hydrocarbons, averaged 0.366 mm (S.E.:0.003) in thickness (Anderson and Hickey, In press). Evidence suggests that significant reproductive failures in raptors are correlated with a mean decrease of 20 percent or more in shell thickness and weight (Cade and Fyfe, 1970; Anderson and Hickey, In press).

A 20 percent decrease from the pre-1947 average of 0.336 mm would be 0.293 mm. The mean thickness (0.306 mm) of eggshells from all of my study areas was above this critical level. This strengthens the contention that prairie falcons in western Montana as a whole are not suffering significant reproductive failures due to thin eggshells. However, the mean thickness of eggshells from Area A showed a decrease of 27 percent. Although the sample from Area A was very small, it suggests that prairie falcons there may be affected by the thin eggshell syndrome.

The sample of 19 eggshells measured for thickness was biased toward nonviable eggs. Only five of the eggs were viable, but this may not have affected the reliability of the sample. The mean thickness of viable eggs was 0.317 mm; nonviable eggs averaged 0.302 mm. As is illustrated in Table 14, the medians of these two groups of samples are not statistically significant (Mann-Whitney U-test, $P \gg .05$).

Comparison of thicknesses of eggshells from successful and unsuccessful eyries shows that eggs from eyries that fledged no young had shells much thinner than eggs from eyries that fledged one or more young (Table 15). The mean thickness of eggshells from successful eyries was 0.318 mm; shells from unsuccessful eyries averaged 0.272 mm. The difference between the two medians is highly significant (Mann-Whitney U-test, $P < .001$). This again suggests that certain pairs of prairie falcons in western Montana are suffering from the thin eggshell syndrome.

Chlorinated Hydrocarbons and Nesting Success

Table 16 summarizes data related to chlorinated hydrocarbons and the productivity of prairie falcons in the three study areas. Measurements of productivity, records of insecticide usage, residues per egg, and thicknesses of eggshells reveal a pattern, and probable cause, of regional differences in nesting success of these falcons in western Montana.

Fledging success was more than twice as high in Area B as in Area A, and was highest in Area C. Mean eggshell thicknesses show a similar trend: 0.226 mm in Area A, 0.313 mm in Area B, and 0.316 in Area C. The

Table 14. Ranking of eggshells of prairie falcons in western Montana by ascending thicknesses (mm), with indication of viable eggs, 1970 and 1971.

Rank	1	2	3	4	5	6	7	8	9	10
Thickness	.253	.266	.278	.279	.280	.281	.292	.293	.295	.315
Viable egg								X		X

Rank	11	12	13	14	15	16	17	18	19
Thickness	.316	.318	.323	.328	.331	.333	.334	.335	.355
Viable egg	X			X		X			

Table 15. Ranking of eggshells of prairie falcons in western Montana by ascending thicknesses (mm), with indication of eggs from unsuccessful eyries, 1970 and 1971.

Rank	1	2	3	4	5	6	7	8	9	10
Thickness	.253	.266	.278	.279	.280	.281	.292	.293	.295	.315
Unsuccessful eyrie	X	X		X	X	X				

Rank	11	12	13	14	15	16	17	18	19
Thickness	.316	.318	.323	.328	.331	.333	.334	.335	.355
Unsuccessful eyrie									

Table 16. Summary of data related to chlorinated hydrocarbon insecticides and productivity of prairie falcons in western Montana, 1970 and 1971.

	A	B	C	Total
(Percentage of pairs successfully fledging young)	(35)	(73)	(88)	(62)
Fledglings per occupied territory	0.9	2.2	2.8	1.8
(Percentage of land area treated with insecticides)				
1964	(0.81)	(0.38)	(0.06)	(0.43)
1969	(0.17)	(0.08)	-	(0.09)
Mean total of residues of organochlorines per egg (ppm, wet weight)	2.58	2.27	1.63	2.15
Mean residues of DDE per egg (ppm, wet weight)	1.70	1.40	1.59	1.58
Mean eggshell thickness (mm)	0.266	0.313	0.316	0.306

markedly lower productivity recorded in Area A was probably caused, at least in part, by correspondingly thinner eggshells.

More than twice as much land in hay was treated with insecticides in Area A as in Area B, and negligible land area was treated in Area C. These differences are reflected in the mean total residues of organochlorine compounds found per egg in each area: 2.58 ppm in Area A, 2.27 ppm in Area B, and 1.63 ppm in Area C. Mean residues of DDE per egg were highest in Area A (1.70 ppm), but were higher in Area C (1.59 ppm) than in Area B (1.40 ppm) (Table 16). This seemingly disproportionately high level of DDE found in Area C may be the result of the small size of the sample.

Thicknesses of individual eggshells are compared in Table 17 with total residues of organochlorine compounds and residues of DDE found in each egg. The correlation coefficient between eggshell thickness and total residues is -.786. This highly significant ($P < .005$) negative correlation suggests that chlorinated hydrocarbons probably caused the eggshell thinning found regionally in western Montana during the present study. The correlation between eggshell thicknesses and residues of DDE is not significant ($P > .05$), but may again be due to the small size of the sample. This low correlation also suggests the possibility that residues other than DDE may be additive or synergistic as causative factors in the thinning of eggshells.

Suspicions that the thin eggshell syndrome is affecting prairie falcons in Area A are strengthened by a study of red-tailed hawks in parts of Park, Sweetgrass, and Meagher Counties during 1966 and 1967

Table 17. Thicknesses of eggshells and residues of chlorinated hydrocarbons from eggs of prairie falcons in western Montana, 1971.

Area/Sample	Eggshell thickness (mm)	Residues (ppm, w. wt.)	
		Total	DDE
<u>A</u>			
1	0,266	2,26	1,28
2	0,279	2,34	0,96
3	0.253	2,44	2.19
<u>B</u>			
4	0.318	1,87	1.17
5	0.278	3,05	1,88
6 (1970)	0.280	1,90	1,16
<u>C</u>			
7	0.323	1,51	1,51
8	0.292	1,91	1.91
9	0,355	1,24	1.24
10	0,295	1,85	1.71

(Seidensticker and Reynolds, 1971). In that study, five eggs which were measured showed a 10.9 percent decrease in shell thickness when compared to eggs laid prior to 1946. A single egg was analyzed and contained lower levels of chlorinated hydrocarbons than those found in the present study. Red-tailed hawks and prairie falcons in this area prey heavily upon Richardson's ground squirrels, but falcons generally supplement their diets with more birds than do redtails. Because many of the birds preyed upon are on higher trophic levels than ground squirrels, biological magnification of pesticides should be more prevalent in falcons than in redtails.

CHAPTER VI

SUMMARY

A study was initiated and conducted during 1970 and 1971 to determine the population status of prairie falcons in western Montana. Collection of data was concentrated in three multi-county study areas, two (Areas A and B) to the east of the Continental Divide, and one (Area C) to the west.

Eighty-three percent of all prairie falcon eyries which were discovered were located between 4,000 and 6,000 feet above sea level. This range in elevation is typically vegetated by the prairie grasslands that falcons most frequently inhabit.

Seventy-two percent of all eyries faced south or east. Southern exposures are warmed by the sun's rays during incubation; eastern exposures are favored by warmth during cold mornings and shade during hot afternoons.

Ninety percent of the eyries in potholes or caves and 84 percent of those in vertical cracks were sheltered from most weather. Only 40 percent of the eyries on horizontal shelves received similar protection. Seventy-eight percent of all eyries were sheltered, thus indicating that nesting pairs usually select protected sites.

Nesting success was determined at 58 of 68 nesting territories. Only 35 percent of nesting pairs of prairie falcons in Area A fledged one or more young. The percentage of pairs successfully fledging young was 73 percent in Area B, 88 percent in Area C, and 62 percent for all three areas.

Mean number of eggs per clutch for 20 clutches from all areas was 4.3. Mean number of hatchlings per eyrie for 27 eyries from all areas was 2.4. A mean of 1.9 fledglings per territory was observed for 58 territories. These measures of reproductive success are equal to or greater than those observed in several other states or provinces. This indicates that prairie falcons throughout western Montana are maintaining a stable population.

Nesting prairie falcons in Area A fledged an average of only 0.9 young per year. This rate of productivity may be below that necessary to maintain a stable population, and may indicate a declining population in that region of the State.

Alfalfa is the major agricultural crop treated with chlorinated hydrocarbon insecticides in all study areas. According to the 1964 and 1969 censuses of Agriculture, more than twice as much land in hay was treated in Area A as in Area B; treatments in Area C were negligible.

Mean total residues of organochlorine compounds in eggs from all study areas were 2.15 ppm, a relatively low level, and one which probably did not affect the prairie falcon population in western Montana as a whole. Although sample sizes were small, total residue levels were highest in eggs from Area A, lower in Area B, and lowest in Area C. Levels of DDE in all areas were low (1.58 ppm).

Mean eggshell thickness of eggs from throughout western Montana was 0.306 mm, or above the 0.293 mm level which represents a 20 percent decrease in thickness from the pre-1947 average of 0.366 mm. This indicates that prairie falcons in western Montana as a whole are not suffering from significant reproductive failure due to thin eggshells.

However, although the sample size was very small, the mean thickness of eggshells in Area A showed a decrease of 27 percent.

Comparison of thicknesses of eggshells from successful and unsuccessful eyries shows that eggs from eyries that hatched no young had shells that were thinner (0.272 mm) than the shells (0.318 mm) from eyries that hatched one or more young.

The correlation coefficient between eggshell thickness and total residues of organochlorine compounds is -.786. This highly significant ($P < .005$) negative correlation suggests that chlorinated hydrocarbons probably caused the eggshell thinning found regionally in western Montana. The low correlation between DDE and eggshell thinning may be due to small sample size or to the possibility that residues other than DDE may be factors in the thinning of eggshells.

LITERATURE CITED

Ames, P. L. 1966. DDT residues in the eggs of the osprey in the northeastern United States and their relation to nesting success. J. Appl. Ecol. 3 (Suppl.): 87-97.

Anderson, D. W., and J. J. Hickey. In press. Eggshell changes in certain North American birds. In K. H. Voous (ed.), Proc. XVth Intern. Ornithol. Cong. E. J. Brill, Leiden.

Beebe, F. L. 1960. The marine peregrines of the northwest Pacific coast. Condor 62: 145-189.

_______ and H. M. Webster. 1964. North American falconry and hunting hawks. World Press, Inc., Denver. 315 p.

Bent, A. C. 1961. Life histories of North American birds of prey, part two. Dover Publications, Inc., N. Y. 482 p.

Berger, D. D., D. W. Anderson, J. D. Weaver, and R. W. Risebrough. 1970. Shell thinning in eggs of Ungava peregrines. Canadian Field-Naturalist 84(3): 265-267.

_______, C. R. Sindelar, Jr., and K. E. Gamble. 1965. The status of breeding peregrines in the eastern United States. p. 165-173. In Hickey, 1969.

Cade, T. J. 1971. Survival of the peregrine falcon: protection or management. Raptor Research News 5(2): 83-87.

_______, and R. W. Fyfe. 1970. The North American peregrine survey, 1970. Canadian Field-Naturalist 84(3): 231-245.

_______, M. C. White, and J. R. Haugh. 1968. Peregrines and pesticides in Alaska. Condor 70: 170-178.

_______, J. L. Lincer, C. M. White, D. G. Roseneau, and L. G. Swartz. 1971. DDE residues and eggshell changes in Alaskan hawks and falcons. Science 172: 955-957.

Craighead, F. C. Jr., and J. J. Craighead. 1956. Hawks, owls, and wildlife. The Stackpole Co., Harrisburg, Pa. 443 p.

Cramp, S. 1963. Toxic chemicals and birds of prey. Brit. Birds 56: 124-139.

Dawson, W. L. 1923. The birds of California, Vol. IV. South Moulton Co., San Francisco. p. 1549-2121.

Decker, F. R. and J. H. Bowles. 1930. The prairie falcon in the State of Washington. Auk 47: 25-31.

Dightman, R. A. 1960. Climates of the states: Montana. U. S. Dept. of Comm., Weather Bureau, Climatography of the U. S. no. 60-24. 20 p.

Enderson, J. H. 1964. A study of the prairie falcon in the central Rocky Mountain region. Auk 81: 332-352.

_______. 1965. Peregrine and prairie falcon life tables based on band recovery data. p. 505-509. In Hickey, 1969.

_______ and D. D. Berger. 1968. Chlorinated hydrocarbon residues in peregrines and their prey species from northern Canada. Condor 70: 149-152.

_______ and D. D. Berger. 1970. Pesticides: eggshell thinning and lowered production of young in prairie falcons. BioScience 20(6): 355-356.

Fowler, F. H. 1931. Studies of food and growth of the prairie falcon. Condor 33: 193-201.

Fyfe, R. W., J. Campbell, B. Hayson, and K. Hodson. 1969. Regional population declines and organochlorine insecticides in Canadian prairie falcons. Canadian Field-Naturalist 83(3): 191-200.

Hickey, J. J. (ed.) 1969. Peregrine falcon populations: their biology and decline. Univ. Wisc. Press, Madison. 596 p.

_______ and D. W. Anderson. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162: 271-273.

Koplin, J. R., D. L. MacCarter, and D. S. MacCarter. 1969. Flathead Lake osprey study. Unpubl. Prog. Rpt. No. 2, Univ. of Mont., Missoula.

Kupfer, D. 1967. Effects of some pesticides and related compounds on steroid function and metabolism. Residue Review 19: 11-30.

Lincer, J. L., T. J. Cade, and J. M. Devine. 1970. Organochlorine residues in Alaskan peregrine falcons (Falco peregrinus Tunstall), rough-legged hawks (Buteo lagopus Pontoppidan) and their prey. Canadian Field-Naturalist 84(3): 255-263.

McGahan, J. E. 1968. Ecology of the golden eagle. Auk 85: 1-12.

Nelson, M. W. 1965. The status of the peregrine falcon in the Northwest. p. 61-72. In Hickey, 1969.

Peakall, D. B. 1967. Pesticide-induced enzyme breakdown of steroids in birds. Nature 216: 505-507.

Ratcliffe, D. A. 1967a. The peregrine situation in Great Britain, 1965-66. Bird Study 14: 238-246.

_______. 1967b. Decrease in eggshell weight in certain birds of prey. Nature 215: 208-210.

_______. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. J. Appl. Ecol. 7: 67-115.

Reynolds, H. V. III. 1969. Population status of the golden eagle in south-central Montana. Unpubl. M.Sc. Thesis, Univ. of Mont., Missoula.

Seidensticker, J. V. IV, and H. V. Reynolds III. 1971. The nesting, reproductive performance, and chlorinated hydrocarbon residues in the red-tailed hawk and great horned owl in south-central Montana. Wilson Bull. 83(4): 408-418.

Skinner, M. P. 1938. Prairie falcon. p. 18-42. In Bent, 1961.

Sprunt, A. IV. 1965. Population trends of the bald eagle in North America. p. 347-351. In Hickey, 1969.

U. S. Department of Agriculture. 1968. Extent of farm pesticide use on crops in 1966. Agric. Econ. Rpt. No. 147. 23 p.

_______. 1970. Quantities of pesticides used by farmers in 1966. Agric. Econ. Rpt. No. 179. 61 p.

U. S. Department of Commerce, Bureau of the Census. 1967. Census of agriculture, 1964: statistics for the state and counties, Montana. U. S. Govt. Printing Office, Wash., D.C. 333 p.

_______. 1971. Census of agriculture, 1969: county data. Unbound.

U. S. Department of Commerce, Weather Bureau, 1971. Climatological data: Montana. 74(3-7): 45-178.

Webster, H. Jr. 1944. A survey of the prairie falcon in Colorado. Auk 61: 609-616.

Wiemeyer, S. N., and R. D. Porter. 1970. DDE thins eggshells of captive American kestrels. Nature 227: 737-738.

Woodwell, G. M., P. P. Craig, and H. A. Johnson. 1971. DDT in the biosphere: where does it go. Science 174: 1101-1107.

APPENDIX I. Pesticides and the birds of prey.

There is little doubt at this time that certain synthetic pesticides are at least partially responsible for the population declines of some species of raptors and fish-eating birds. Field observations and laboratory studies strongly implicate the DDT metabolite DDE as the main causative factor in a reproductive failure syndrome characterized by high pesticide residues in affected birds and the contents of their eggs, eggshell thinning, and hatching failure.

More recently, reports of the presence of dieldrin, the PCB's, and mercury in raptors have created new cause for concern. Although these chemicals probably have been significant pollutants for several decades, their discovery has added new complexity to the determination of the exact importance of specific contaminants.

DDT and other organochlorine insecticides are among the most thoroughly investigated pesticides, but scientific data cover only a few of their effects on about 1,000 of the estimated 200,000 possible nontarget species (Pimentel, 1971). Although several other chemical pollutants will be discussed briefly, the main purpose of this literature review is to summarize the information now known about the chlorinated hydrocarbons and their effects upon the birds of prey, thereby examining thoroughly one small but vital aspect of pesticides as environmental contaminants.

CHLORINATED HYDROCARBONS

In order to understand the problems involved with the organochlorine insecticides, one must first know something about their history and nature. Therefore, this and the following section will cover necessary background material before proceeding to the raptors *per se*.

History and Use

DDT was first used as an insecticide during World War II. Other types of organochlorine insecticides have been developed since then, including dieldrin, aldrin, endrin, lindane, chlordane, heptachlor, and others (Niering, 1968). The usage of these synthetic chemicals has spread to many countries in the past twenty years, millions of pounds having been applied annually on a worldwide basis. Statistics compiled by the U. S. Tariff Commission (In Woodwell *et al.*, 1971) show that DDT production in the United States reached a maximum of 179 million pounds in 1963. Production in 1970 fell by more than 50 percent. About 70 percent of the amount of DDT produced appears to have been used outside of the United States. Although no data is available, Woodwell *et al.* (1971) suggest that the amount of DDT produced in the world is approximately twice that produced in the United States.

Another group of chlorinated hydrocarbons expected to be of greater signifiance than formerly realized is the polychlorinated biphenyls (PCB), industrial products used in certain manufacturing processes (Risebrough, 1968).

Because DDT has been the most heavily used and intensively studied chlorinated hydrocarbon, much of this paper deals primarily with it and its metabolites. One should keep in mind, however, that the properties of the other organochlorines are generally similar and might be expected to have similar ecological effects.

Properties

Although intended primarily as insecticides, the chlorinated hydrocarbons are highly toxic to a broad range of living organisms. Being nerve poisons, they cause instability of the nerve axons, acute poisoning causing tremors and convulsions (Wurster, 1969). Sublethal doses have been shown by O'Brien (1967) to result in increased nervousness, hyperactivity, and abnormal behavior. In addition, recent studies indicate that sublethal doses can also change the breeding cycles of many animals by inducing liver enzymes to break down steroid sex hormones (Conney *et al*., 1967; Kupfer, 1967; Peakall, 1967).

Chlorinated hydrocarbons have a half-life of approximately 10 to 15 years or more and are not readily metabolized aerobically (Edwards, 1966; Woodwell *et al*., 1971). While the liver can slowly degrade DDT to DDE and DDD, these metabolites, although less toxic than DDT, can still effect steroid breakdown (Conney *et al*., 1967; Kupfer, 1967). The stability of organochlorines in the environment is a factor of major importance in ecological considerations.

DDT is virtually insoluble in water. Dieldrin, 100 times as soluble, must still be considered as being almost insoluble (Edwards, 1966). All chlorinated hydrocarbons, however, are very soluble in organic solvents and fatty materials and are, therefore, soluble in biological material of almost any kind. The flow of organochlorines in an ecosystem is thus from the abiotic to the biotic (Wurster, 1969).

RESIDUES IN THE ENVIRONMENT

The stability of the chlorinated hydrocarbons insures that once they are applied they will remain in the environment for many years. This has been considered a desirable quality for an insecticide. Unfortunately, much of the pesticide used never reaches its target in the first place, and most of that which does will eventually leave it. For example, it is common for less than fifty percent of aerially applied sprays to reach the intended site of application (Pillmore and Finley, 1963).

Furthermore, organochlorines are somewhat volatile and enter the atmosphere by evaporation from soil (Decker, 1966) and codistillation with water (Bowman _et al._, 1964). They also form suspensions in water and adsorb to particulate materials (Edwards, 1966). Once in the air, they are carried rapidly around the world, settling out in oceans, mountains, and cities alike (Risebrough _et al._, 1968a). Woodwell _et al._ (1971) state that the pattern of movement of DDT residues through the world ecosystem appears to be from the land through the atmosphere into the oceans and into the oceanic abyss.

It is easy to see, then, why the organochlorines are so widespread and how they can be picked up by many organisms. They have, in fact, been reported in the tissues of resident animals in both the Arctic (Cade _et al._, 1968) and the Antarctic (Sladen _et al._, 1966).

RESIDUES IN THE RAPTORS

One might ask at this point why the raptors seem to have been more seriously affected by chlorinated hydrocarbons than most other animals. The answer lies in a phenomenon called biological magnification, or, more plainly, the accumulation and concentration of residues up the food chain (Cottam, 1969; Hickey, 1969; Hickey and Anderson, 1968).

For instance, an animal low on the food chain ingests or otherwise takes small amounts of DDT into its body. This DDT and its metabolites are stored in the fatty tissues, and, if the animal is eaten by a predator or scavenger, these accumulated residues are in turn transferred to and stored in the lipids of the feeding animal. Residues are thus concentrated in the carnivores at the top of the food chain, a category which includes the birds of prey.

Presence of Insecticide Residues

Numerous studies have confirmed the idea of biological magnification by showing that the amount of residues found in birds is related to food habits, the raptors and fish-eating birds having higher organochlorine accumulation than herbivorous birds (Moore, 1965; Holmes *et al.*, 1967; Cottam, 1969). Ratcliffe (1965) found that eggs of peregrines (*Falco peregrinus*), merlins (*F. columbarius*), golden eagles (*Aquila chrysaetos*), buzzards (*Buteo buteo*), and kestrels (*F. tinnunculus*) in Great Britain contained more residues than those of five species of omnivorous corvid birds. Concentrations in the eggs averaged from 1.0 to 13.8 ppm for the raptors and from 0.4 to 0.8 ppm for all the corvids except the largely carnivorous raven at 2.1 ppm.

The chlorinated hydrocarbon residues found in eggs and chicks of Alaskan peregrine falcons averaged 10 to 100 times the concentrations found in prey species; the concentrations in whole adults were at least 100 times that of their prey, primarily vegetarian and insectivorous birds (Cade _et al._, 1968). It also was determined in the same study that adult peregrines had residue concentrations 10 to 20 times higher than juveniles but that the juveniles quickly acquired higher residue levels than their food species. Working with peregrines in northern Canada, Enderson and Berger (1968) found that mean residues of DDE in breeding adults was 284 ppm compared to 14.0 ppm in migrant immatures and 0.66 ppm in some potential prey.

A Canadian survey of residues in the eggs of 13 species of raptors showed that those that eat birds are more contaminated than those that eat mammals, the bird and mammal prey showing correspondingly lower residue levels (Keith, 1971). The reason for this occurrence seems to be that the mammals, mostly small rodents, are primary consumers low on the food chain, whereas many of the avian prey species are secondary consumers or predators themselves.

Similarly, Lincer _et al._, (1970) determined that the resident small mammals constituting the prey of Arctic-breeding, rough-legged hawks (_Buteo lagopus_) contained one-tenth to one-twentieth as much DDE as the peregrine falcon's migratory avian prey, and that these and higher residue ratios were repeated in the roughlegs and peregrines themselves. For example, the mean DDE levels (dry weight) for brains and eggs of peregrines were 58.2 ppm and 131 ppm, respectively, while those for roughlegs were 0.67 ppm and 7.07 ppm.

Birds with similar feeding habits living in widely separated areas often have similar residue concentrations. For example, osprey (*Pandion haliaetus*) eggs from Maryland and Connecticut contained residues of the same magnitude as eggs of English estuarine birds (Stickel, 1968), and bald eagles (*Haliaeetus leucocephalus*) and brown pelicans (*Pelecanus occidentalis*) in the United States (Stickel, 1968) had high concentrations similar to herons in Great Britain (Moore and Walker, 1964). The widespread occurrence of organochlorine insecticide residues in the birds of prey could be illustrated further, but the above examples should serve to demonstrate the point sufficiently.

Little has been said thus far about the specific residues most often found in declining raptor populations. Although dieldrin, heptachlor expoxide, and other insecticides and their metabolites usually are present, DDE frequently constitutes as much as 90 to 95 percent of all residues (Berger *et al.*, 1970; Cade *et al.*, 1971) and is almost always the largest residue component found (Fyfe *et al.*, 1969; Enderson and Berger, 1970).

Polychorlinated Biphenyls

As mentioned previously, the various PCB compounds are also chlorinated hydrocarbons and have properties similar to the organochlorine insecticides. Used commercially in electrical transformers and condensers and in manufacturing certain plastics, they are somehow spread through the environment as industrial effluent and finished products alike (Holmes *et al.*, 1967). Although production figures are largely unknown, production of PCB's in the United States may amount to as much as hundreds of millions of pounds annually, and their presence in the world ecosystem appears to be in quantities similar to DDE (Dustman *et al.*, 1971).

Long presented as unknown peaks in organochlorine chromatography analyses, PCB's were first identified in wild animal tissues on a mass spectrograph by Jensen in Sweden (Jensen, 1966, 1970). When present, they can be confused with DDD, DDT, and TDE, but DDE values undergo virtually no change by PCB separation (Lincer *et al.*, 1970; Dustman *et al.*, 1971; Keith, 1971). Arochlor 1254 is the PCB mixture making up the greatest proportion of PCB compounds found in the tissues of wild birds (Dustman *et al.*, 1971).

Holmes *et al.* (1967) found PCB's in the residues of various birds, including kestrels and golden eagles. In this research, the PCB compounds detected frequently were found to be in higher concentration than the organochlorine pesticides. Similar high concentrations have been found in some of the fish and birds of San Francisco Bay and lower concentrations have been found in wide-ranging oceanic birds (Risebrough, 1968). That PCB's undergo biological magnification was illustrated by Jensen *et al.* (1969) when they showed that residues in fish were measured in hundreds to tenths of ppm, while residues in the muscle of white-tailed eagles (*Haliaeetus albicilla*) measured from 150 to 240 ppm.

Measurements made by the Patuxent Wildlife Research Center show that the median PCB residues in 12 Alaskan bald eagle eggs were only 1.65 ppm whereas the median for 11 eggs from Maine, Michigan, Minnesota, and Florida was 9.7 ppm (Dustman *et al.*, 1971). In this same survey, osprey eggs from Connecticut contained a median concentration of 15.9 ppm while eggs from Maryland ospreys had a median concentration of only 2.5 ppm. Adipose tissues biopsied from 10 tundra peregrines by Risebrough et al. (1970) contained 17.9 ppm DDE and 52.2 ppm PCB. On the other hand, 7 merlins from the boreal forest averaged more DDE than PCB, possibly indicating a differential pollutant fallout pattern.

Risebrough et al. (1970) state that there is often a high correlation between DDE and PCB concentrations and that they show similar patterns of accumulation, concentration, and excretion. Research to date has shown no definite connection between the PCB's and raptor population declines, but the potentialities are clear. More research is needed, however, before drawing any conclusions.

Heavy Metals

Other pollutants thought by some researchers to be possible factors in raptor population declines include the heavy metals mercury and lead. Mercury is used as a fungicide in treating the seeds of many grain crops and is ingested by a variety of seed-eating birds and mammals constituting the main prey of some raptors (Fimreite et al., 1970). Birds of prey such as the peregrine falcon that feed upon ducks that have ingested shotgun pellets may, in turn, accumulate high concentrations of lead (Risebrough et al., 1970). It is upon the more widespread occurrence of mercury, however, that scientific investigation has been focused.

Analyses of feathers from goshawks (*Accipiter gentilis*) in Swedish museum collections showed that a sudden rise in mercury levels occurred in 1940, the same year that alkyl mercury seed dressings were introduced in that country (Johnels, 1970). Borg et al. (1969) examined 412 raptors and found that 62 percent had mercury levels in the liver exceeding 2 ppm, 36 percent had residues exceeding 5 ppm, 19 percent had residues exceeding 10 ppm, and 11 percent had residues exceeding 20 ppm.

Fimreite _et al._ (1970) showed that Alberta and Saskatchewan seed-eaters and their avian predators contained much higher levels of mercury in areas where mercury seed dressings were most commonly used. Furthermore, falcons and accipiters that feed most heavily upon birds were found to have much higher mercury concentrations than eagles, buteos, and harriers that prey largely upon rodents. This difference would be expected because the mercury levels in the avian prey were higher than in the rodents. The eggs of prairie falcons (_F. mexicanus_) and merlins in particular had consistently high residue concentrations.

PREDATOR-PREY RELATIONSHIPS

Another relatively unknown but potentially significant aspect of pesticide-raptor relationships is the delicate but dynamic relationship between raptors and their prey. Studies by Craighead and Craighead (1956) have shown that high raptor densities usually are associated with high prey densities and increased prey vulnerability. Pesticides can affect both of these factors in several ways.

There have been many documented instances of DDT killing large numbers of birds and fish (Tarzwell and Henderson, 1957; Keith, 1966), and it is likely that rodent populations have been depleted from time to time, also. Predators depending upon the availability of such animals for food must leave the treated area with its reduced prey populations or face possible starvation. For example, a Cooper's hawk (_A. cooperii_) with no birds to eat or a kestrel that can find no insects or mice would have to fly elsewhere to find new food supplies.

To take this idea a step further, insectivorous birds have been observed leaving an area sprayed for insects (Rudd, 1964). In such a case, a Cooper's hawk might be forced to move from an area just as surely as if its food source had been exterminated rather than merely having migrated. Rudd (1964) believes that the temporary reduction in the number of predators in a sprayed area is due to this kind of behavior more often than to direct toxic effects.

There is suspicion that the vigor of animals in areas of heavy pesticides application is often low (Rudd, 1964). Certainly, animals with acute poisoning symptoms would not be as wary or agile as healthy animals, and would thus be more vulnerable to predation; fish rising to the surface of a poisoned lake or stream would present easy targets for ospreys or bald eagles, and so on.

Evidence for this type of interaction might be implied from the findings of Reynolds (1969, unpubl.), who determined that jackrabbits taken by golden eagles contained higher levels of organochlorine insecticide residues than jackrabbits which he shot. In other words, it is possible that raptors might feed more heavily than expected by random chance on the individuals most seriously contaminated by pesticides, thus accumulating more residues than normally would be expected.

Another interesting consideration concerning pesticides and predator-prey relationships comes to light when one notes the regional intra-species variations in residue loads found in studies such as the prairie falcon research of Fyfe *et al.* (1969). That is, certain areas within a larger region may have birds that are much more or less contaminated than those in other nearby areas.

While local differences in pesticide-use patterns may explain part of this phenomenon, it also is likely that local food preferences might vary. For example, prairie falcons in one area might prey predominantly upon rodents with low residue levels whereas the same species in another area might prey most upon highly contaminated birds. Such differences could easily be the result of corresponding differences in the availability of prey in each area.

MORTALITY

According to Rudd (1964), delayed expression of toxicity of pesticides may be described as the transferral of chemicals along a food chain in a way that kills only the terminal member of that chain. That is, accumulation of persistent pesticides such as the chlorinated hydrocarbons may not reach a level high enough to cause death until accumulated additively by a tertiary carnivore such as a bird of prey. This type of poisoning may be aggravated by weight loss, starvation drawing upon fat reserves and thus decreasing the buffering effect of the lipids in storing the pesticides and shielding the nervous tissues from them (Durham, 1967).

Delayed expression has undoubtedly killed many birds, but discovery of these birds and determination of the actual cause of death has been difficult and often uncertain (Hickey, 1969). While good field data on this problem are, therefore, quite scarce, it is not expected that this factor alone could be the primary cause of the long-term decline of most raptor populations (Cramp, 1963).

On the other hand, Ratcliffe (1963, 1970) has long contended that the sudden population declines of British peregrines and sparrow hawks (A. nisus) after 1955 involved unusually heavy adult mortality, and that declines in breeding success helped to prevent recovery. These declines began very shortly after introduction of such highly toxic insecticides as dieldrin into agricultural use.

Laboratory and field analyses by Turtle et al. (1963) supported the conclusion that mixtures of aldrin, dieldrin, endrin, and heptachlor used as seed dressings were the main cause for unprecedented wood pigeon deaths in Britain between 1956 and 1961. It follows logically that high residue loads were transferred to bird-eating raptors preying upon the pigeons and other avian seed-eaters.

In a similar situation in the Netherlands (Fuchs, 1967), many birds of prey were found dead after the sowing of organochlorine-treated seed. Another agricultural use of dieldrin -- as sheep dip -- is suspected to have been a factor in increased adult mortality and the population decline of golden eagles in western Scotland (Lockie et al., 1969).

Hickey (1970) states that the peregrine falcon population of the eastern United States would have dropped only 10 percent per year had the decline been due to reproductive failure alone. Instead, from 1947 to 1960, the annual decline was over 20 percent, thus indicating that an unrecorded increase in adult mortality must have occurred. Hickey uses more field evidence by citing Pennsylvania Cooper's hawks and Connecticut ospreys as examples of other raptor populations that probably fell due to increased adult mortality rates in conjunction with reproductive failure.

Still, there is no experimental evidence on delayed mortality with which to prove these hypotheses, and, as mentioned before, even good field data are rare. Various studies now have established a few minimum residue levels in the brain that may be used as reliable indications of organochlorine poisoning deaths in a variety of animals, including raptors (Stickel, 1968; Pimental, 1971). It is hoped that this information will encourage better monitoring in the future so that this particular aspect of the pesticides problem will be more fully understood. Such understanding will become increasingly important as raptor populations continue to fall; mortality caused by delayed expression would be especially critical in the scarcer or less adaptable species where even a small decline in numbers could be significant.

POPULATION CHANGES

Downward Trends

Earlier statements referred to the plight of the peregrine falcon population of Great Britain (Ratcliffe, 1967a) and the virtual extermination of the peregrine as a breeding species in the eastern United States (Berger *et al.*, 1965). These, together with the bald eagle, were among the first raptors recognized as suffering widespread and devastating population declines of an unprecedented nature.

Time and research have shown clearly that there have been other similar declines. The downward trend for the peregrine, in fact, is also true for most of Western Europe and the western United States, declines ranging from about 50 percent to over 80 percent in the last ten years (Hickey, 1969).

Not long ago thought to be maintaining a stable population (Cade _et al_., 1968; Enderson and Berger, 1968), even the peregrines of relatively pristine Arctic and boreal North America now are known to be undergoing a decline (Cade and Fyfe, 1970). Both tundra and Taiga populations apparently have fallen locally since 1966, and, of 82 known former eyries in the more southern portions of Canada, only 4 were occupied during the 1970 breeding season. These declines have been accompanied by concurrent reproductive failure, with up to 72 percent of active eyries failing on the Colville River in Alaska (Cade _et al_., 1971).

In addition to the peregrine, the British sparrowhawk, a once common accipiter, has suffered widespread declines, and the kestrel and golden eagle have shown marked decreases in parts of their ranges (Prestt, 1965). An illustration of the severity of some of these declines is provided by the golden eagles of the Scottish Highlands, where the number of pairs fledging young fell from 72 percent during 1937-60 to 29 percent during 1961-63 (Lockie and Ratcliffe, 1964). Other British raptors have declined at a slower rate over a longer period of time (Prestt, 1965).

Although well publicized, it seems unlikely that most people have realized fully the extent of the decline of the bald eagle, our National Emblem. The National Audubon Society began an intensive survey of the status of this fish eagle in 1960 and has compiled some frightening statistics. Outside of Canada, Alaska, and portions of the Rocky Mountain States, the decline of the breeding populations since 1942 has exceeded

50 percent in some regions, has reached 90 to 100 percent in others, and has been accompanied by nesting failures of 55 to 90 percent (Sprunt, 1965). Perhaps as few as 600 Southern bald eagles still survive (Cottam, 1969). It is important to note that the decline in numbers is paralleled by a marked lowering in reproductive success, for this trend is common to all raptors now suffering widespread population declines.

Another large fish-eating raptor, the osprey, is also in serious trouble. The breeding population of the Atlantic coast from New Jersey to Maine has decreased catastrophically: 95 percent in New Jersey since 1960; 80 percent in a ten-year period in Massachusetts and Maine (Peterson, 1965). Peterson (1965) reported hatching failures of up to 81 percent and has predicted the possible extirpation of the osprey in Connecticut by 1974, a view supported by data from Ames and Mersereau (1964) which shows a decrease in nesting pairs on the Connecticut River from about 220 in the early 1940's to 24 in 1963, and to 12 in 1965 (Ames, 1966). Decreasing populations and reproductive success have also been reported for Michigan, Wisconsin, Germany, and France (Hickey, 1969), and for western Montana on Flathead Lake (Koplin _et al_., unpubl.).

The Cooper's hawk was the most common bird of prey in western Pennsylvania twenty years ago. It is now one of the rarest (Schriver, 1965). Prairie falcons have declined in Canada, there being a 34 percent reduction in occupancy of known territories over a 10-year period (Fyfe _et al_., 1969). Furthermore, the merlin population apparently has disappeared in part of Saskatchewan (Fyfe, 1971). Additional research likely will show more raptors declining in more areas on a worldwide basis.

Causes of Declines

This brief summary gives a good indication of the magnitude of some of the raptor declines. Because natural decimating factors such as disease and predation upon young have always been in effect, it seems unlikely that they would cause more than relatively isolated short-term declines. The blame, then, falls upon man and his interference in the ecosystem. There are a number of human factors which probably have had adverse effects, but evidence now points most strongly to the role of chlorinated hydrocarbons in reproduction failures as the main causative factor in these population crashes. Mention of several other factors will be made here, however, because of their interest and local importance.

One of the most obvious factors that might affect some raptors is the outright destruction of nesting sites and feeding areas. Housing developments along waterways and under cliffs and modern farm monocultures are examples of this (Cramp, 1963; Hickey, 1969), but birds are declining in remote areas. Mere proximity to man may scare away some birds, but some raptors, such as the osprey, are tolerant of man's presence (Peterson, 1965). Shooting and trapping kill many raptors (White, 1965), but, in some regions, they receive no such harassment. This list could be extended, but none of these tentative explanations can account for the biggest and most widespread problem; that is, the failure of eggs to hatch.

On the other hand, circumstantial evidence linking the organochlorines with raptor declines is strong. Residue concentrations in the birds of prey and other declining bird populations generally are higher than in more stable species (Stickel, 1968). This is due to biological magnification.

A second link is the correlation in timing between large scale pesticide use and the beginning of the first noticeable declines; that is, use of the chlorinated hydrocarbon insecticides started during World War II and increased throughout the 1950's, and the general declines of several species were observed first in the mid-1950's (Cramp, 1963; Prestt, 1965; Ratcliffe, 1970). Finally, in Great Britain at least, the areas of greatest raptor decline are closely associated with the areas of greatest pesticide use (Cramp, 1963; Prestt, 1965; Ratcliffe, 1970).

REPRODUCTION FAILURE

Organochlorine Insecticides - Field Studies

An even more direct clue to the relationship between the organochlorines and reproduction in raptors was provided by Ames' (1966) study of ospreys. The eggs of Connecticut birds contained 5.1 ppm of DDT residues and productivity was 0.5 young per nest. Eggs of Maryland ospreys contained 3.0 ppm of residues and productivity was 1.1 young per nest. Normal productivity traditionally has been approximately 2.4 young per nest. Both of these populations have declined, but the Connecticut birds are down more and it has been found that the fish they eat have DDT residue concentrations from five to ten times higher than the fish eaten by the Maryland birds.

More recently, an Audubon Society survey of bald eagles in Maine revealed that only 8 out of 30 active eyries produced young (Conservation News, 1970). According to additional Audubon Society statistics, while it would take 100 pairs of Maine eagles to produce only 35 young, 100 pairs of Florida eagles would produce 70 young, and the same number of Wisconsin and Alaskan birds would produce 80 and 104 offspring, respectively. Especially interesting are the corresponding levels of DDT residues found in eagle eggs from these same states: 23 ppm for Maine, 11 ppm for Florida, 5 ppm for Wisconsin, and 2 ppm for Alaska. In other words, the reproductive success is lowest where the residue levels are highest.

Although not associated with pesticides at first, instances of egg breakage, egg eating, and nest abandonment by breeding adults were observed in peregrine falcons soon after the beginning of heavy DDT usage (Ratcliffe, 1958; Herbert and Herbert, 1965). This type of abnormal behavior has increased and has been documented for most other raptors known to be suffering declines (Lockie and Ratcliffe, 1964; Ames, 1966; Ratcliffe, 1967b). There is close correlation between these field observations and the results of studies by researchers measuring eggshell thickness of selected raptors and fish-eating birds.

Reports indicate that the eggs of the birds of prey hardest hit by declines have undergone sudden and widespread decreases in shell thickness and weight. For example, the eggs of British peregrines, sparrowhawks, and golden eagles underwent a seven to twenty-five percent reduction in shell thickness during 1946-50 compared to eggs from 1904-46 whose calcium content was stable (Ratcliffe, 1967b). Ratcliffe (1970) found a strong correlation between geographical variations in degree of chlorinated hydrocarbon contamination, amount of change in eggshell weight, and frequency of egg breakage. Recent eggs from peregrines suffering such reproductive failure contained an average of 13.7 ppm DDE in the fresh weight contents.

Hickey and Anderson (1968) described similar occurrences during the same period of time in the United States for peregrines, bald eagles, and ospreys. Once again, the years of eggshell thinning and population decline coincided with widespread introduction of organochlorine pesticides into the environments of the regions studied. In this same research, a regression analysis run between shell thickness and DDE residues in herring-gull eggs showed a strong negative correlation: the more DDE found, the thinner the eggshells.

Peregrines of Arctic and boreal North America also are suffering from the thin-eggshell syndrome. Diminishing reproductive success has been accompanied by a 15 to 20 percent decrease in eggshell thickness since 1947, and populations have declined locally since 1966 (Berger _et al._, 1970; Cade and Fyfe, 1970). There is, again, a highly significant negative correlation between DDE levels in egg contents and the thickness of eggshells.

That changes in eggshell thickness seem to be directly correlated with differences in degree of exposure to DDE contamination is illustrated well by the research of Cade _et al._ (1971) in Alaska. Eggshells are reported to have undergone the following reductions in thickness: tundra peregrines, 21.7 percent; taiga peregrines, 16.8 percent; Aleutian peregrines, 7.5 percent; rough-legged hawks, 3.3 percent; gyrfalcons

(F. rusticolus), none. DDE residues in eggs ranged from a high of 889 ppm (lipid basis) for tundra peregrines to a low of 3.88 ppm for gyrfalcons, the levels for the hawks in between corresponding proportionately to the varying degrees of observed eggshell thinning. The major prey species of each of these hawks likewise carried organochlorine residue loads more or less proportional to the levels found in the raptors that eat them.

Reproduction in prairie falcons also appears to have been affected adversely by organochlorine insecticides. Enderson and Berger (1970) state that thinner eggs have accompanied lower hatching success of Colorado and Wyoming prairie falcons. DDE residue levels found in northern peregrines coincide with very thin shells in prairie falcons. A study of Canadian prairie falcons by Fyfe et al. (1969) substantiates these findings by revealing that high DDE levels in eggs, thin eggshells, decreased production, and declining populations are correlated events in portions of Alberta and Saskatchewan.

Although minor changes in eggshell thickness have been reported for many other raptors and fish-eating birds (Anderson and Hickey, In press), not all of these changes have had obvious effects at the population level. It now seems evident that significant reproductive failures are correlated with a mean decrease of 20 percent or more in shell thickness and weight (Anderson and Hickey, In press).

The relationship of concentrations of DDE in eggs to the thinning of eggshells of brown pelicans was essentially linear ($P < 0.01$) on a logarithmic residue scale. This indicates that shell thickness decreases in a predictable manner as DDE concentration increases, and that the percentage change was greater per unit of DDE when the concentration of DDE was lower. This relationship follows mathematically similar patterns in different species, but operates at different levels in different species. Brown pelicans and prairie falcons both seem to be unusually susceptible to shell thinning, a 15 percent thinning being associated with DDE residues between 4 and 5 ppm (Blus et al., 1972; Fyfe et al., 1969, Cited in Blus et al., 1972).

The significance of pesticide residue levels in eggs is still uncertain. At this time, probably the most important aspect of residue loads in eggs is as an indication of circulation levels in ovulating females (Lincer et al., 1970). Enderson and Berger (1970) found a weak positive correlation between DDE in the fat of female prairie falcons and their eggs. The correlation coefficient for the same relationship with dieldrin was 0.87 (n = 44). It would seem, then, that egg contamination might, indeed, serve as a convenient and acceptable indication of parental contamination.

Organochlorine Insecticides - Laboratory Studies

The main problem with thin-shelled eggs is that they cannot be incubated properly, the weight and movements of incubating adults cracking or completely breaking them and thereby killing developing birds. Although more controlled experiments must be performed before absolute statements may be made, enough evidence has been accumulated to formulate the probable mechanism causing changes in the shells.

In breeding birds, calcium is absorbed from food, deposited in the bone marrow, and transported from the marrow to the oviduct, where it becomes a crucial part of the eggshell. This process is regulated by the steroid sex hormone estrogen, a subnormal level of which interrupts this vital part of the reproductive cycle (Simkiss, 1961; Taylor, 1970).

Working with pigeons, Peakall (1967) showed that DDT and dieldrin stimulate the liver to produce enzymes that destroy steroid sex hormones. Taking this idea a step further, he suggested that increased metabolism of estrogen could lead to thin-shelled eggs and possibly cause population declines such as those observed in the birds of prey. Conney _et al._ (1967) observed similar results in laboratory animals that accumulated only 10 to 15 ppm of DDT in their fat, stating that "The stimulating effect of halogenated hydrocarbon insecticides on steroid hydroxylation possibly explains the effect of these pesticides to decrease fertility in experimental animals."

Several studies now tend to confirm these hypotheses. Japanese quail fed DDT in the concentration of 100 ppm produced eggs with thinner shells and lower calcium content than normal (Bitman _et al._, 1969). Although the organochlorine concentration was high, the accumulated residues in lipids were still only 1,561 ppm compared to levels of 2,600 ppm and higher found in some wild peregrine falcons.

The research of Heath _et al._ (1969) is especially revealing. Penned mallard ducks (_Anas platyrhynchos_) were fed DDT, DDD, and DDE in concentrations ranging from 10-40 ppm in dry feed. DDT and DDD both impaired reproductive success, but not as severely as DDE, which caused eggs to be 13 percent thinner and 25 percent more liable to crack than the eggs of control birds. All three residues increased embryo mortality in uncracked eggs. Total duckling production was reduced as much as 75 percent by DDE.

As important as the above-mentioned studies are, they do not deal directly with the birds of prey. Wiemeyer and Porter (1970) have done much to fill in this gap by performing similar experiments with American kestrels (*F. sparverius*). They placed 12 pairs of hawks on a diet containing 10 ppm DDE on a dry weight basis, a level of contamination commonly found in prey of wild raptors (Keith and Hunt, 1966; Cade *et al.*, 1968; Risebrough *et al.*, 1968a). The birds first laid eggs from one day before to several weeks after dosage began, the eggs containing an average of 3 ppm DDE. After remaining on dosage for approximately one year, the hawks laid eggs again, this time containing an average of 30 ppm DDE. Eggs of control birds contained an average of less than 1 ppm both years. The mean shell thickness of eggs laid by the DDE-dosed hawks was 10 percent thinner the second year than the first. Thus, DDE is implicated further as an important causative factor in eggshell thinning in the birds of prey.

Earlier research by Porter and Wiemeyer (1969) showed that eggshell thinning and egg disappearance in kestrels could be induced by feeding them a diet containing DDT and dieldrin. It is now suspected, however, that DDE metabolized from the DDT and stored in the birds' tissues probably contributed to the thinning of these eggshells (Wiemeyer and Porter, 1970).

The effects of dieldrin in combination with DDT and/or its metabolites is unknown. A stepwise linear regression used by Blus *et al.* (1971) to test the relationship of chemicals to eggshell thinning in brown pelicans showed the DDE, not dieldrin, accounted for differences in thickness. Correlations between dieldrin and shell condition were spurious because of similar patterns of contamination for the 2 chemicals.

Although not a laboratory experiment, a controlled field study by Enderson and Berger (1970) may shed some light on the role of dieldrin in the thinning of raptor eggshells. Wild prairie falcons were fed tethered starlings highly contaminated with dieldrin. Eggs from dieldrin-treated falcons proved to be thinner and much less likely to hatch when dieldrin exceeded 20 ppm (dry weight) in egg contents. However, eggs with less than 20 ppm dieldrin from treated birds were not significantly different from eggs of the control group. Eggs exceeding 20 ppm dieldrin averaged 41.5 ppm, or 22 times the untreated group mean of 1.9 ppm. On this basis, it would seem unlikely that dieldrin contributes significantly to eggshell thinning in wild birds of prey.

On the other hand, dieldrin caused significant eggshell thinning when fed to penned mallard ducks in dry feed at 1.6, 4.6, and 10 ppm concentrations (Lehner and Egbert, 1969). This could mean either that effects differ between species, or that variations in the experimental procedures used affords no valid comparison. Whatever the reason for such apparently contradictory results, it is clear that much more evidence must be gathered before drawing conclusions.

Eggshell thinning is a vital aspect of reproductive failure caused by organochlorine insecticides, but other possible causes of embryo and chick mortality must not be overlooked. Dunachie and Fletcher (1969) injected chicken eggs with varying doses of different chlorinated hydrocarbon insecticides. Starvation experiments on recently hatched chicks were carried out for each insecticide until 50 percent of the controls died. Endrin and aldrin were the most lethal, chicks hatched from eggs injected with 5 ppm of either residue showing complete mortality by the fifth day. Chicks hatching from eggs contaminated with 100 ppm DDT all died in four days.

Implications of this research are easily related to field situations. For instance, availability of prey in the wild is occasionally uncertain, and raptor chicks contaminated with even relatively low levels of certain pesticides possibly could undergo enough stress due to lack of food to die when normally they would have survived. As always, more research is needed.

Polychlorinated Biphenyls

The presence of PCB's in many fish-eating birds and birds of prey undergoing population declines has led some researchers to suggest that these pollutants might be contributing to the reproductive failures associated with the declines (Risebrough *et al.*, 1968b). To date, however, no such cause and effect relationship has been shown.

Evidence now suggests that PCB's at least do not contribute to the eggshell thinning commonly symptomatic of reproductive failures of the type apparently caused by DDE. No correlation between PCB's and shell thinning was found in eggs of white pelicans (*P. erythrorhynchos*) (Anderson *et al.*, 1969) or in eggs of great blue herons (*Ardea herodias*) (Vermeer and Reynolds, 1970). Statistical analyses of brown pelican eggs have shown that DDE residues correlate better with eggshell thinning than do residues of PCB's (Risebrough *et al.*, 1970; Blus *et al.*, 1971).

Furthermore, Anderson *et al*. (1969) make the interesting observation that while there is a correlation between PCB's and shell thinning in double-crested cormorants (*Phalacrocorax auritus*), PCB's are also correlated with DDE. Blus *et al*. (1971) confirmed this intercorrelation of residues, stating that DDE was the only residue that accounted for significant amounts of variability in eggshell thickness in brown pelicans.

Results of controlled experiments are mixed, but largely substantiate these findings in the field. Dietary levels of 25 and 50 ppm of Arochlor 1254 fed to mallards and bobwhite quail (*Colinus virginianus*) over two breeding seasons produced no significant change in eggshell thickness (Heath *et al*., In press). In addition, the number of eggs laid, hatachability of eggs, and survival of young were similar in both treated and untreated birds.

Dahlgren and Linder (1971) gave pheasants (*Phasianus colchicus*) 50 mg doses of Arochlor 1254 weekly for seventeen weeks. Breeding birds produced eggs with shells of normal thickness, but fewer eggs were laid, and hatching success and chick survival rates were less than those of controls. Tests by the Industrial Bio-Test Laboratories (In Dustman *et al*., 1971) showed that Arochlor 1242 at 10 or 100 ppm and Arochlor 1254 at 100 ppm in the diet of chickens decreased egg production and hatachability and caused thin eggshells.

Experimental studies with pigeons (Risebrough *et al*., 1968b) and kestrels (Lincer and Peakall, 1970) show that PCB's can induce microsomal enzyme activity which causes increased breakdown of estradiol. Lincer and Peakall (1970) suggest that the physiological actions of PCB's are similar to those of DDT and its metabolites. Risebrough *et al*.

(1970) hypothesize further that if PCB's can cause lower concentrations of estradiol in the blood and that if they can delay egg laying as has been reported for DDT in ringdoves (Peakall, 1970), then delayed breeding might possibly be an environmental effect of PCB's. Such an effect could be especially critical to Arctic-breeding birds with limited time in which to complete their reproductive cycles.

Studies of PCB's are as yet too inconclusive to make positive statements concerning their possible roles in population declines of predatory birds. Until more data become available, however, they must continue to be viewed as a potential environmental problem.

Mercury

Large numbers of seed-eating and raptorial birds have been found dead in Sweden of mercury poisoning (Borg *et al*., 1969). Direct mortality of birds has not yet been documented in North America, but widespread mercury contamination has been revealed for a variety of Canadian prairie wildlife, including birds of prey (Fimreite *et al*., 1970).

Because mercury is persistent and undergoes biological magnification, raptors would be expected to be especially vulnerable to potential poisoning in the field. A study by Fimreite and Karstad (1971) demonstrated that a steady dietary intake of cockerel chicks containing 7 to 10 ppm of methyl mercury in the liver may kill red-tailed hawks (*B. jamaicensis*). Mercury levels ranged from 17 to 20 ppm in the hawks that died. This level is well below the levels of 67 to 171 ppm found by Borg *et al*. (1969) to be lethal in pheasants, and indicates differences either in experimental procedures or in the tolerance levels of the two species.

As with the oranochlorine insecticides, it is possible that mercury might have such sub-lethal effects upon raptors as reduced productivity. There is as yet, however, no evidence linking mercury to the thin-eggshell syndrome. No correlation was found between eggshell thickness and mercury content in 59 Canadian prairie falcon eggs (Fimreite et al., 1970).

Pheasants kept under experimental conditions by Fimreite (1970) had levels of mercury in their livers ranging from 3 to 13 ppm and laid eggs containing 0.5 to 1.5 ppm of mercury. These eggs had significantly lower hatachability than controls. Borg et al. (1969) noted similar results. Interestingly, four unhatched Canadian prairie falcon eggs were found to contain mercury levels ranging from 0.9 to 1.7 ppm, or well within the range having had adverse effects upon reproduction in pheasants (Fimreite et al., 1970). Finally, as is the case for all environmental contaminants, possible synergistic effects with other pollutants must be considered as a potential problem.

SUMMARY

Further physiological and reproduction experiments undoubtedly will be conducted with raptors and other birds to establish positively the mechanisms involved in reproductive failures and other possible causes of local and widespread population declines. Much more field investigation is required. Meanwhile, one must rely upon the evidence at hand. The implications are clear -- chlorinated hydrocarbon insecticides either have exterminated, or are on the verge of exterminating, many birds of prey in large portions of their former ranges. In a few cases, complete extinction is within the realm of possibility.

The DDT metabolite DDE has been demonstrated to cause reproductive failures of the kind associated with these population crashes. Although the mechanisms involved still are not certain, it now appears that high residue levels stimulate production of hepatic microsomal enzymes which destroy steroid hormones required for the normal calcification of egg-shells. The resultant thin shells are more liable to break or crack, and hatching failure becomes more frequent.

This decrease in production of young may be coupled with increased adult mortality due to delayed expression; the combination of these two factors would make recovery very difficult. Both interspecific and intraspecific differences in productivity and population change probably are due to differential uptake and biochemical response to particular residue levels.

The evidence against DDE as the causative factor in hatching failures grows, but there are many other possible effects of pesticides upon raptors that require intensive research. Little or nothing is known about synergism of various chemicals, delayed breeding and other abnormal behavior, infertility, or increased susceptibility to disease and other stress factors. Still, more is known about the chlorinated hydrocarbon insecticides than about any other pesticides, and the birds of prey, viewed as indicator species, provide ideal subjects for continuing studies of the effects of synthetic pollutants upon wildlife. One can only hope that the peregrine falcon or other species do not have to vanish entirely to complete the case histories now being documented.

LITERATURE CITED

Ames, P. L. 1966. DDT residues in the eggs of the osprey in the northeastern United States and their relation to nesting success. J. Appl. Ecol. 3 (Suppl.): 87-97.

_______ and G. S. Mersereau. 1964. Some factors in the decline of the osprey in Connecticut. Auk 81: 173-185.

Anderson, D. W., and J. J. Hickey. In press. Eggshell changes in certain North American birds. In K. H. Voous (ed.), Proc. XVth Intern. Ornithol. Congress. D. J. Brill, Leiden. In press.

_______, J. J. Hickey, R. W. Risebrough, D. F. Hughes, and R. E. Christensen. 1969. Significance of chlorinated hydrocarbon residues to breeding pelicans and cormorants. Canadian Field-Naturalist 83(2): 91-112.

Berger, D. D., D. W. Anderson, J. D. Weaver, and R. W. Risebrough. 1970. Shell thinning in eggs of Ungava peregrines. Canadian Field-Naturalist 84(3): 265-267.

_______, C. R. Sindelar, Jr., and K. E. Gamble. 1965. The status of breeding peregrines in the eastern United States. p. 165-173. In Hickey, 1969.

Bitman, J., H. C. Cecil, S. J. Harris, and G. F. Fries. 1969. DDT induces a decrease in eggshell calcium. Nature 224: 44-46.

Blus, L. J., R. G. Heath, C. D. Gish, A. A. Belisle, and R. M. Prouty. 1971. Eggshell thinning in the brown pelican: implication of DDE. BioScience 21(24): 1213-1215.

_______, C. D. Gish, A. A. Belisle, and R. M. Prouty. 1972. Logarithmic relationship of DDE residues to eggshell thinning. Nature 235: 376-377.

Borg, H., H. Wanntorp, K. Erne, and E. Hanko. 1969. Alkyl mercury poisoning in terrestrial Swedish wildlife. Viltrevy 6: 301-379.

Bowman, M. C., F. Acree, Jr., C. S. Lofgren, and M. Meroza. 1964. Chlorinated insecticides: fate in aqueous suspensions containing mosquito larvae. Science 146: 1480-1481. Cited in Stickel, 1969.

Cade, T. J., and R. W. Fyfe. 1970. The North American peregrine survey, 1970. Canadian Field-Naturalist 84(3): 231-245.

_______, M. C. White, and J. R. Haugh. 1968. Peregrines and pesticides in Alaska. Condor 70: 170-178.

_______, J. L. Lincer, C. M. White, D. G. Roseneau, and L. G. Swartz. 1971. DDE residues and eggshell changes in Alaskan hawks and falcons. Science 172: 955-957.

Canadian Wildlife Service. 1971. Pesticides and wildlife. Minster of Fisheries and Forestry, Information Canada, Ottawa. 24 p.

Conney, A. H., R. M. Welch, R. Kunteman, and J. J. Burns. 1967. Effects of pesticides on drug and steroid metabolism. Clin. Pharm. Therapeutics 8: 2-10.

Conservation News. 1970. 35(16): 7. Cited in Raptor Research News 5(1): 4-5.

Cottam, C. 1969. Pesticide pollution. National Parks Magazine 43(266): 4-9.

Craighead, F. C. Jr., and J. J. Craighead. 1956. Hawks, owls, and wildlife. The Stackpole Co., Harrisburg, Pa. 443 p.

Cramp, S. 1963. Toxic chemicals and birds of prey. Brit. Birds 56: 124-139.

Dahlgren, R. B., and R. L. Linder. 1971. Effects of polychlorinated biphenyls on pheasant reproduction, behavior, and survival. J. of Wildl. Mgmt. 35: 315-319.

Decker, G. C. 1966. Significance of pesticide residues: practical factors in persistence. Illinois Nat. Hist. Sur., Bio. Notes no. 56. 8 p. Cited in Stickel, 1968.

Dunachie, J. F., and W. W. Fletcher. 1969. An investigation of the toxicity of insecticides to birds' eggs using the egg-injection technique. Ann. Appl. Biol. 64: 409-423. Cited in Pimentel, 1971.

Durham, W. F. 1967. The interaction of pesticides with other factors. Residue Review 18: 21-103. Cited in Stickel, 1968.

Dustman, E. H., L. F. Stickel, L. J. Blus, W. L. Reichel, and S. N. Wiemeyer. 1971. The occurrence and significance of polychlorinated biphenyls in the environment. N. Amer. Wildl. and Nat. Res. Conf. Trans. 36: 118-133.

Edwards, C. A. 1966. Insecticide residues in soils. Residue Review 13: 83-132. Cited in Wurster, 1969.

Enderson, J. H. 1964. A study of the prairie falcon in the central Rocky Mountain region. Auk 81: 332-352.

_______, and D. D. Berger. 1968. Chlorinated hydrocarbon residues in peregrines and their prey species from northern Canada. Condor 70(2): 149-152.

_______, and D. D. Berger. 1970. Pesticides: eggshell thinning and lowered production of young in prairie falcons. BioScience 20(6): 355-356.

Fimreite, N. 1970. Mercury uses in Canada and their possible hazards as sources of mercury contamination. Envir. Pollution 1(2): 119-131.

_______, R. W. Fyfe, and J. A. Keith. 1970. Mercury contamination of Canadian prairie seed eaters and their avian predators. Canadian Field-Naturalist 84(3): 269-276.

_______ and L. Karstad. 1971. Effects of dietary methyl mercury on red-tailed hawks. J. of Wildl. Mgmt. 35(2): 293-300.

Fuchs, P. 1967. Death of birds caused by application of seed dressings. Gent, Rijksfaculteit Landbouwwetenschappen 32: 855-859. Cited in Pimentel, 1971.

Fyfe, R. W. 1971. Pesticides and wildlife. p. 4-13. In Canadian Wildlife Service, 1971.

_______, J. Campbell, B. Hayson, and K. Hodson. 1969. Regional population declines and organochlorine insecticides in Canadian prairie falcons. Canadian Field-Naturalist 83(3): 191-200.

Hamerstrom, F. 1970. Excerpts from the abstracts of the XVth International Ornithological Congress. Raptor Research News 4(5): 142-145.

Heath, R. G., J. W. Spann, and J. F. Kreitzer. 1969. Marked DDE impairment of mallard reproduction in controlled studies. Nature 224: 47-48.

_______, J. W. Spann, J. F. Kreitzer, and C. Vance. In press. Effects of polychlorinated biphenyls on birds. In K. H. Voous (ed.), Proc. XVth Intern. Ornithol. Congress. E. J. Brill, Leiden.

Herbert, R. A., and K. G. S. Herbert. 1965. Behavior of peregrine falcons in the New York City region. Auk 82: 62-94.

Hickey, J. J. (ed.) 1969. Peregrine falcon populations: their biology and decline. Univ. Wisc. Press, Madison. 596 p.

_______. 1970. Peregrine falcons, pollutants, and propaganda. Canadian Field-Naturalist 84(3): 207-208.

_______ and D. W. Anderson. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162: 271-273.

Holmes, D. C., J. H. Simmons, and J. O'G. Tatton. 1967. Chlorinated hydrocarbons in British wildlife. Nature 216: 227-229.

Jensen, S. 1966. Report of a new chemical hazard. New Scientist 32: 613. Cited in Dustman et al., 1971.

_______. 1970. PCB as contaminant of the environment: history. Environment Protection Board, PCB Conference, Uppsala, Sept. 29, 1970. Cited in Dustman et al., 1971.

_______, A. G. Johnels, M. Olsson, and G. Otterlind. 1969. DDT and PCB in marine animals from Swedish waters. Nature 224: 247-250.

Johnels, A. G. 1970. The avifauna of Sweden and the environmental contamination with organomercurials with a note on the presence of chlorinated hydrocarbons. p. 142-143. In Hamerstrom, 1970.

Keith, J. A. 1971. Some results and implications of Canadian Wildlife Service pesticide research. p. 21-24. In Canadian Wildlife Service, 1971.

Keith, J. O. 1966. Insecticide contamination in wetland habitats and their effects on fish-eating birds. J. Appl. Ecol. 3(Suppl.): 71-85.

_______ and E. G. Hunt. 1966. Levels of insecticides residues in wildlife. N. Amer. Wildl. and Nat. Res. Conf. Trans. 31: 150-176.

Koplin, J. R., D. L. MacCarter, and D. S. MacCarter. 1969. Flathead Lake osprey study. Unpublished progress report no. 2, Univ. of Mont.

Kupfer, D. 1967. Effects of some pesticides and related compounds on steroid function and metabolism. Residue Review 19: 11-30.

Lehner, P. N., and A. Egbert. 1969. Dieldrin and eggshell thickness in ducks. Nature 224: 1218-1219.

Lincer, J. L., T. J. Cade, and J. M. Devine. 1970. Organochlorine residues in Alaskan peregrine falcons (Falco peregrinus Tunstall), rough-legged hawks (Buteo lagopus Pontoppidan) and their prey. Canadian Field-Naturalist 84(3): 255-263.

_______ and D. B. Peakall. 1970. Metabolic effects of polychlorinated biphenyls in the American kestrel. Nature 228: 783-784.

Lockie, J. D., and D. A. Ratcliffe. 1964. Insecticides and Scottish golden eagles. Brit. Birds 57: 89-102.

_______, D. A. Ratcliffe, and R. Balharry. 1969. Breeding success and dieldrin contamination of golden eagles in west Scotland. J. Appl. Ecol. 6: 381-389.

Moore, N. W. 1965. Pesticides and birds - a review of the situation in Great Britain in 1965. Bird Study 12: 222-252.

_______ and C. H. Walker. 1964. Organic chlorine insecticide residues in wild birds. Nature 201: 1072-1073.

Niering, W. A. 1968. The effects of pesticides. BioScience 18: 869-874.

O'Brien, R. D. 1967. Insecticides, action and metabolism. Academic Press, N. Y. 332 p. Cited in Wurster, 1969.

Peakall, D. B. 1967. Pesticide-induced enzyme breakdown of steroids in birds. Nature 216: 505-507.

_______. 1970. p,p'-DDT: effect on calcium metabolism and concentration of estradiol in the blood. Science 168: 592-594.

Peterson, R. T. 1965. Population trends of ospreys in the northeastern United States. p. 333-337. In Hickey, 1969.

Pillmore, R., and R. B. Finley Jr. 1963. Residues in game animals resulting from forest and range insecticide applications. N. Amer. Wildl. Conf. Trans. 28: 409-422.

Pimentel, D. 1971. Ecological effects of pesticides on non-target species. Superintendent of Documents, U. S. Govt. Printing Office, Wash., D.C. 220 p.

Porter, R. D., and S. N. Wiemeyer. 1969. Dieldrin and DDT: effects on sparrow hawk eggshells and reproduction. Science 165: 199-200.

Prestt, I. 1965. An enquiry into the recent breeding status of some of the smaller birds of prey and crows in Britain. Bird Study 12(3): 196-221.

Ratcliffe, D. A. 1958. Broken eggs in peregrine eyries. Brit. Birds 51: 23-66.

_______. 1963. The status of the peregrine in Great Britain. Bird Study 10: 56-90.

_______. 1965. Organo-chlorine residues in some raptor and corvid eggs from northern Britain. Brit. Birds 58: 65-81.

_______. 1967a. The peregrine situation in Great Britain, 1965-66. Bird Study 14: 238-246.

_______. 1967b. Decrease in eggshell weight in certain birds of prey. Nature 215: 208-210.

_______. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. J. Appl. Ecol. 7: 67-115.

Reynolds, H. V. III. 1969. Population status of the golden eagle in south-central Montana. Unpublished M.Sc. thesis, Univ. of Mont.

Risebrough, R. W. 1968. Pollution, wildlife, and science. Canadian Field-Naturalist 82(4): 241-243.

_______, R. J. Huggett, J. J. Griffin, and E. D. Goldberg. 1968a. Pesticides: transatlantic movement in the northeast trades. Science 159: 1233-1236.

_______, P. Reiche, D. B. Peakall, S. G. Herman, and M. N. Kirven. 1968b. Polychlorinated biphenyls in the global ecosystem. Nature 220: 1098-1102.

_______, G. L. Florant, and D. D. Berger. 1970. Organochlorine pollutants in peregrines and merlins migrating through Wisconsin. Canadian Field-Naturalist 84(3): 247-253.

Rudd, R. L. 1964. Pesticides and the living landscape. Univ. Wisc. Press, Madison, 320 p.

Schriver, E. C. Jr. 1965. The status of Cooper's hawks in western Pennsylvania. p. 356-359. In Hickey, 1969.

Simkiss, K. 1961. Calcium metabolism and avian reproduction. Biol. Rev. 36: 321-367. Cited in Wurster, 1969.

Sladen, W. J. L., C. M. Menzie, and W. L. Reichel. 1966. DDT residues in adelie penguins and a crabeater seal from Antarctica: ecological implications. Nature 210: 670-673.

Sprunt, A. IV. 1965. Population trends of the bald eagle in North America. p. 347-351. In Hickey, 1969.

Stickel, L. F. 1968. Organochlorine pesticides in the environment. U.S. F. and W. Ser. Spec. Sci. Rept. - Wildl. no. 119. 32 p.

Tarzwell, C. M., and C. Henderson. 1957. Toxicity of dieldrin to fish. Trans. of the Amer. Fish. Soc. for 1956, p. 245-257. Cited in Stickel, 1968.

Taylor, T. G. 1970. How an eggshell is made. Scientific American 222(3): 89-95.

Turtle, E. E., A. Taylor, E. N. Wright, R. J. P. Thearle, H. Egan, W. H. Evans, and N. M. Soutar. 1963. The effects on birds of certain chlorinated insecticides used as seed dressings. J. Sci. Food Agr. 14: 567-577. Cited in Pimental, 1971.

Vermeer, K., and L. M. Reynolds. 1970. Organochlorine residues in aquatic birds in the Canadian prairie provinces. Canadian Field-Naturalist 84(2): 117-130.

White, C. M. 1965. Population trends in Utah raptors. p. 359-363. In Hickey, 1969.

Wiemeyer, S. N., and R. D. Porter. 1970. DDE thins eggshells of captive American kestrels. Nature 227: 737-738.

Woodwell, G. M., P. P. Craig, and H. A. Johnson. 1971. DDT in the biosphere: where does it go. Science 174: 1101-1107.

Wurster, C. F. 1969. Chlorinated hydro-carbon insecticides and the world ecosystem. Biological Conservation 1(2): 123-129.

APPENDIX II. Form for recording data at eyrie sites.

Eyrie location: Dates:

No. of eggs:

No. of hatchlings:

No. of fledglings:

Exposure of cliff:

Exposure of eyrie:

Height of cliff:

Height of eyrie:

Elevation of eyrie:

Type of eyrie:

Eyrie protection:

Habitat and land use:

Nearest water:

Nearest road or habitation;

Prey at eyrie:

Additional notes:

APPENDIX III. Reproductive success of prairie falcons in Area C, 1970.[1]

Nesting attempt	Eggs per clutch	Hatchlings per eyrie	Fledglings per territory
1	3	-	-
2	5	5	5
3	4	4	3
4	3	1	1
5	-	5	5
6	4	-	-
7	-	3	3
Total	19	18	17

Mean size of clutch = 3.8

Mean number of hatchlings per eyrie = 3.6

Mean number of fledglings per territory = 3.4

---

[1] All information gathered by Gerald Geiger, Missoula, Montana.

APPENDIX IV. Analysis of chlorinated hydrocarbons. (Prepared by Chris Servheen.)

Sample preparation

Total weights were taken on each sample in tared plates. The entire sample was then ground in sodium sulfate to a free-flowing powder and the plate and the remains of the sample were weighed and subtracted from the total to give the total wet weight of the sample to be analyzed.

The sample in the sodium sulfate was then transferred to extraction thimbles and extracted in a soxhlet apparatus for 8 hours with a mixture of ethyl ether: petroleum ether; 70:170. After extraction, the ethers were evaporated at room temperature for 24 hours and the weight of the fat determined.

The fat was transferred to a separatory funnel and the procedure of acetonitrile portioning was followed according to the Pesticide Analytical Manual, Section 211.14 (FDA, 1963, rev. 1968).

The extract was then transferred to the Florisil column. Pesticides were eluted from the column with 5:95 ethyl ether: petroleum ether and 15:85 ethyl ether: petroleum ether solutions. The solutions obtained were then concentrated in a Kuderna Danish concentrator to less than 5 ml and transferred to a centrifuge tube. A known volume of this was then injected into the gas chromatograph for analysis.

Instrumental conditions

W. G. PYE SERIES 104 CHROMATOGRAPH equipped with a ^{63}N. electron capture detector.

Column 1/4" Pyrex	10% DC 200 on Chrom G
Column temp	190 °C.
Detector temp	250 °C.

Gas - N_2 , flow rate 100 cc/min.