RELATIONSHIPS OF CERTAIN CLIMATOLOGICAL FACTORS TO THE AUTUMN MIGRATION OF WATERFOWL IN THE CENTRAL FLYWAY

by

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CHAPTER I

INTRODUCTION

Migration of birds has been a phenomenon of great interest to man for many centuries. In temperate regions of the world, seasonal movements of birds between breeding and wintering grounds are apparent to the most disinterested observer. This phenomenon has provided the student of ornithology an area for extensive scientific investigation. Early studies were concerned with the origin of migration, how and when birds migrate, and the routes followed. Study results were publicized by the writings of William Eagle Clarke, T. A. Coward, and A. Landsborough Thomson in England and Wells W. Cooke, Frederick C. Lincoln, and Alexander Wetmore in America.

Recent investigations have not only continued the early studies, but extended them into the mechanics of bird navigation, the physiological basis for annual migrations, and the relationships to meteorological variables. In spite of this assemblage of information, little is known about the underlying principles regulating seasonal movements of birds.

One controversial aspect of the migration problem concerns the relationship of weather factors to migratory movements. Cooke (1910) maintained that weather conditions revealed no relationship to migration except to permit flight or hold back movements. Clarke (1912) and Thomson (1926) concluded that weather conditions, principally in the area of origin of movement, have a marked influence. The controversy has continued to the present. Current thinking, as summarized by Welty (1963), describes three types of weather influences: one, control of the advance of the season and, therefore, the first bird "arrivals;" two, weather either aids or hinders birds already in flight; and three, weather may provide the stimulus initiating migratory flight, providing the bird is physiologically prepared.

Lack (1960) noted that almost all field observations on weather and migration have been made on passerine species. Since much of the emphasis has been placed on the migration of small birds, there is less knowledge of the movements of larger birds such as waterfowl. Likewise, a larger percentage of the studies has related to spring migration rather than the fall movements. It was the purpose of this investigation to study the relationships of meteorological conditions to the autumn migration of waterfowl. The area of study was confined to the Central Flyway and extended from the Prairie Provinces of Canada to the Gulf Coast of Texas. The autumn migrations of 1953, 1954, and 1955 provided the study periods.

CHAPTER II

REVIEW OF THE LITERATURE

General Weather Relationships

Studies of bird migration over extended periods tend to reveal a relationship between arrival dates and regional climatic cycles. However, migration is undoubtedly dependent upon many additional factors. Attempts to isolate these factors and relate them to the annual movements of birds have resulted in conflicting conclusions. Thomson (1926) noted that although relationship between migration and climate is obvious, existence of a relationship between migration and weather has been the subject of much controversy.

Early studies by Cooke (1910) supported the hypothesis that birds migrate in the fall when the young are capable of caring for themselves and almost without exception the beginning of southward migration has no relation to weather. Noting that a number of species begins the southward migration in August when food and habitat conditions are excellent, he maintained that once the migration had started, its advance may be hastened by fall storms or slowed by fair weather. According to Wetmore (1926), most species of ducks do not flee from the cold, providing food is available. The search for food and escape from man are cited as prime factors. In Europe, ducks appear to make shorter migratory flights, since the extremes of climate are not great and satisfactory wintering range is less distant. Phillips and Lincoln (1930) presented similar views, noting that fall migration of waterfowl results in slow southward drifting of flocks with long intervals of loafing in favorite feeding grounds. Although weather conditions in the north may accelerate or retard movement, waterfowl, if undisturbed, are likely to remain almost indefinitely in an area where food is abundant. Lincoln (1935), referring principally to spring movements, maintained that migrations of birds have evolved to a state in which movements are synchronized with average climatic conditions. Each species is believed to move north in the spring when the average weather encountered is endurable. He found the northward movement of Canada geese coinciding with the advance of isotherm 35^{o} Fahrenheit. Stormy weather may interrupt migration; fair weather permits movements.

Evidence of a close relationship between the departure of migrants and the incidence of certain meteorological factors has been advanced Thomson (1924). These factors were not considered the primary cause for migration, but secondary stimulii related more to the day of the flight than to the time of the year when the flight occurred. Coward (1912), referring to European birds, observed pronounced autumn migrations to Britain during periods of anticyclonic conditions in Scandinavia. Movements continued until confronted with northeast cyclonic weather. Ritchie (1940) made a similar observation while studying an extensive migratory movement of Waxwings (Bombycilla garrulus) from Scandinavia to Great Britain. Lack (1959) maintained that seacrossings of migrants to Britain involve different factors from those related to migration over land. Day migrants refrain from heading out to sea under unfavorable conditions. Migrants over land, confronted with bad conditions, frequently alight.

In summarizing the current view, Lack (1960) stated that migrants do not react to the general weather situation, but to one or more specific weather factors linked with it. Robbins (1949) and Lincoln (1950) studied individual weather factors and agreed that arrival of migrating birds is governed primarily by weather at origin of flight, rather than at the point of arrival.

Temperature

Investigators do not agree concerning the relation of temperature to the autumn migration of birds. Lack (1960) stated, those who maintain existence of a negative relationship, base their view on three reasons. First, other factors may be important and have an overriding influence. Second, a change in temperature may coincide with some more conspicuous weather factor, notably, wind direction, to which the observer incorrectly attributes the difference in migration. Third, in some studies the temperature did not reach its critical value until after migration had occurred. In spite of these objections, numerous observers have maintained a positive relationship does exist.

Cooke (1910) made extensive studies of the spring migration of passerine birds and found no definite temperature limits to which migration was confined. He declared average temperature at a given locality determines average time of bird arrival. Later, Cooke (1915) noted that the lowering of the average temperature did not appear to coincide with autumn migration. A comparison of spring and fall migrations indicates southward movements are less orderly and less regular than the northward flights (Chapman 1937). Spring migrations in Texas were observed by Williams (1950) to be related to the day-to-day temperature, instead of to average conditions. From a study of the relation of temperature to physiological discomfort and limits of physiological tolerance, Kendeigh (1934) concluded average night temperature was the critical factor for passerine birds. However, the number of hours of darkness when birds were without food appeared important.

The significance of food availability has been noted by other investigators. Clarke (1902, 1913), studying European birds, found a definite drop in autumn temperature produced quickening of bird movements. He declared a temperature drop in the early fall served to notify birds that the time had arrived to retreat to winter quarters; whereas, a lowering of temperature later in autumn compelled late migrants to move, due to a reduction of food supplies. Walter (1908) also found an apparent relationship of temperature drop and scarcity of food supply. A more recent study by Svardson (1953) designates food supply as the ultimate factor with falling temperature termed approximate factor for the late migrant, but insignificant for the early ones. His study with the shield-duck revealed a definite correlation of late autumn migration and temperature drop. Milne and Milne (1958) found that such birds as the Canada goose and pintail duck appeared reluctant to leave the nesting areas and move south. Only when their food was hard to reach, because of ice and snow, were "bird avalanches" observed coincident with a sudden drop in temperature. Low temperature by itself had little or no bearing on movement. In contrast to this, Dorst (1934) declared late winter movements were directly caused by adverse weather and the temperature of the air currents had an effect on the time and duration of migration.

Other investigators also found temperature a significant factor in initiating the southward migration of birds. In Finland, Siivonen (1936) used a device for registering variations of migratory restlessness in caged song thrushes, Turdus erictorum. He found every drop in temperature stimulated restlessness. These periods of restlessness coincided with migrating waves of similar birds. Radar studies of migration along the Atlantic coast of North America revealed most southward migration in autumn follows a drop in temperature (Drury, 1960). In the interior of the United States, migration of ducks was studied in the Mississippi Flyway by Bellrose and Sieh (1960). Three mass waterfowl flights (one each in the falls of 1955, 1956, 1957) occurred while temperature was dropping. A cold front was involved only in the autumn of 1955. Lack (1960) noted, from his radar studies of autumn migration from Holland to Norfolk, England, a strong connection between drop in temperature and departure of migrants. However, in these instances, there was associated anticyclonic weather, clear skies and light easterly winds, which made it difficult to separate temperature from these factors.

The passage of a cold front with the accompanying drop in temperature has been described as prerequisite to migratory movement. The spectacular waterfowl migration in Central North America, described by Bellrose (1957), was found to be associated with a flow of Continental Arctic air, triggering mass movements. Laskey (1957) studied television tower casualties and noted cold fronts with the accompanying north winds always brought flights of migrant passerine birds. Graber and Cochran (1960) also found most fall waves of passerine migration were associated with cold fronts. An eastward passage of a cold front across the northeastern United States was observed by Baird, et al. (1958) as the beginning of a potentially good migratory period. McClure (1954), in Japan noted an unusual migration in which flights were moving with a cold front.

Some investigators declare a cold front is not the important factor in migration, but favorable north or northwest winds which follow a front are more important. Bennett (1952) reported the largest waves of migrants on the first two days following passage of a cold front. Mueller and Berger (1961) studied autumn hawk migration in Wisconsin and found 92 per cent of the movements occurred with westerly winds and the recent passage of a cold front. They concluded that this combination of weather factors provided suitable updraft and hence, good soaring and gliding conditions.

Dorst (1962) referred to temperature as one of the most important elements of weather. Thermal factors seem to control the seasonal variations in autumn migration, and when temperature does not exert a dominant influence, it is often hard to trace migratory behavior to any single climatic or meteorological factor. Dorst maintains that all the diverse components of weather, including temperature, seem to govern migration.

Wind

Importance of wind as a factor in migration has been a controversial subject. About as many investigators declare a relationship exists between wind and migration as there are those who find no relationship.

Cooke (1910) concluded there was no evidence wind that had an effect on spring migration. Late fall migration was undoubtedly due to a temperature drop accompanying a cold north wind and not due to wind alone. Studies of night migrants in Germany, conducted by Thomson (1936, 1953), revealed nights of heavy migration did not correlate with a particular wind direction. In the United States, Bellrose (1958) experimented with trapped juvenile blue-winged teal, detained until late autumn, before being released. He also found a lack of correlation between wind direction and the migratory movement. Radar studies of migration from England, over the North Sea to Scandinavia, revealed that wind had little effect on migratory departure (Lack, 1958). In a later study, Lack (1960a) obtained similar results and concluded that the significant factor was not the direction of wind, but some other associated weather element. Clarke (1912) also agreed that the apparent correlation between wind direction and migration was because both were produced by the same general weather situation.

Numerous investigators have maintained that wind direction does affect migration. Birds have been observed migrating when the wind was at every point of the compass, but the route followed may be influenced by the wind direction (Baxter and Rintoul, 1918) and guiding topographical features (Koch, 1934). Changes in migratory routes have been observed when the wind direction was abnormal. Birds have been known to "pile up" against barriers, such as mountain ranges and seashores, during strong winds which hampered movement (Allen, 1939). The albatross and golden plover have been known to engage in quartering flight when at low altitude, presumably to take advantage of air pulsations caused by wave motion of the water (Hoffman, 1931). According to Peterson (1941), birds seldom travel in a straight line, but are shifted by the wind. He declared large numbers of birds would not appear at Cape May or other places along the Atlantic Coast if the wind did not carry the birds along as logs in a current.

McMillan (1938, 1940, 1943) also observed that the wind serves as a vehicle in migration. Birds were often seen at upper air levels, taking advantage of a tailwind. These upper air prevailing winds coincided with direction of autumn migratory movement. Williams (1950) disagreed with McMillan. His telescopic observations of birds in the upper air, flying across the moon's surface, revealed movement in four or five directions in a short lapse of time. Lowery (1951) and Newman (1952), using the same moon-watching technique, found that the flow of migration was, in general, coincident with the air flow.

Lincoln (1935, 1952) declared headwinds are unfavorable to migration and may force down weaker species. Moderate tailwinds or quartering breezes appeared to provide the best conditions. An unusual case was cited by Preston (1955). Passerine birds were migrating in a middle layer of air with a tailwind, while no birds were observed at lower or higher levels where the air direction was either a strong cross wind or headwind. Landsberg (1948), a meteorologist, studied the problem of over-water migration and noted a close correspondence to the trajectories of most frequent winds. He stated, it appears these birds have developed a remarkable system of what is called in modern aviation, "pressure pattern flying." This system takes advantage of the maximum amount of tailwind in long-distance flights.

By recording the frequency of nocturnal migrant calls, Graber and Cochran (1960) determined the pattern of migration in Champagne County, Illinois. Seventy-six per cent of the calls during fall migration occurred with a northwest flow of air (tailwind). In three mass duck flights studied by Bellrose and Sieh (1960) in the Northern Great Plains of North America, they found most flights developed with a shift in wind to the northwest, giving a tailwind. Hochbaum (1944, 1955) noted canvasback ducks usually arrived at Delta Station, Manitoba in the spring with a south wind. Although he found ducks often moved with a favoring wind, this was not always the case. Lesser snow geese and blue geese often moved northeast with a crosswind. Ducks were observed flying against winds of fifteen to twenty miles per hour when slower birds remained grounded.

Several investigators maintain that birds seek a headwind for migration. Ritchie (1940) found migratory movements of Bohemian Waxwings, Bombycilla garrulus, into Great Britain and Denmark, rarely oame with favoring wind. According to Svardson (1953), the greater the strength of the wind, the greater is the tendency for birds to fly against it. He stated that only ducks are known to fly regularly in a strong tailwind. In studies of passerine species, Lack (1959) observed that birds follow the coastline into the wind, before heading out to sea. Vleugel (1954) cited cases of chaffinch migration in the Netherlands in which volume of movement was 2.5 times as intense with moderate headwinds as with moderate tailwinds. He concluded that these birds navigate by maintaining a certain angle with the prevailing wind. This angle is easier to maintain with a headwind. Deelder (1949) suggested the reason birds may be seen migrating with a headwind is that a tailwind weakens guide lines, causing birds to fly higher, and with a headwind, they fly lower along guide lines. In the latter case, they are more often seen and, therefore, observers incorrectly conclude birds prefer headwinds. Meinertzhagen (1954) agreed birds fly lower with a headwind. This is believed due to reduced speed of surface winds caused by ground friction and that birds seek the lesser headwinds.

The strength of the wind appears to be a factor in migration. Phillips (1910) noted the major autumn flights of Canada geese in Eastern

Massachusetts. The noteworthy feature on the date of flight appeared to be the absence of wind or presence of only light north or northwest winds. Lack (1960a) found light winds of three to seven knots favorable; whereas, rarely did a large movement occur with a wind of more than seventeen knots. Lincoln (1952) agreed strong winds, even when blowing in the direction of bird travel, are unfavorable to migration.

Lack (1960) noted that in North America and Europe migrants tend to arrive in autumn with cold following winds and in spring with warm following winds, but since laboratory experiments on migratory restlessness indicate that warmth in spring and cold in fall are favorable to migration, field evidences are inadequate to prove that wind direction alone has any influence. He questions the importance of wind in triggering migration, but believes the associated temperature is the important factor.

Barometric Pressure

Studies of the relation of migration to barometric pressure have produced little evidence that any relationship exists. Lack (1960) summarized the findings and declared the reason there is an apparent tendency for migration to occur in anticyclonic weather could be attributed to factors other than pressure, such as light winds, clear skies and in autumn, low temperatures.

Walter (1908) cited an early study of woodcock migration in Europe in which the movement of birds was from anticyclonic areas of high pressure to cyclonic areas of low pressure. Although this coincided with the general direction of wind, it was not believed that wind controlled movement. Rather, wind and migrations were caused by similar conditions, namely, proximity of two areas of unequal barometric pressure. In this paper it was noted that during fall and winter, the polar regions form an anticyclonic area of high pressure with low temperature and clear air, while the tropics have a corresponding low pressure area with high temperature and much humidity. The prevailing winds are from the north. In spring and summer, conditions are reversed. Birds were thought to be sensitive to these pressure changes and were, therefore, stimulated to migrate as the barometric maxima and minima shifted.

Rowan (1929) cited an observation of an early mass exodus of ducks and geese from the lakes of Alberta, Canada during the fall of 1928. The migration was associated with a high barometric pressure, gently falling temperature and clear skies. Only in the general area where these conditions existed was there a mass movement south. Similar observations were made by Ritchie (1940) in Europe during the fall migration of Bohemian waxwings, *Bombycilla garrulus*. Lowery (1951) found birds travelled by pressure pattern flying. Maximum migration occurred in regions of high barometric pressure and no activity occurred in regions of low pressure. Hochbaum (1955) also noted duck movements in Manitoba, Canada followed pressure pattern migration. South winds and rising temperature marked onset of heaviest spring migration; north winds and falling temperature marked onset of autumn flights. The relative position of high and low pressure areas produced these weather conditions.

Spring migration appears to be pronounced on the east side of a low pressure area. Here there are south winds and rising temperatures. Several early investigators, including Cooke (1888), Eaton (1904), and Smith (1917), made these observations. More recently, Bagg (1948, 1950) and Nichols (1949) reported similar findings.

Some researchers minimize the importance of atmospheric pressure on migration. Bellrose and Sieh (1960) found mass flights of waterfowl more related to temperature and wind than to barometric pressure. Ducks migrated during high and low pressure conditions. Although Graber and Cochran (1960) noted heavy migration when barometric pressure was rising in the fall and dropping in the spring, they concluded pressure change alone did not initiate migratory flight. In the migration studies by Lack (1960a), the mean volume of migration across the North Sea was similar in settled and disturbed weather. Pressure appeared to have no influence.

Precipitation

Very little investigation has been done on the relation of precipitation to bird migration. In the course of other studies, investigators have reported isolated observations of the effects of rain and snow. During spring migration in the United States, frontal activity and precipitation appeared to produce a great "pile up" of the migration of land birds (Bagg, 1956). In Britain, Lack (1960a) noted spring migration was small during periods of rain or snow.

Autumn flights from Siberia to Japan were studied by McClure and Yoskii (1957). Precipitation reduced the volume of movement. They found that as the subsequent arrival of favorable weather approached the Siberian Coast, it released the migrants grounded by bad weather, thus producing a migratory wave. In the United States, Graber and Cochran (1959), using an audio technique to detect volume of nocturnal migrants, observed a mass migration during intermittent rain.

An early observation by Phillips (1911) revealed, in two separate instances, unusual flights of Canada geese. In both cases, severe storms occurred in northern regions prior to flight arrival dates. On this occasion, weather in Newfoundland was extremely stormy with heavy precipitation one or two days previous to the large flights of geese over Massachusetts. The birds were moving with a north to northeast wind. Jones and Gilmore (1955), reporting observations on migration of the pink-footed goose, Anser brachyrhynchus, from Iceland to Great Britain, found snow most important in triggering fall departure. Temperature seemed to have little effect on geese. The three mass flights of ducks in the Mississippi Flyway, reported by Bellrose and Sieh (1960), originated when snow was falling extensively on the plains of Canada.

Cloud Cover

Reports of the relationship of sky cover and volume of migration are conflicting. Some investigators claim bird movements occur during anticyclonic conditions with attending clear weather. Others have reported extensive movements during complete overcast skies.

Among the early investigators who studied sky cover and migration, Cooke (1888) found sixty per cent of the 1884 spring migration occurred in cloudy weather. In Europe, Ritchie (1940) conducted a fall migration study of Bohemian waxwings and reported thirteen migratory waves during the 1921 bird invasions. Twelve of these started under overcast skies. Graber and Cochran (1958, 1960) reported mass autumn migrations during periods of complete sky cover. Their work indicated migration was not reduced on nights with opaque overcast. These conditions appeared incidental to other factors. Studies of television tower bird kill revealed that heavy cloud cover and low ceiling contributed to the greatest bird destruction (Brewer, 1958). In these instances, birds were migrating during poor visibility, resulting from fog and haze.

Two separate reports of duck migration provide evidence of mass movement under overcast skies. Hochbaum (1955) found waterfowl may move north into the Delta region of Lake Manitoba under heavy cloud cover. He concluded that flights may proceed above the clouds or at least with no reference to terrestrial clues. All three individual autumn mass movements of ducks reported by Bellrose and Sieh (1960) occurred with overcast skies.

Lack (1960), in his review of migration and weather, appeared to overlook completely the work of investigators who reported migration under heavy sky cover. He stated all authorities have agreed migration is favored by clear weather and, although statistical evidence is lacking, this conclusion can be accepted. He declared his studies in Great Britain indicate that clouds had a significant effect in reducing seaward emigration from England. Although cloud cover did not necessarily halt migration, the volume was smaller than on clear nights. Other researchers made similar observations. Major flights of passerine night migrants have been observed making a sea crossing from southwest Iberia, but always with clear skies and light northwest winds (Hentz, 1961). An unusual migration of geese, reported by Cooch (1955), covered a distance of 1,700 miles in a period of less than sixty hours. Weather was clear to the north, but overcast to the south. Miskimen (1955) noted a vast reduction of ducks in the Columbus, Ohio region following evenings of clear skies.

The hypothesis that birds must have clear skies for purpose of orientation has received some support. Nisbet (1957) declared diurnal migrants react strongly to topographical features and suggested birds cannot maintain orientation without a fixed reference. Day migrants must be able to check their position at each stage and adapt flight direction accordingly. This would suggest the necessity of clear skies. In Europe, Tinbergen (1956) found autumn migration of chaffinches did continue on overcast days with orientation only slightly less accurate. When several dark days succeeded each other, disorientation increased. Hamilton (1962) conducted studies on the orientation of mallard ducks. His experimental releases of ducks in unfamiliar country resulted in disorientation only under overcast skies.

Atmospheric Stability

The only extensive study of stability of the atmosphere as related to migration was conducted by Raynor (1957). He investigated nocturnal land bird migration east of the Rocky Mountains during the spring of 1953. From 2,500 records of actual observations, he found atmospheric stability and favorable wind direction to be of major importance in initiating and maintaining nocturnal flights. The two combined factors gave a better correlation than either separately, but stability seemed to be more important than wind direction. Raynor stated that flights were often terminated at the edge of an unstable area. Noting migrating birds do not have to expend as much energy flying in stable air, he postulated that migrants are sensitive to smooth air flow.

Lack (1960) questioned the findings of Raynor, although he produced no data to discredit this study. Lack maintained that until other factors, such as wind velocity, temperature, rain and cloud cover, have been eliminated as possible accompanying factors in Raynor's study, the results should not be accepted.

CHAPTER III

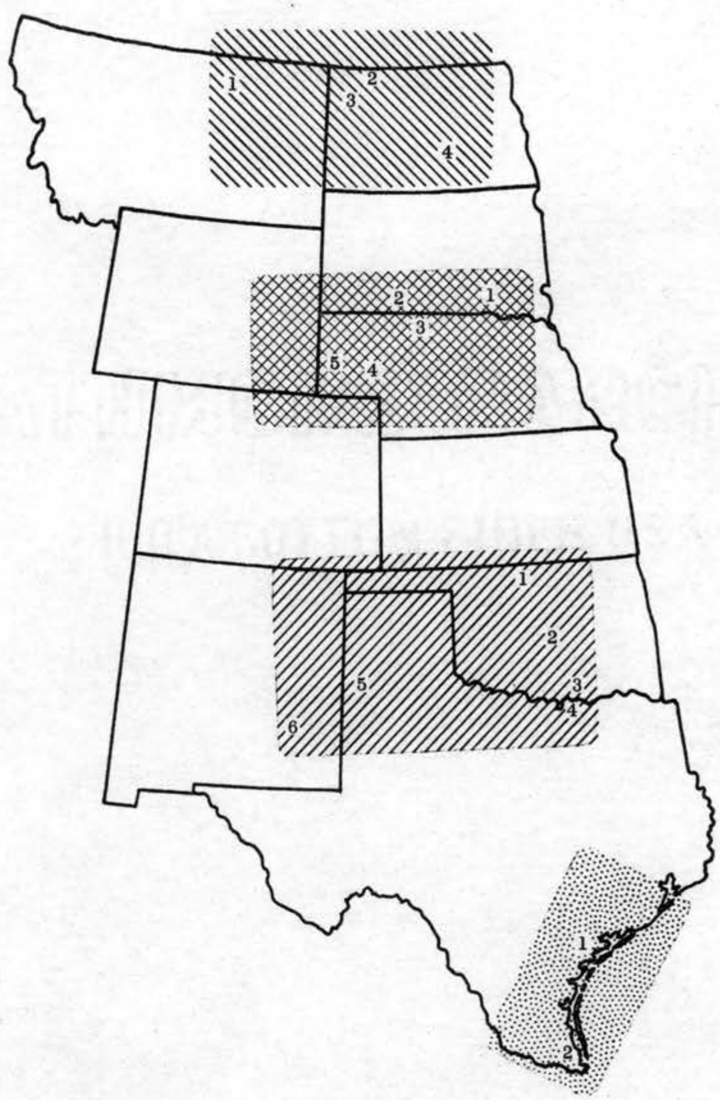
DESCRIPTION OF STUDY AREA

Bird migration in North America, primarily a north-south movement, proceeds on a broad front, though confined to bands of differing sizes. The shape and expanse of each band is determined by the physiography of the region. These bands, described by Lincoln (1950) as "flyways," are well defined. North American waterfowl migrate along these routes. Of the four flyways defined by the United States Fish and Wildlife Service, this study is confined to that part of the Central Flyway extending from the Canadian border to the Gulf Coast of Texas. The area comprises four separate regions (Figure 1).

Region I, Eastern Montana and Western North Dakota, has four waterfowl census stations: Bowdoin National Wildlife Refuge, Malta, Montana; Des Lacs National Wildlife Refuge, Kenmare, North Dakota; Lostwood National Wildlife Refuge, Lostwood, North Dakota; and Long Lake National Wildlife Refuge, Moffitt, North Dakota.

Region II, Southern part of South Dakota and Western Nebraska, includes five census stations: Lake Andes National Wildlife Refuge, Lake Andes, South Dakota; La Creek National Wildlife Refuge, Martin, South Dakota; Valentine National Wildlife Refuge, Valentine, Nebraska; Crescent Lake National Wildlife Refuge, Ellsworth, Nebraska; and North Platte National Wildlife Refuge, Scottsbluff, Nebraska.

Region III, Oklahoma, North Texas and Southeastern New Mexico,



LEGEND:

REGION I

Station
1. Bowdoin National Wildlife Refuge
2. Des Lacs National Wildlife Refuge
3. Lostwood National Wildlife Refuge
4. Long Lake National Wildlife Refuge

REGION II

Station
1. Lake Andes National Wildlife Refuge
2. Lacreek National Wildlife Refuge
3. Valentine National Wildlife Refuge
4. Crescent Lake National Wildlife Refuge
5. North Platte National Wildlife Refuge

REGION III

Station
1. Salt Plains National Wildlife Refuge
2. Lake Overholser
3. Tishomingo National Wildlife Refuge
4. Hagerman National Wildlife Refuge
5. Muleshoe National Wildlife Refuge
6. Bitter Lake National Wildlife Refuge

REGION IV

Station
1. Aransas National Wildlife Refuge
2. Laguna Atascosa National Wildlife Refuge

Figure 1. The study area, showing the four regions and waterfowl census stations in the Central Flyway of the United States.

includes six census stations: Salt Plains National Wildlife Refuge, Jet, Oklahoma; Lake Overholser, Oklahoma City, Oklahoma; Tishomingo National Wildlife Refuge, Tishomingo, Oklahoma; Hagerman National Wildlife Refuge, Denison, Texas; Muleshoe National Wildlife Refuge, Muleshoe, Texas; and Bitter Lake National Wildlife Refuge, Roswell, New Mexico.

Region IV, the South Gulf Coast of Texas, includes two stations: Aransas National Wildlife Refuge, Austwell, Texas; and Laguna Atascosa National Wildlife Refuge, San Benito, Texas.

The four study regions, located entirely within the Central Flyway, are completely separate areas. The distance from the most southern station of one region to the most northern station of the next region varies from 250 to 400 miles. Regions I and II are 250 miles apart; Region III is 400 miles south of Region II and Region IV is 375 miles south of Region III.

Topography

The study area is located principally in the Great Plains Province of the United States, although the eastern border of the flyway traverses part of the Central Lowlands. The southern part of the migration route reaches the Coastal Plains (Figure 1). The Great Plains, a belt of highland, slopes from the foothills of the Rocky Mountains, eastward to the Central Lowlands. Altitude ranges from an average of 5,500 feet in the west to 1,500 feet in the east. Drainage, from west to east, is a part of the Mississippi drainage system (Blair, 1942).

Region I, located in the Northern Great Plains Province, consists of a glaciated portion of the Missouri Plateau. Uneven glacial deposits have formed rolling grasslands with nearly every depression containing water during spring months. These water areas, called "potholes," vary from small temporary puddles to lakes of many hundred acres (Evans and Black, 1956). Elevation ranges from 2,300 feet in the west to 1,600 feet on the east border.

Region II is situated in the Great Plains where the unglaciated portion of the Missouri Plateau is in the north and the Nebraska High Plains are in the south. The region is dotted by open freshwater ponds and inland fresh meadows containing shallow lake basins and sloughs (Shaw and Fredine, 1956). Elevation ranges from 3,900 to 1,500 feet, west to east.

Region III is characterized by two physiographic dimensions. Oklahoma and North Texas are located in the Central Lowlands. The western half of the region, part of the Great Plains Province, includes the uneroded High Plains of West Texas and the Pecos Valley portion of Eastern New Mexico. Limited wetland areas consist of man-made lakes, reservoirs, and farm ponds. Highest elevation, 3,500 feet, is located near Station Six. Seven hundred feet elevation at Station Four is the lowest.

Region IV, located entirely within the Coastal Plains Province, is situated on the Texas Gulf Coast. This area has extensive salt flats submerged regularly by high tides. Surrounding salt meadows are characterized by shallow potholes which are filled with water during the growing season, but rarely covered by tidewater. Shallow salt water sounds and bays extend along the entire coastal area providing vast areas of protected open water (Shaw and Fredine, 1956). Elevation is sea level.

General Weather

Although the study regions are all located in the north temperate zone, they include four climatic types as described by Blair (1942). Because of the close correlation between climate and vegetation zones, his classification indicates natural plant cover (Figure 2).

Middle Latitude Steppe Climate

This type climate, found in most of Region I and parts of Regions II and III, is semi-arid. Short or tall grasses comprise the dominant vegetation of the area. Principal cause of semi-arid climate is location in the continent. The area, far removed from coasts and on windward side of mountain barriers, receives little precipitation. A large annual range in temperature is characteristic. Summer temperatures are high as continental air masses develop over heated land surfaces. Winter air masses are continental, but are associated with outbreaks of polar air (Critchfield, 1960).

Precipitation is light and variable. Winter precipitation is frontal and comes with high winds and polar outbreaks in the form of blinding snowstorms from the north. Summer precipitation comes with scattered thunderstorms. Tornados often form along belts of frontal thunderstorms during spring and summer in southern areas (Koeppe and DeLong, 1958). In the Northern Great Plains, the chinook or foehn-type wind appears in winter and spring (Trewartha, 1954). Vegetation may remain dormant during extended periods of drought, but shows rapid growth with spring rains.

Humid Continental Climate

This climatic type includes a wide divergence of temperature and rainfall conditions and, therefore, includes two subtypes. The northern part, referred to as cold subtype, extends into the east part of study

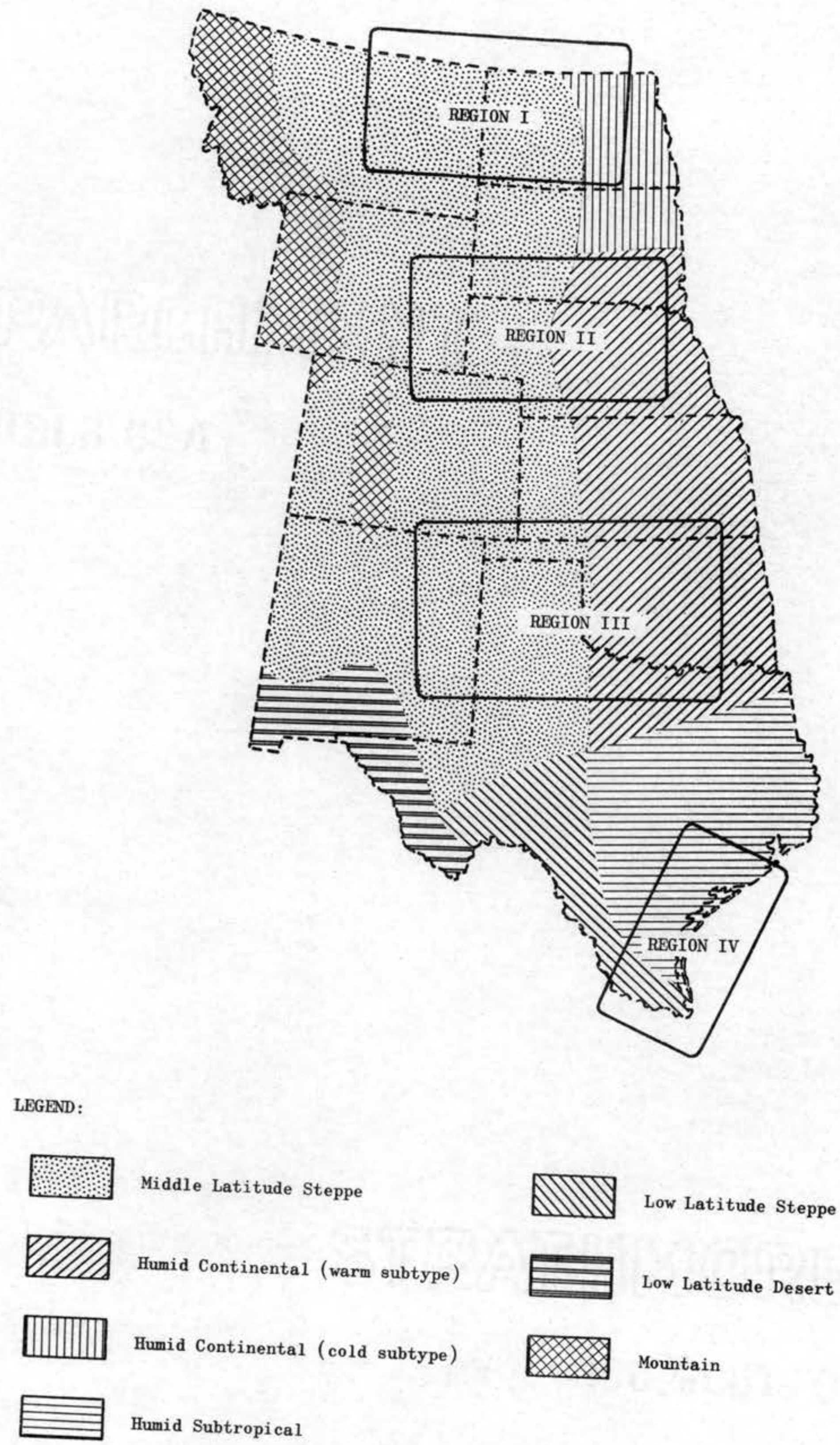


Figure 2. Location of the four study regions in relation to climatic zones of the central United States. Classification of climate is according to Blair (1942).

Region I. Here the mean temperature is below 32° F. for four or five months and 50° F. for an equal period of time. Average annual rainfall varies from 15 to 25 inches. Low temperatures result in little evaporation and, therefore, produce more effective growing conditions than those of southern regions with a higher annual rainfall. The high latitude provides a climate affected by polar air masses for an extensive period of time (Critchfield, 1960).

The south part of the climatic zone, between latitudes 35° and 40° N., is called the warm subtype. This area extends into the east part of Regions II and III. The mean temperature during the coldest month is below 43° F. and six to nine months is above 50° F. Average frost free season varies from 150 days in the north to 200 days in the south (Critchfield, 1960). Rainfall varies between twenty and forty inches. Native vegetation includes prairie grasses and some deciduous forests.

Humid Subtropical Climate

This climate is found in the northern part of Region IV. Here the rainfall is moderate to heavy, coming at all seasons. Mean temperature of the coldest month is 40° to 45° F. Mean monthly temperature of the warmest month is 80° F. During the summer months the maximum reaches 90° to 100° F. with extremes above 100° F. (Critchfield, 1960). Only occasional temperatures drop below freezing. Typical vegetation is broadleaf evergreen.

Low Latitude Steppe

This climatic type reaches only the southern part of Region IV, including one station, Laguna Atascosa National Wildlife Refuge. The climate is arid with irregular rainfall and the average annual temperature is above 64^{o} F. In the area of the refuge, freezing temperatures occur an average of three days a year. A feature of the climate is occasional occurrence in winter of relatively cold "northers" composed of continental air. This occurs from November to March and sometimes causes a drop of 40^{o} F. in temperature along the Gulf Coast (Blair, 1942). The area is characterized by low grasses, with scattered xerophytic shrubs.

CHAPTER IV

METHODS AND PROCEDURES

General Methods

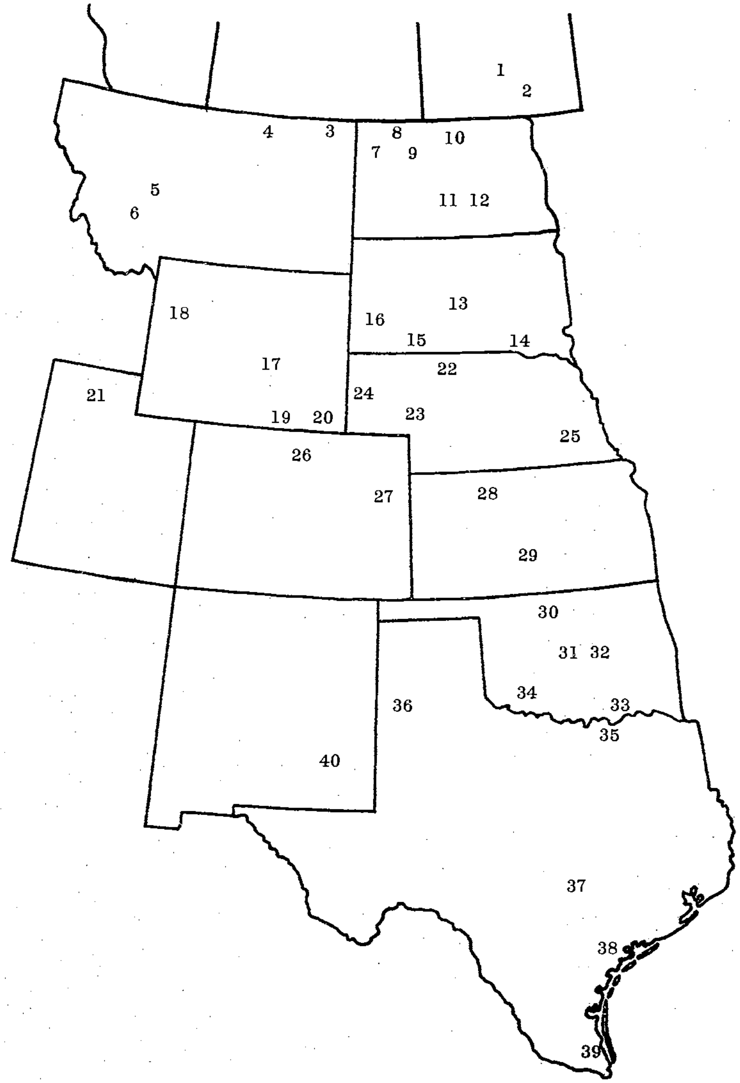
In order to determine the effects of weather upon waterfowl migration, it was necessary to accurately trace the time and scope of waterfowl movements throughout the Central Flyway. Data on numbers of waterfowl were obtained from forty stations through the cooperative efforts of a large number of people who made regular counts of these birds.

Precise data on weather conditions and changes were required in order to measure the influences of weather upon waterfowl movements. The summarization and analysis of U. S. Weather Bureau records were made for stations distributed throughout the Central Flyway. Such analyses revealed the pattern of general weather conditions during each of the three autumn periods and also made it possible to compare waterfowl distribution and movements with specific weather conditions.

The voluminous records on waterfowl numbers and weather conditions were tabulated on sheets designed to correspond to the IBM 80-column punch card. These punch cards were programmed for a reduction of the data to measures that could be readily compared and analyzed.

Waterfowl Records

In a migration study of this scope, it was essential to secure waterfowl population data representative of the Central Flyway. Records taken regularly throughout the entire fall period were required for a



LEGEND:

1. Waterfowl Research Station, Delta, Manitoba
2. Ducks Unlimited, Winnipeg, Manitoba
3. Medicine Lake National Wildlife Refuge
4. Bowdoin National Wildlife Refuge
5. Freeze-up Lake State Refuge
6. Montana Game and Fish Department
7. Lostwood National Wildlife Refuge
8. Des Lacs National Wildlife Refuge
9. Upper Souris National Wildlife Refuge
10. Lower Souris National Wildlife Refuge
11. North Dakota Game and Fish Department
12. Long Lake National Wildlife Refuge
13. South Dakota Game and Fish Department
14. Lake Andes National Wildlife Refuge
15. Lacreek National Wildlife Refuge
16. Belle Fourche National Wildlife Refuge
17. Pathfinder National Wildlife Refuge
18. National Elk Wildlife Refuge
19. Hutton Lake National Wildlife Refuge
20. Wyoming Game and Fish Commission
21. Bear River National Wildlife Refuge
22. Valentine National Wildlife Refuge
23. Crescent Lake National Wildlife Refuge
24. North Platte National Wildlife Refuge
25. Nebraska Game and Fish Commission
26. Colorado Game and Fish Commission
27. Bonny Dam, Burlington, Colorado
28. Kirwin National Wildlife Refuge
29. Quivira National Wildlife Refuge
30. Salt Plains National Wildlife Refuge
31. Lake Overholser, Oklahoma City
32. Oklahoma Game and Fish Commission
33. Wichita National Wildlife Refuge
34. Tishomingo National Wildlife Refuge
35. Hagerman National Wildlife Refuge
36. Muleshoe National Wildlife Refuge
37. Texas Game and Fish Commission
38. Aransas National Wildlife Refuge
39. Laguna Atascosa National Wildlife Refuge
40. Bitter Lake National Wildlife Refuge

Figure 3. Forty areas visited for purpose of locating sources of waterfowl census data.

complete picture of migration. Eighty-two sources were contacted, including waterfowl biologists of state game and fish departments, managers of federal wildlife refuges, professors engaged in biological research, and amateur ornithologists. In addition, professional ornithologists and investigators familiar with the problem of migration were contacted. These included: Fredrick C. Lincoln, United States Fish and Wildlife Service, Washington, D. C.; Alexander Wetmore, Smithsonian Institution, Washington, D. C.; Ernst Mayr, American Museum of Natural History, New York City, New York; Seth Low and Chandler Robbins, Patuxent Research Refuge, Laurel, Maryland; B. W. Cartwright, Chief Naturalist, Ducks Unlimited, Winnipeg, Canada; and H. Albert Hochbaum, Delta Waterfowl Research Station, Delta, Manitoba, Canada. From information obtained from these sources, forty areas were selected for more detailed investigation. These were visited and their records reviewed (Figure 3).

Ducks Unlimited

Records were obtained from B. W. Cartwright, Chief Naturalist, Ducks Unlimited, Winnipeg, Canada, for the three prairie provinces of Alberta, Saskatchewan and Manitoba, for the period of the study. Although the information did not provide actual waterfowl census data, pertinent facts were obtained concerning hatching success, water conditions, dates of first migratory movements and subsequent mass migration and general weather conditions, including freeze-up dates. From this information, it was possible to relate the general movements of waterfowl with census data derived from Region I of the study.

State Game and Fish Department Records

State waterfowl biologists in the Central Flyway were interviewed and their census records surveyed. Although the majority of these records did not provide the systematic censusing required for this study, some of the aerial censuses were helpful. Notable among these was the aerial waterfowl survey by Ray Murdy, Maurice Anderson, and Leo Kirsch who made weekly counts over the Missouri River, Red Lake, and Lake Andes areas of South Dakota during the 1953, 1954, and 1955 fall waterfowl migrations. Another aerial census, conducted by The Colorado Cooperative Wildlife Research Unit under the direction of Jack R. Grieb, wildlife statistician, was confined to the north-central portion of Colorado, during the months of November and December, 1953 through 1955. A Texas Coastal Waterfowl Survey conducted by J. R. Singleton (1953) provided pertinent information concerning Region IV of the present study.

Federal Wildlife Refuge Census

Twenty-six Federal Wildlife Refuges in the Central Flyway were visited (Figure 3). At each location the refuge manager was interviewed. Banding data provided evidence of migration routes and the refuge narrative reports gave information relating to size of refuge, waterfowl usage, and effect of hunting pressure. Particular attention was given to specific habitat conditions, such as water level of impoundments and availability of food, which have a bearing on waterfowl populations.

Records from sixteen refuges were chosen for this study (Figure 1). The typical census data consisted of a weekly count of waterfowl with the census broken down to the species level. Data were obtained for the three fall periods of 1953, 1954, and 1955. Each fall period was divided into eighteen weeks, beginning about September 1 and extending to December 31.

Local Daily Census

Lake Overholser, a reservoir maintained by the Water Department of

Oklahoma City, was selected as the seventeenth census station. This impoundment, supplied by the North Canadian River, provides good habitat for migratory waterfowl. With the aid of lake rangers, daily population counts were made throughout the three fall periods. These were total population counts, with no attempt to provide species composition. Separate records were obtained for geese.

Weather Records

Weather data for the study were obtained from the Climatological Service Division, United States Weather Bureau, Washington, D. C. These records, sent directly from the National Weather Records Center, Asheville, North Carolina, included Climatological Data, Local Climatological Data and Supplement, Surface Weather Charts, and Upper Air Observations.

Climatological Data

This monthly publication was obtained for the entire study period for the states of Montana, North Dakota, South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas. Weather summaries for each state provided information related to general trends and unusual conditions. The publication provided daily weather data, including temperature (maximum and minimum) and precipitation (rain and snow). These data were selected from the United States Weather Station nearest the waterfowl census area.

Local Climatological Data and Supplement

This publication was secured for fifteen weather stations: Havre and Glasgow, Montana; Williston and Bismark, North Dakota; Rapid City, South Dakota; Valentine, Scottsbluff, and North Platte, Nebraska; Wichita, Kansas; Oklahoma City, Oklahoma; Roswell, New Mexico; Fort

Worth, Lubbock, Corpus Christi, and Brownsville, Texas. Records for two additional stations, Ponca City and Ardmore, Oklahoma were obtained by microfilm copy of Form WBAN 10, Surface Weather Observations.

Surface weather data obtained for these seventeen stations included temperature (maximum, minimum, average, and depreciation from normal), precipitation (rain and snow), wind (direction and speed), and sky cover.

Surface Weather Charts

From the National Weather Records Center, daily United States Surface Weather Charts for 1953 and North American Surface Weather Charts for 1954 and 1955 were obtained by microfilm. These provided 2,928 weather maps for the study period (three-hour charts for 122 days of each fall migration). The surface weather charts were used primarily for barometric pressure and frontal system records.

Upper Air Observations

Information concerning upper air wind (direction and speed) and atmospheric stability was derived from microfilm copies of Form WBAN 33, Summary of Constant Pressure Data. Records up to the 700 millibar level were obtained for the third and fifteenth hours of each day of the study for each of the following stations: Glasgow, Montana; Bismark, North Dakota; Rapid City and Huron, South Dakota; Scottsbluff and North Platte, Nebraska; Oklahoma City, Oklahoma; Fort Worth, Corpus Christi, and Brownsville, Texas. Microfilm copies of WBAN 22, Winds Aloft Summary Form, were obtained for Havre, Montana; Williston, North Dakota; Wichita, Kansas; Roswell, New Mexico; and Lubbock, Texas.

From the upper air records, wind direction and speed were derived for each 1,000 feet above surface level, extending to the 7,000 foot

REGION (1) ______

STATION (2) ______

Pop.	Geese	Ducks	Dabblers	Divers	Date	Max. Temp.	Min. Temp.	Ave. Temp.	Dep. Nor.	Rain	Snow	Dir. Wind	Speed Wind	Sky Cover	Baro. Pres.	Fr. Sys.	Time Fr.P.	Dir. U. W. Night	Speed U. W. Night	Dir. U. W. Day	Speed U. W. Day	Sta. N.	Sta. D.
3-9	10-14	15-21	22-28	29-35	36-39	40-42	43-44	45-46	47-48	49-52	53-55	56-57	58-60	61-62	63-67	68	69-70	71-72	73-74	75-76	77-78	79	80

Figure 4. Sample of original data sheet designed to correspond to the IBM 80-column punch card. One month of data was tabulated on each sheet. System of coding is presented in Appendix A, (Table I).

level. Atmospheric stability was derived by plotting (on a pseudo-adiabatic chart) temperatures at the various elevations from surface to the 700 millibar level. By comparing the existing temperature lapse rate with the adiabatic lapse rate, the atmosphere was classified as stable, conditionally unstable, or unstable.

Analysis of Data

Waterfowl census figures and weather records were tabulated on data sheets designed to correspond to the IBM 80-column punch card (Figure 4). With the assistance of the Oklahoma State University Computer Center, the data were placed on punch cards and programmed for a reduction of data to meaningful measures. With the information in this condensed form, the investigator sought to determine whether waterfowl migration and weather factors were related.

CHAPTER V

GENERAL WEATHER CONDITIONS

The fall seasons of 1953, 1954, and 1955 provided varied climatological conditions for migratory movements of waterfowl in the Central Flyway. The 1953 season, generally mild, began with drought conditions. November rains filled refuge impoundments to normal levels. Above average temperatures throughout the 1954 season resulted in open water until the end of the fall period. Extreme drought conditions were not appreciably relieved by rains. In contrast to the two previous seasons, 1955 was characterized by an exceptionally early arrival of winter in the northern states. By the first week of November, water areas were frozen and did not open again during the remainder of the period. Heavy snowfalls with frequent blizzards were common. Conditions in the south were near normal.

Fall Migratory Period of 1953

Region I. Mild temperatures and drought conditions prevailed throughout the region for a major portion of the period. September and October were extremely warm. Montana records revealed the third warmest October in forty-nine years and North Dakota data gave evidence of the warmest October since the beginning of the state's climatological records. November continued the warm, dry trend. Above average temperatures in December kept the snow cover to a minimum; however, precipitation was above normal (Weather Bureau, 1954, 1954a).

Water levels on the refuges were generally high at the beginning of the period, but lowered as drought prevailed. The first snowfall came November 26 at Lostwood Refuge and arrived December 1 at Des Lacs Refuge, approximately one month later than normal. Bowdoin Refuge in Montana had open water until December 15.

Region II. The warm weather prevailing in Region I was also present here. September and October were very dry months. South Dakota had the fourth warmest October on record and November was the sixth warmest since 1890 (Weather Bureau, 1954b). Nebraska had a warm fall period. Drought conditions in the north were also present in Region II for September and October. Precipitation came in November with Nebraska receiving above nromal amounts. South Dakota and Nebraska received heavy snowfalls (Weather Bureau, 1954b, 1954c).

Refuges had adequate water levels in lakes and impoundments throughout the period. The Valentine Refuge in Nebraska had very little snow and no prolonged cold weather. Crescent Lake Refuge had fair weather throughout the period. In South Dakota, mild weather prevailed at the Lacreek Refuge. The weather here is usually more mild than that of the surrounding areas, apparently the result of a chinook influence produced by the 7,000 foot Black Hills uplift.

Region III. The season began with above normal temperatures. The entire area was warm and dry in September. Weather records from New Mexico revealed the driest September in 62 years. October was a warm month in New Mexico, but North Texas and Oklahoma had cooler temperatures as a result of extensive rains. In New Mexico the rains did not arrive until November. The first general freeze in Oklahoma and North Texas occurred November 9. December was mild in the eastern part of the region and unusually cold in the west (Weather Bureau, 1954e, 1954f).

Most of the refuges had low water levels at the beginning of the period. Rains that came near the middle of autumn produced favorable conditions for the arrival of migratory waterfowl.

Region IV. The weather along the Gulf Coast of Texas was variable throughout the fall months. September was very warm, but below normal. October temperatures were about average, but below normal conditions returned in November; however, a freeze did not occur. December was a month of intermittent invasion of cold air masses (Weather Bureau, 1954f).

Precipitation for September was below normal. Heavy rains arrived in October, but a drying trend began in November and continued in December. Water levels on the Aransas and Laguna Atascosa Refuges were adequate throughout the period.

Fall Migratory Period of 1954

Region I. The period was characterized by a cooler than normal September, near normal temperatures in October, followed by unusually warm months of November and December. Above normal amounts of precipitation occurred throughout the region in September, but drought conditions prevailed for the next three months. In Eastern Montana, the first snow occurred in late September. A general snowstorm covered the state on October 24. With only scattered snowstorms in November and December, the ranges were nearly free of snow at the close of the period (Weather Bureau, 1955). North Dakota received light snowfall during the last half of the period. In only one instance in the state climatological records was December warmer and precipitation less (Weather Bureau, 1955a).

Rains which filled refuge impoundments in September were sufficient to provide adequate supply during the remainder of the period. Proof of mild weather was evident from the existence of open water until the last week of December at Bowdoin Refuge in Montana. Lostwood Refuge, North Dakota reported a temporary freeze-over on November 1, when temperatures lowered to 2° F. Above normal temperatures for the remainder of the period caused water areas to re-open.

Region II. September was warmer than normal. A cool October was followed by above normal temperatures the last half of the period. Amounts of precipitation varied within the region. Nebraska was dry in September, but South Dakota received normal amounts of precipitation. Throughout the region, October was wet and cloudy, followed by a drying trend for the next two months. South Dakota received the first general snowstorm, October 24-26, and the second major storm on November 30. Heavy snowfalls along the northern border of Nebraska came the last of November. Both states had an extremely warm December. November and December total precipitation in Nebraska was the lowest since 1904 (Weather Bureau, 1955b, 1955c).

Because of rains early in the period, water levels were adequate on the refuges. Except for temporary freeze-overs on November 29 and 30 at Lacreek Refuge, South Dakota, and on November 2 at Valentine Refuge, Nebraska, open water existed throughout most of the period. Conditions to the south at Crescent Lake and North Platte Refuges were similar.

Region III. Exceptionally warm temperatures prevailed throughout Oklahoma, North Texas, and Eastern New Mexico during September and the first half of October. Drought conditions existed throughout the region during this time. In the previous fifty-five years, Oklahoma had only one September with higher temperatures and less rain. North Texas reported only one September which was drier. Drought conditions were terminated by a cold rainy period which arrived the last of October. In Eastern New Mexico, warm moist air from the Gulf of Mexico arrived early in October, resulting in heavy rains and extensive flooding in the Pecos River area. November and December were mild and dry (Weather Bureau, 1955d, 1955e, 1955f).

Most of the refuges had low water levels at the beginning of the period. Rains arriving in October aided Tishomingo and Hagerman Refuges, but Salt Plains and Muleshoe Refuges showed little change. Conditions at Salt Plains Refuge, Oklahoma, were so serious that the lake became saline, causing a heavy fish-kill. Waterfowl used the lake only for resting. Bitter Lake Refuge, New Mexico, which had a low water level in September, was in good condition by November, despite damage from the flooding Pecos River.

Region IV. Weather on the Gulf Coast during autumn, 1954, was similar to conditions in Region III. September was hot and dry. The first two weeks of October continued the trend and then returned to normal for the remainder of the month. Precipitation in October was excessive, with over ten inches in much of the coastal region. November and December were warm, dry months. No freezing temperatures occurred during the period (Weather Bureau, 1955f).

The Aransas Refuge received more than normal rainfall for the period; however, most of the precipitation came in heavy rains during a few days interval. In spite of these October rains, lakes were fall from full. Tides during the period were exceptionally low, resulting in drainage of much of the tide flats. Laguna Atascosa Refuge had low water levels until the October rains arrived. Impoundments maintained satisfactory levels for waterfowl use.

Fall Migratory Period of 1955

Region I. The 1955 weather differed completely from that of the two previous years. Mild weather prevailed during most of September and October. The last few days of October were unusually cold and winter weather arrived nearly two months early. November and December were exceptionally cold months. November was the coldest in Montana since 1896. Temperatures averaged 19.6° F., which was 12.3° F. below normal (Weather Bureau, 1956). Temperatures in North Dakota were 12.0° F. below normal for November. December was 8.5° F. below normal (Weather Bureau, 1956a). Below normal precipitation in September and October was followed by normal amounts in November and December. Snowfall in Montana was twice the normal amount for the state. North Dakota had similar conditions. Blizzards were reported on several occasions.

Refuges had adequate water levels. Winter that arrived early produced a "freeze-up" by November 3 and continued for the remainder of the period. The condition which existed at Lostwood Refuge, North Dakota was typical for the region. Rain arrived October 27, and snow on October 31. The first two days of November established the pattern for the month. Strong, cold northwest winds and blowing snow produced the first blizzard of winter. Temperatures dropped to 1° F. below zero on November 3 and froze all water areas. From November 11 to the end of the month, the minimum temperature exceeded zero only on four days.

Region II. Weather in this region followed the same pattern as in Region I. The first half of the period, September and October, was mild with above normal temperatures. November and December were cold. South Dakota reported the coldest November on record. Cold temperatures intensified in December. Nebraska was extremely cold during this same time. Considerable precipitation arrived in September, but the drying trend returned in October. Snowstorms which came with the winter weather of November provided considerable precipitation in Western Nebraska, but South Dakota and Eastern Nebraska were still in need of moisture. Heavy snows in December provided normal precipitation throughout the region. Blizzards were common during the last two months of the period (Weather Bureau, 1956b, 1956c).

Water levels on the refuges were adequate. Valentine Refuge, Nebraska, had a general reduction in water in the impoundments, but larger lakes maintained adequate levels for waterfowl use.

Region III. The characteristic weather pattern of Regions I and II was reflected in the northern part of Region III (Oklahoma), but the southern part of the region (North Texas and Eastern New Mexico) was less affected by the surge of Arctic air that brought an early winter to the northern states. In Oklahoma, September and October were warm months with considerable rainfall. A return to dry weather occurred in November and continued in December. During this half of the period, temperatures were considerably below normal with a series of cold fronts invading the state (Weather Bureau, 1956d). Average temperatures in North Texas and Eastern New Mexico were normal to slightly above normal for this entire 1955 period, although some alternating cold and warm weather was experienced in November. The period was generally dry, although rains which arrived in late September and early October filled many of the ponds (Weather Bureau, 1956e, 1956f).

Low water levels existed at the beginning of the period. September and October rains improved the conditions considerably. Sufficient water was present to accommodate the migratory waterfowl.

Region IV. The 1955 weather on the Gulf Coast was different from that of the previous year. September was warm with above normal precipitation. The next two months were dry with normal temperatures. The drying trend continued in December, as temperatures dropped below normal during the third week. A killing frost arrived at Aransas Refuge on December 11 (Weather Bureau, 1956f).

Water levels at the Aransas and Laguna Atascosa Refuges were high from the early rains that filled all impoundments. Good water storage remained throughout the period.

CHAPTER VI

MIGRATION PATTERNS

General Movement of Waterfowl

Waterfowl patterns of migration in the Central Flyway were determined by tabulating weekly population counts at each station in the study region. The eighteen census periods were those designated by the United States Fish and Wildlife Service, Washington, D. C. The region count for each census period was the combined station counts. An example is given in Table 1. The use of region totals eliminates many population fluctuations which are the result of local conditions at each station. Migration patterns were determined for total waterfowl, geese, dabbler ducks (five representative species), and diver ducks (four representative species).

Migration of Total Waterfowl

Region I. The northern border states of Montana and North Dakota had numerous waterfowl at the beginning of the autumn season. Total of the four stations in the region ranged between 100,000 and 260,000 (Figure 5). Peak populations were reached between October 8 and 22, followed a general southward movement. By November 30, most of the waterfowl had left the region. Similar patterns of population build-up were found in each year of this study. In 1953 and 1955, peak populations were reached during the seventh week; whereas, the 1954 peak came one week earlier. By mid-October, 1953 and 1954, southward migration was widespread throughout

Table 1. Weekly census for total waterfowl at six stations in Region 3, autumn 1953.

Census Period	Salt Plains	Lake Overholser	Tisho-mingo	Hager-man	Mule-shoe	Bitter Lake	Region Total
1	70	30		44	60		204
2	1,431	90		56	108	186	1,871
3	1,361	300		75	342	775	2,853
4	1,418	1,500		245	373	1,009	4,545
5	1,333	2,000	95	205	127	2,021	5,781
6	3,755	1,003	130	1,170	150	3,390	9,598
7	9,773	4,125	3,000	2,550	227	3,159	22,834
8	19,200	7,200	5,570	2,407	1,900	6,966	43,423
9	26,890	300	9,200	6,308	6,008	25,890	75,003
10	26,610	300	19,160	6,575	10,020	24,338	87,003
11	28,060	2,000	19,160	10,594	20,152	27,661	107,627
12	38,820	3,500	58,500	22,097	28,052	29,945	180,914
13	38,820	5,005	37,800	50,345	75,000	32,455	239,425
14	39,440	8,000	31,300	92,646	83,001	33,934	288,321
15	42,460	10,000	9,735	93,805	119,426	35,977	311,393
16	36,230	10,000	5,501	95,095	129,583	19,701	296,110
17	37,276	9,000	2,505	97,245	129,485	14,807	288,318
18	35,046	10,000	370	93,640	129,485	45,728	314,269

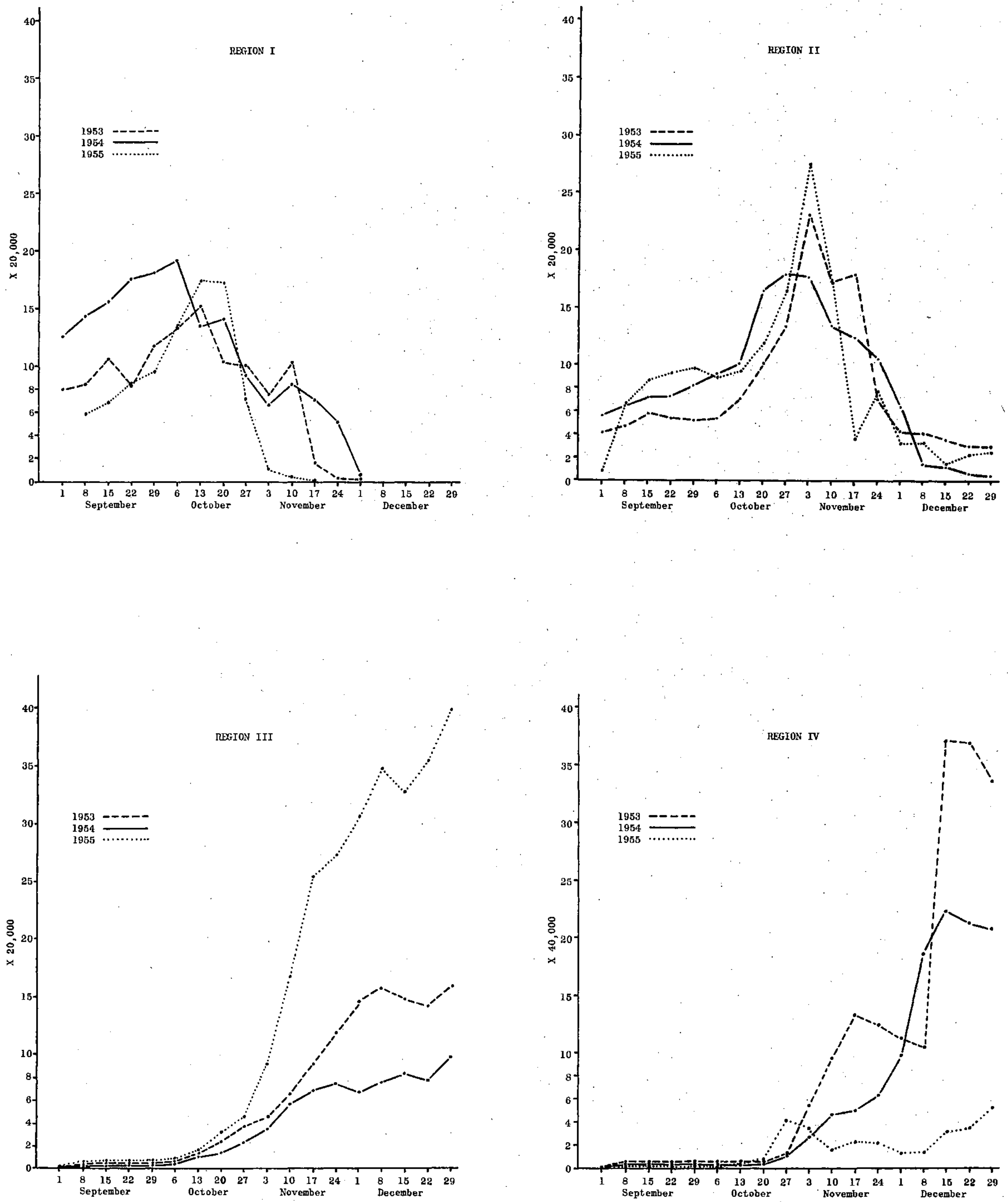


Figure 5. Patterns of total waterfowl migration in the Central Flyway, fall periods of 1953, 1954, and 1955. Weekly population numbers are census totals of the stations in the region, (Appendix B, Tables II and III).

the region. Waterfowl began moving south one week later in 1955; however, the movement was greater and nearly all birds left the region by the first week in November.

Region II. South Dakota and Nebraska began the autumn periods with concentrations of waterfowl ranging between 17,000 and 111,000 at the five stations in the region. The patterns of population build-up for the three years of study were similar. Peak populations were reached between October 27 and November 3. General movement south began the first week of November and by December 15, populations had reduced to the level at which the autumn began. Many waterfowl remained until the close of the period, December 31. More than 60,000 were still in the area by this date in 1953. Comparison of the three years revealed a similar pattern of general movement. As in Region I, the 1955 southward migration was more intense than the other two years. A population of 555,275 on November 3 was reduced to 75,255 by November 17 (Figure 5).

Region III. Oklahoma, North Texas, and Eastern New Mexico had practically no waterfowl on the six census stations at the beginning of the autumn period. Few birds arrived from the north before October 15. About November 1, a general migration from the north became evident. This population increased until the end of the period. Comparison of the three years revelaed much higher population in 1955. A peak population of 798,394 was reached by December 29. Between November 3-17, mass departures were reported in Region II and mass arrivals were evident in Region III (Figure 5).

Region IV. Migratory waterfowl were absent from the Gulf coastal area at the start of the autumn periods. Very few waterfowl arrived from the north before the last of October. The 1953 and 1954 migratory patterns were similar although numbers of waterfowl differed. The 1955 population remained low in comparison to the two previous years. Peak population for 1955 was 222,298 compared to 1,485,856 in 1953.

From the foregoing study, it appears that by September 1 a large number of waterfowl are already present in the northern border states of Montana and North Dakota. Populations continue to build-up until the middle of October. A general southward migration begins at this time and may be completed by the first week of December. South Dakota and Nebraska have fewer birds than the northern states at the beginning of the autumn period. Peak populations appear to be reached two weeks later in Region II. Although many waterfowl leave the region by December 15, appreciable numbers remain in the area. Data in this study imply few birds arrive in Oklahoma, North Texas, and Eastern New Mexico before November 1. From this date until December 31, populations continue to increase.

Waterfowl migrations during 1953 and 1954 were similar with general movement of birds through Regions I and II and with good population build up in Regions III and IV. The year 1955 was decidedly different. Populations built up in Regions I and II and then a mass southward movement occurred during a brief period of time. Oklahoma and North Texas had exceptionally high populations of wintering waterfowl, but the birds never arrived at the Gulf coastal stations, Aransas National Wildlife Refuge and Laguna Atascosa National Wildlife Refuge.

Migration of Geese

<u>Region I</u>. Goose populations in Montana and North Dakota remained at low levels during the three years of this study. Peak population for the

four stations was 6,410 occurring in 1954. Geese moved into the region early in the autumn migratory period and reached a peak population during the last week of September or the first week of October. A general movement south began early in October. By the end of the month, most birds had departed except for a few scattered populations which remained until the end of November (Figure 6).

Region II. The population of geese in South Dakota and Nebraska, like that of Region I, never reached a high level. Peak population during the study was 5,194 in 1953. Very few geese were in the region before October 1. Arrivals from the north began at this time and continued until November 3-10, when peak levels were reached. By November 17 most of the geese had departed. In 1953 major arrivals occurred between October 6-13 and numbers of geese reached a peak by November 3. Populations never built up in 1954, for only a total of 2,080 geese were reported for any census period. Counts in 1955 were near the 1953 level, but the build-up came three weeks later (Figure 6).

Region III. Oklahoma and North Texas had the largest concentrations of geese in the Central Flyway of the continental United States. A peak population of 47,288 was reached in 1955. Few birds arrived in the area before October 1. During the next six weeks, major flights from the north brought the populations to peak levels by November 17. Although population reductions occurred from this date until the close of the period, many geese remained beyond December 31. Migration patterns for the three years were similar. The major exception was the rapid reduction in 1955 when many geese moved south into Region IV.

Region IV. Goose populations on the Texas Gulf Coast never reached the

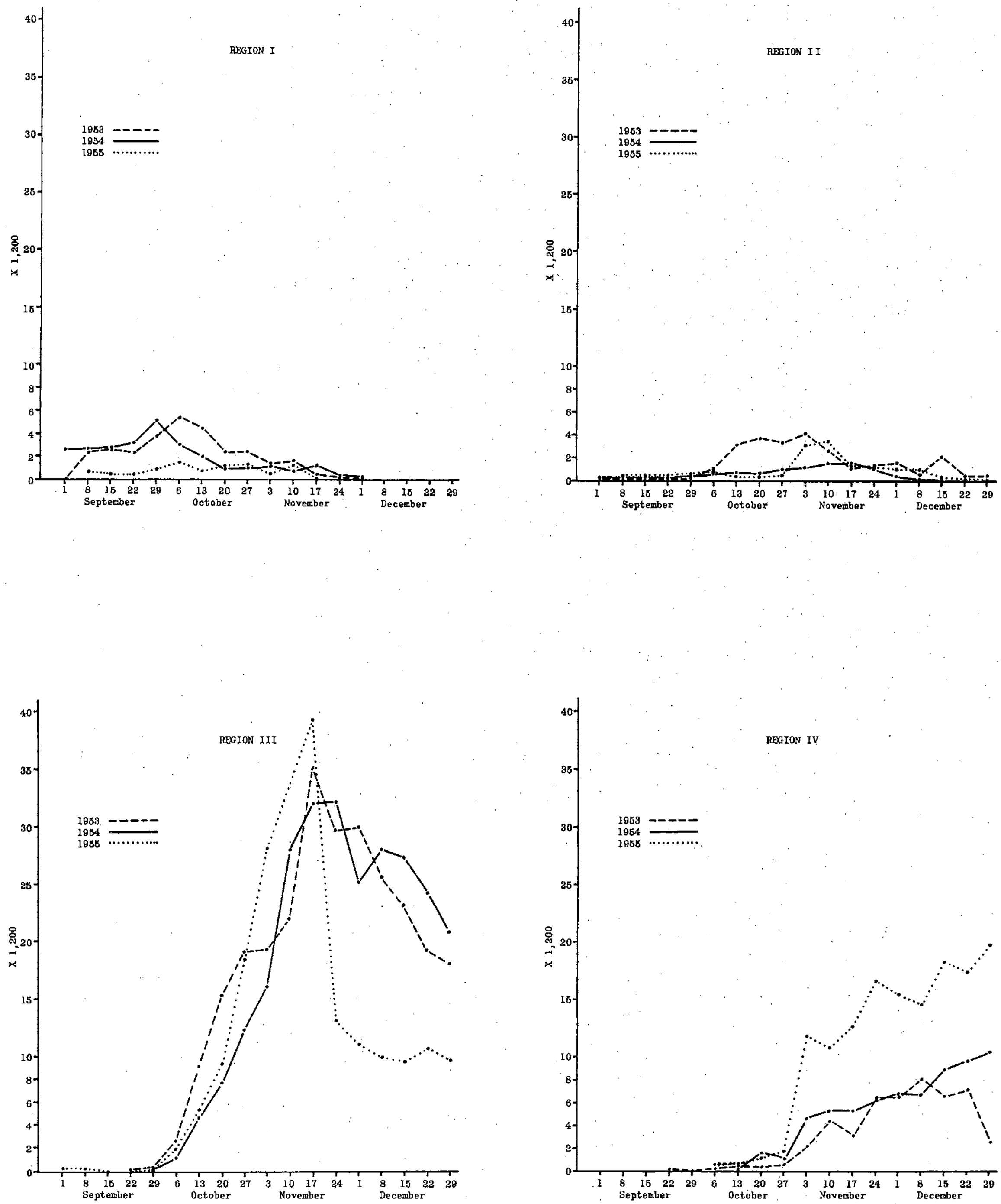


Figure 6. Patterns of goose migration in the Central Flyway, fall periods of 1953, 1954, and 1955. Weekly population numbers are census totals of the stations in the region, (Appendix B, Tables IV and V).

proportions of Region III. Few geese were observed in the area before October 1 and then only scattered flights arrived during the next four weeks. A noticeable movement began the first week in November and populations increased gradually until the last of the period (Figure 6). The 1953 and 1954 migrations were very similar, but 1955 was different. During the first week of November, the population increased from 2,397 to 14,252. From November 3 until the end of the period populations fluctuated, although a general upward trend occurred until a total of 23,822 geese were in the area.

Migration of geese in the Central Flyway appears to follow a different pattern than that of total waterfowl. Very few geese were observed in Region I and II. Oklahoma and North Texas, Region III, received high populations of wintering birds. Most of the geese remained in this area and only in an unusual year (1955) did many arrive on the Gulf Coast of Texas. It appears that most geese either move through the northern states without stopping or they remain for only a few days and then move south, never permitting a population build-up. Refuge managers in northern regions cited many instances of major flights of geese that never stopped at refuges during southward migration.

Migration of Dabbler Ducks

Five species of dabbler ducks (subfamily, Anatinae) were selected as representative of the surface feeding ducks. These included: common mallard, Anas platyrhynchos platyrhynchos; gadwall, Chaulelasmus streperus; American pintail, Dafila acuta tzitzihoa; and shoveller, Spatula clypeata. These five species compare favorably in size (Kortright, 1942) and speed of flight (Cottam, 1942). Since the surface feeding ducks comprise the greater part of total waterfowl populations, it is understandable that dabbler migratory patterns would approximate the patterns of total waterfowl. A review of weekly population shifts in each of the four regions reveals almost identical patterns of movement (Figures 5 and 7).

Migration of Diver Ducks

Four species of the subfamily Nyrocine were selected as representative of diving ducks. These included: redhead, *Nyroca americana*; ring-necked duck, *Nyroca collaris*; canvasback, *Nyroca valisineria*; and lesser scaup, *Nyroca affinis*. The migratory pattern of these ducks was different from that of the dabblers and in some respects was similar to the movement of geese.

Region I. Diving duck populations began to build up very early in the autumn migratory period. Major flights began near the middle of September and continued until peak populations were reached between October 6-20 (Figure 8). In 1955 a peak population of 90,180, highest of the three year study, occurred on October 20. A general departure from the region was evident late in October and by November 17 most of the birds had left. In the 1953 and 1954 seasons, a second population build-up was observed between October 27 and November 10. Most of the divers left the region two weeks earlier in 1955. By November 3 only 4,010 were observed on the four stations and two weeks later, November 17, all had departed.

Region II. Divers began to arrive the last week of September and the first week of October. Peak populations were reached between October 27 and November 3. In each of the three years, a major departure occurred from November 3-10 and by December 1 most of the divers had left the region.

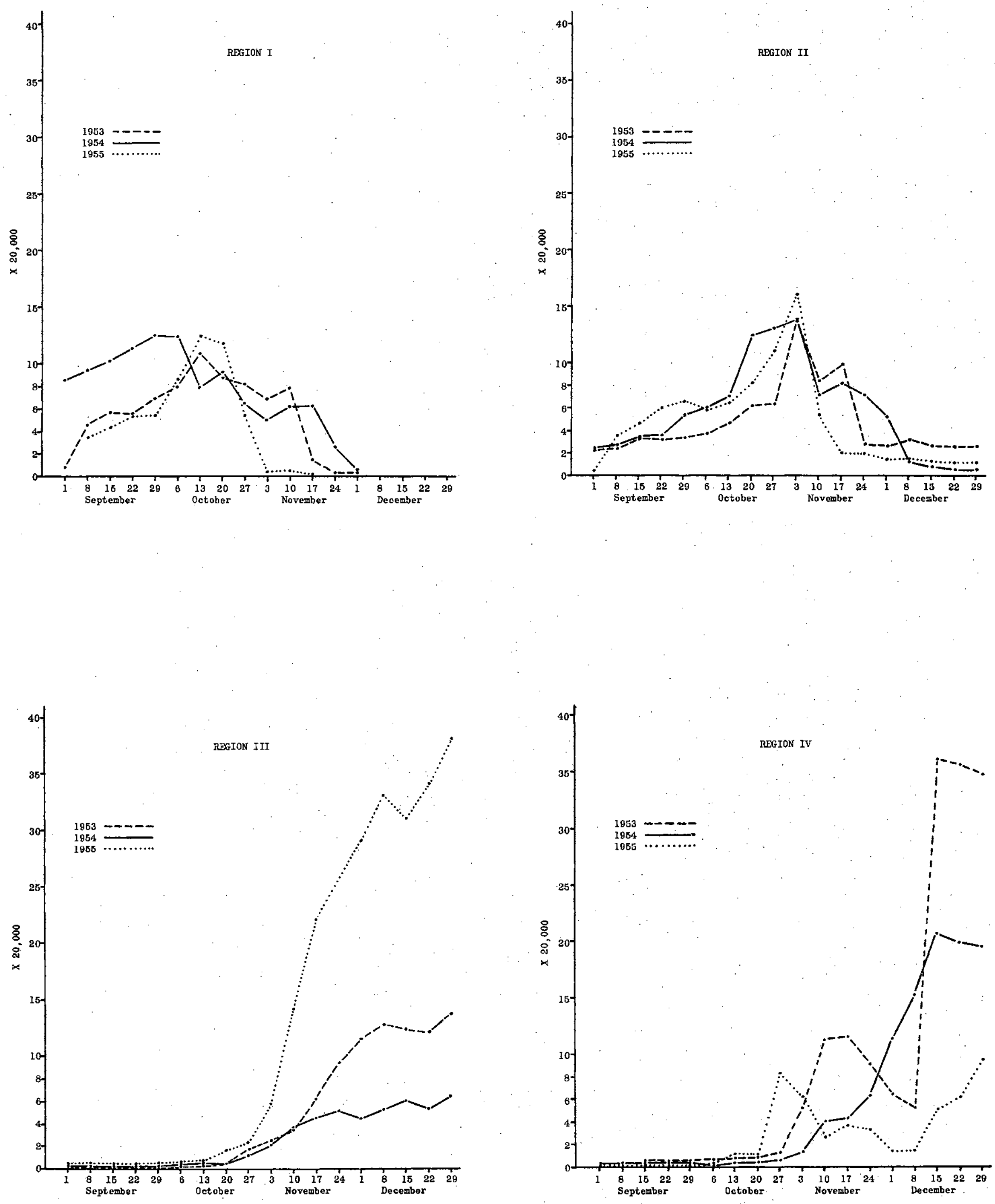


Figure 7. Patterns of dabbler duck migration in the Central Flyway, fall periods of 1953, 1954, and 1955. Weekly population numbers are census totals of the stations in the region, (Appendix B, Tables VI and VII).

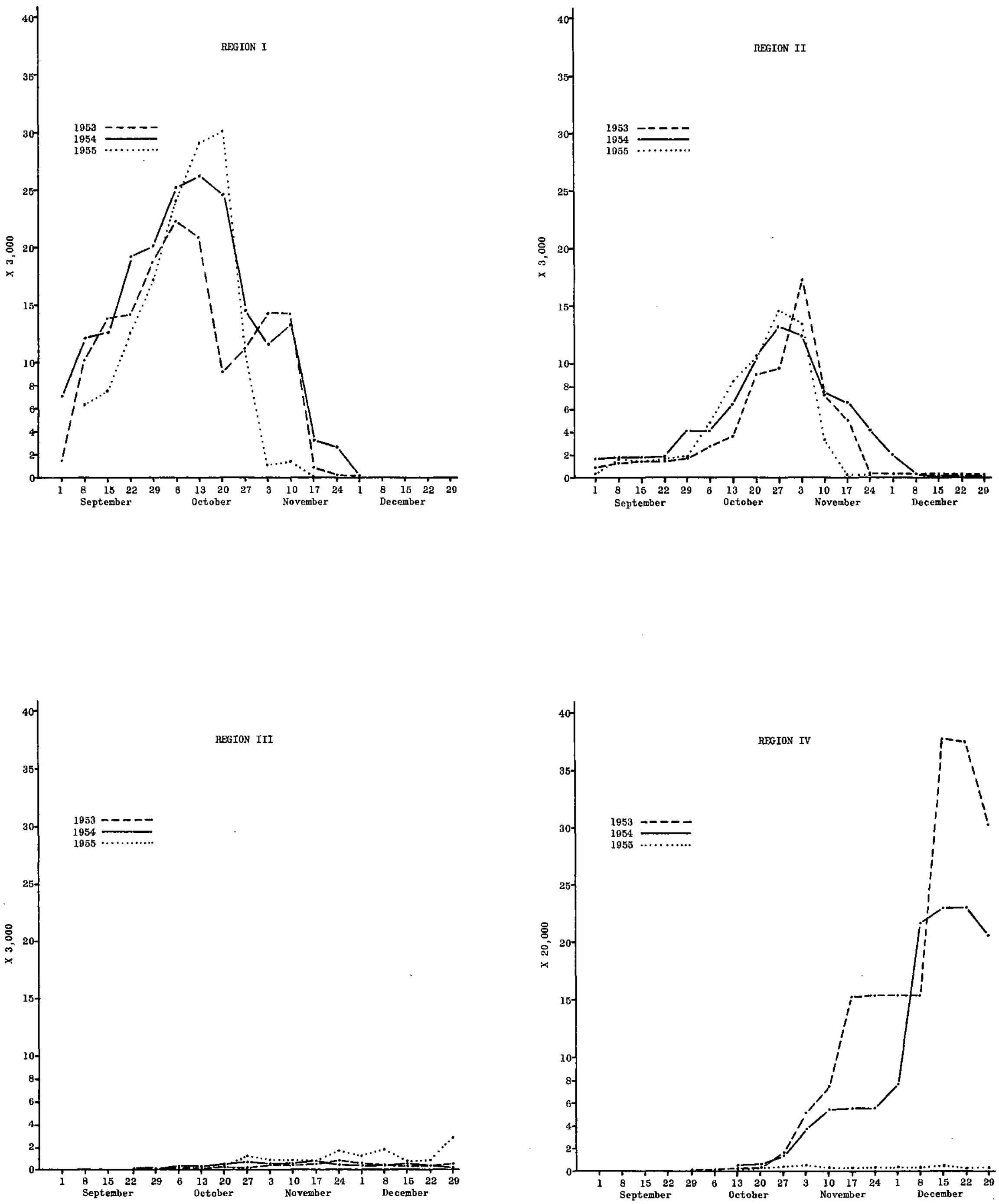


Figure 8. Patterns of diver duck migration in the Central Flyway, fall periods of 1953, 1954, and 1955. Weekly population numbers are census totals of the stations in the region, (Appendix B, Tables VIII and IX).

Except for a more rapid departure in 1955, the patterns of movement for the three years were very much alike.

Region III. The most striking observation in Oklahoma and North Texas was the apparent scarcity of diver ducks in the area. There was no population build-up during this study (Figure 8). Peak population for the six stations was 2,000 in 1953; 1,863 in 1954; and 8,007 in 1955.

Region IV. Along the Texas Gulf Coast, major flights of diving ducks arrived the first week of November in the 1953 and 1954 seasons. Population build-up continued until about December 15, when a small departure occurred. In 1953 a peak of 754,147 birds were observed on December 15. In 1955 the divers never came in appreciable numbers (Figure 8). Since the populations in Region III were extremely low, the location of these divers in 1955 baffled refuge managers. It was though that the general wet conditions north of the coastal region were especially attractive to waterfowl. The Laguna Atascosa Wildlife Refuge was little used by the great concentrations of redhead ducks which were very prominent there the two previous years.

Comparison of the migratory patterns of the diving and surface feeding ducks in the Central Flyway indicates that divers begin a major population build-up approximately two weeks before the dabblers. They reach peak populations about the same time. Departure dates are also similar. The divers appear to by-pass Region III, but the dabblers winter there in great numbers. The mallard, Anas platyrhynchos and pintail, Dafila acuta tzitzihoa are the dominant species. Region IV has approximately an equal number of dabbler and divers, each represented by one species that dominates the population. The dominant dabbler is the pintail, Dafila acuta tzitzihoa, and the redhead, Nyroca americana, is the dominant diver. In 1953 when peak waterfowl population for this region was 1,485,856, the pintail count was 446,462 and the redhead count, 451,604. These two species comprised 60 per cent of the total waterfowl. Comparison of diver and dabbler migration patterns in the Gulf coastal region reveals definite similarity.

Major Migratory Movements

For the purpose of this study, it was desirable to analyze only mass movements of waterfowl. The definition of a major movement created a problem, for the seventeen census stations varied greatly in size and, consequently, their waterfowl carrying capacity. The extremes in size ranged from 443 acres at Lake Andes National Wildlife Refuge, South Dakota to 70,401 acres at Valentine National Wildlife Refuge, Nebraska (Table 2). A standard reflecting the character of each census area was derived from the peak population (Appendix C, Tables 10, 11, 12, and 13). Any movement reflecting a change of 30 per cent of the peak population for that particular season (eighteen weeks) was considered a major movement. The major migratory movements for this study included: total waterfowl, 88; geese, 95; dabbler ducks, 76; and diver ducks, 100 (Table 3).

Major Movements of Total Waterfowl

1953 Migration. Mass migratory movements consisted of thirteen arrivals and nineteen departures. There was a concentration of migratory activity in Regions I and II; whereas, Regions III and IV had a scattering of the migratory movements. Between weekly censuses 7 and 8, October 14-21, major movements were recorded from the Canadian border, south to New Mexico (Figure 9). A second period of movement, though less concentrated,

Table 2. Acreage of the 17 census stations

Station	Acreage
Region 1	
1. Bowdoin N. W. R., Montana	15,437
2. Des Lacs N. W. R., North Dakota	18,841
3. Lostwood N. W. R., North Dakota	26,107
4. Long Lake N. W. R., North Dakota	22,732
Region 2	
1. Lake Andes N. W. R., South Dakota	443
2. LaCreek N. W. R., South Dakota	9,442
3. Valentine N. W. R., Nebraska	70,401
4. Crescent Lake N. W. R., Nebraska	46,540
5. North Platte N. W. R., Nebraska	5,107
Region 3	
1. Salt Plains N. W. R., Oklahoma	31,129
2. Lake Overholser, Oklahoma	1,700
3. Tishomingo N. W. R., Oklahoma	13,449
4. Hagerman N. W. R., Texas	11,429
5. Muleshoe N. W. R., Texas	5,807
6. Bitter Lake N. W. R., New Mexico	23,923
Region 4	
1. Aransas N. W. R., Texas	47,261
2. Laguna Atascosa N. W. R., Texas	38,759

Table 3. Major arrivals and departures of waterfowl in the Central Flyway, 1953, 1954, and 1955.

Migratory Flights	Year 1953	Year 1954	Year 1955	Three Year Total
Total Waterfowl				
Arrivals	13	14	12	39
Departures	19	11	19	49
Total	32	25	31	88
Geese				
Arrivals	19	20	19	58
Departures	9	12	16	37
Total	27	32	35	95
Dabbler Ducks				
Arrivals	13	11	14	38
Departures	14	9	16	39
Total	27	20	30	77
Diver Ducks				
Arrivals	19	16	13	48
Departures	16	18	18	52
Total	35	34	31	100

came between November 4-18 in Regions I and II. Major movements terminated by November 25 in the two northern regions and approximately one month later in the two southern areas. Texas Gulf Coast received its first major arrival between November 4-11.

1954 Migration. Migratory flights totaled twenty-five, a reduction from the previous year. One period of concentrated movement occurred November 3-7 in Regions I, II, and III (Figure 9). Movements were earlier this year in the northern areas, but continued later, until December 1. Less activity in Regions III and IV implies many birds remained north in 1954.

1955 Migration. This year was characterized by mass movements of waterfowl departing for the south in massive flights. Major movements occurred between October 26 and November 2. In Region I no major movements occurred after this date (Figure 9). Mass migration was apparent during the same period in Region II and even on the Texas Gulf Coast an early arrival date was reported.

Major Movements of Geese

1953 Migration. Geese migrated early in the autumn period, with the initial major movements occurring the first week of October. Three major migratory periods were observed in Region I: September 30 to October 7, October 14-21 and November 4-11. Region II had two periods of major movement, the first two weeks in October and November 4-11. Region III had little activity except for Lake Overholser, Oklahoma, where three arrivals and two departures occurred late in September and early in October. These movements generally coincided with those of the northern regions.

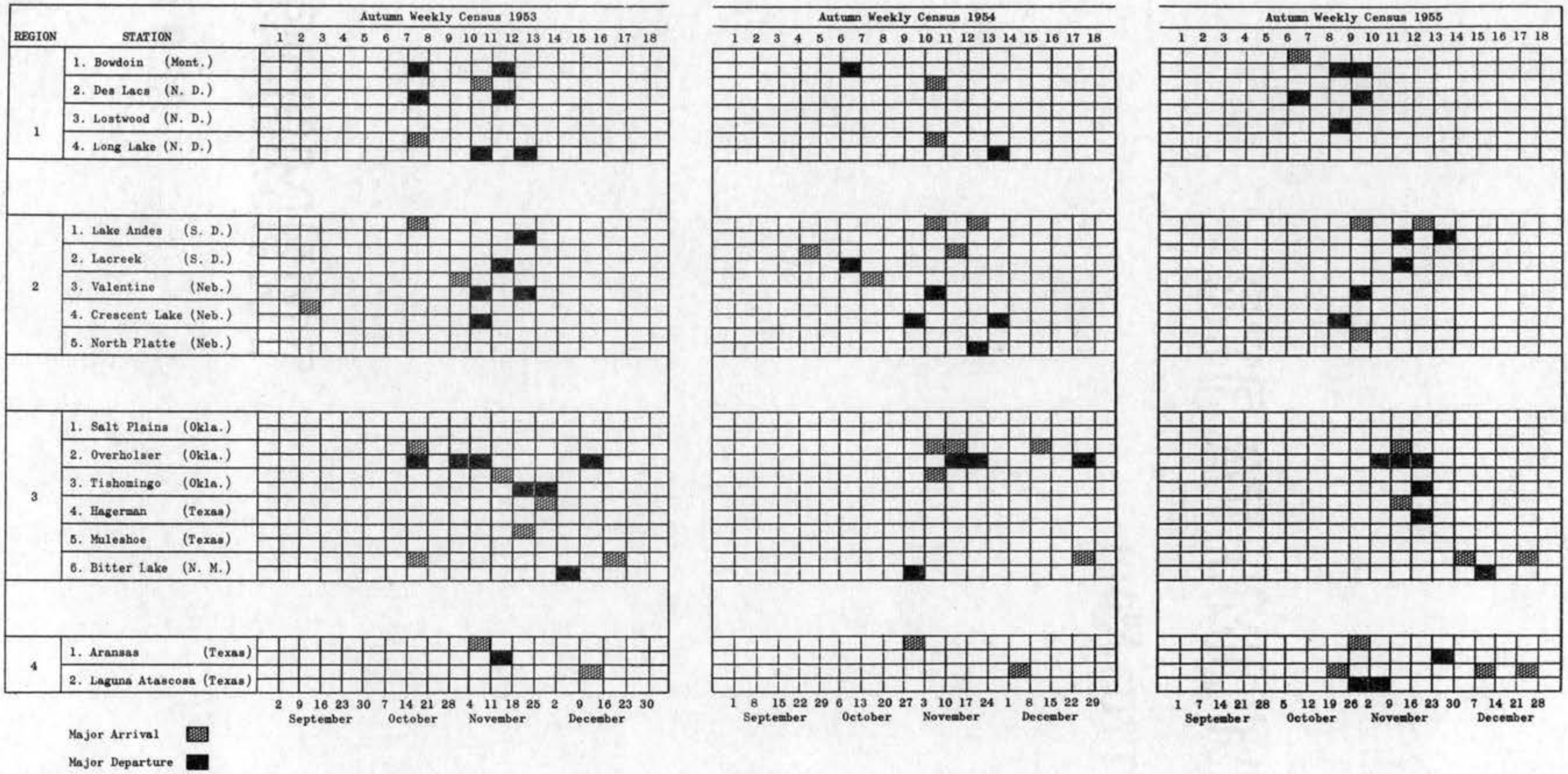


Figure 9. Major migratory flights of total waterfowl in the Central Flyway, fall periods of 1953, 1954 and 1955. Any movement reflecting a change of at least 30 percent of the peak population for that particular season (eighteen weeks) was considered a major movement, (Appendix C, Table X).

1954 Migration. As in the previous year, a major movement occurred between weekly census 5 and 6, September 29 to October 6, in the two northern regions (Figure 10). Region II had the greatest activity with fourteen major movements, 44 per cent of the flyway total for the year. The last major flight was delayed this year until December 1-8.

1955 Migration. The characteristic mass migration noted in total waterfowl movements for 1955 did not appear in the migration of geese in Montana and North Dakota. Considerable concentration of movements did occur in South Dakota and Nebraska between October 27 and November 17. During this period six major arrivals and five major departures were recorded (Figure 10). Region III had ten major movements which were spaced throughout a thirteen week period beginning September 25 and ending December 22.

Major Movement of Dabbler Ducks

Mass migration of dabblers, surface feeding ducks, was determined by a study of five representative species, as given earlier in this report. A comparison of Figures 9 and 11 reveals similar migratory patterns. Since surface feeding ducks comprise a major part of the total waterfowl population, similar patterns of movement would be expected. The 1955 mass migration between October 26 and November 2, reported for total waterfowl and geese was very obvious in the dabbler pattern of movement (Figure 11). During this period, major migratory movments were reported from the Canadian border to the Texas Gulf Coast.

Dabbling ducks and geese demonstrated different migratory behavior patterns. Major flights of geese moved through Regions I and II approximately two weeks before the major flights of dabblers. Region III,

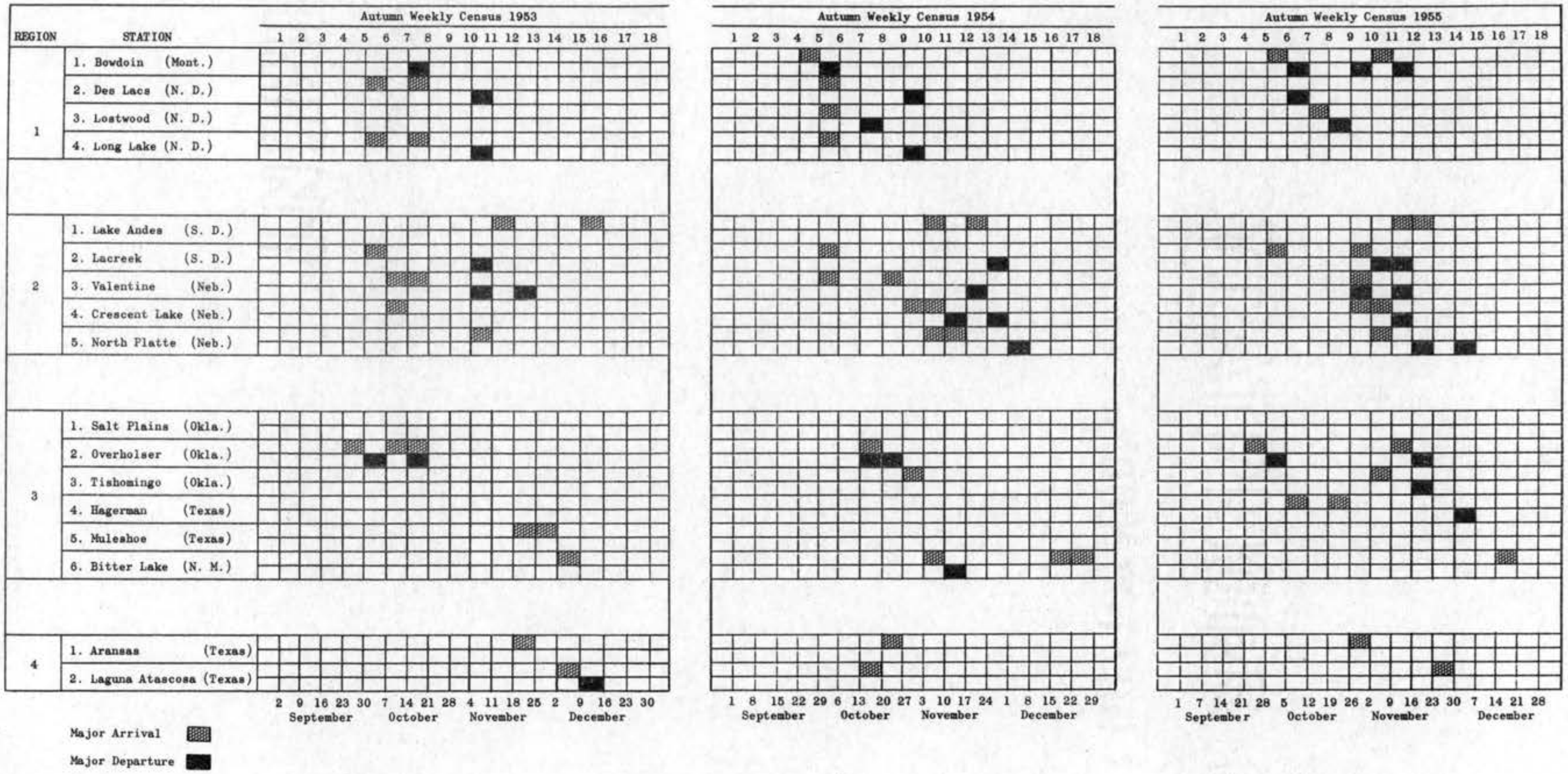


Figure 10. Major migratory flights of geese in the Central Flyway, fall periods of 1953, 1954, and 1955. Any movement reflecting a change of at least 30 percent of the peak population for that particular season (eighteen weeks) was considered a major movement, (Appendix C, Table XI).

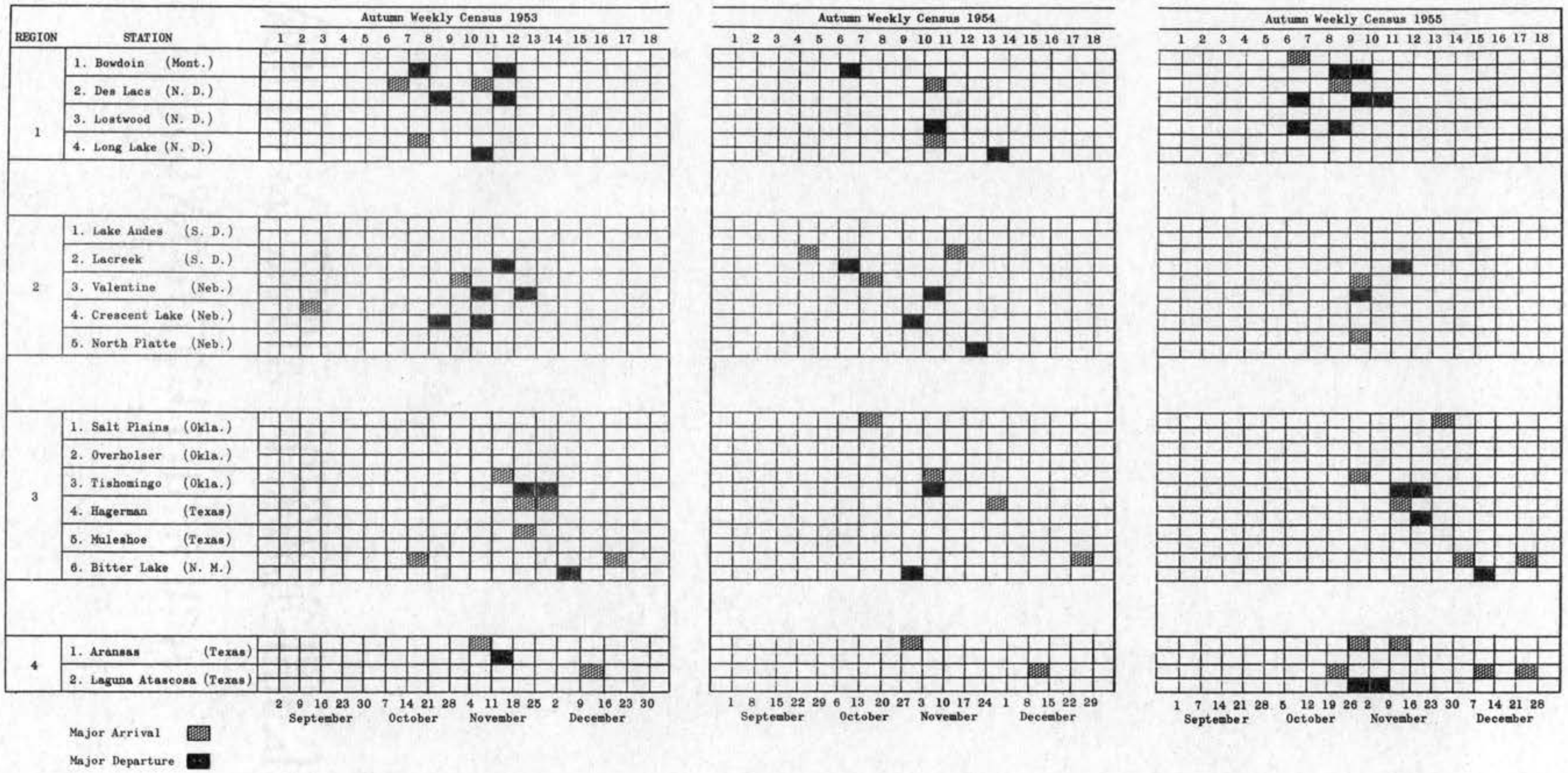


Figure 11. Major migratory flights of dabbler ducks in the Central Flyway, fall periods of 1953, 1954, and 1955. Any movement reflecting a change of at least 30 percent of the peak population for that particular season (eighteen weeks) was considered a major movement, (Appendix C, Table XII).

Oklahoma and North Texas, had few major flights of geese. Since many are known to winter here, it appears that population build-up is one of gradual increase. Major dabbler flights are evident. Vew few geese, but many ducks, arrive at the Gulf Coast.

Major Movement of Diver Ducks

Mass movements of the diver ducks were studied by analysis of records from four representative species, as indicated earlier in this report. Compared with other types of waterfowl, migratory movements of divers revealed a more general scattering of flights.

1953 Migration. In Regions I and II, major arrivals were observed the first week in September and the final mass movement, the last week in November. Two extensive migrations were noted. The first, reported in Regions I, II, and III, occurred between October 14-21. The second mass migration, represented by major departures in Montana, North Dakota, and South Dakota and by major arrivals in New Mexico and Texas, occurred between November 11-18 (Figure 12).

1954 Migration. Major movements were concentrated more in the months of October and November. A five week period from October 13 to November 17 had twenty-five of the total movements, or 71 per cent of the flyway total for the season.

1955 Migration. The pattern of movement for the 1955 fall period consisted of mass migration within a small period of time. In Regions I and II a total of nine major movements, seven departures and two arrivals, occurred between October 19 and November 2 (Figure 12). In Region I, this was the only activity for the season. Region II had only one arrival

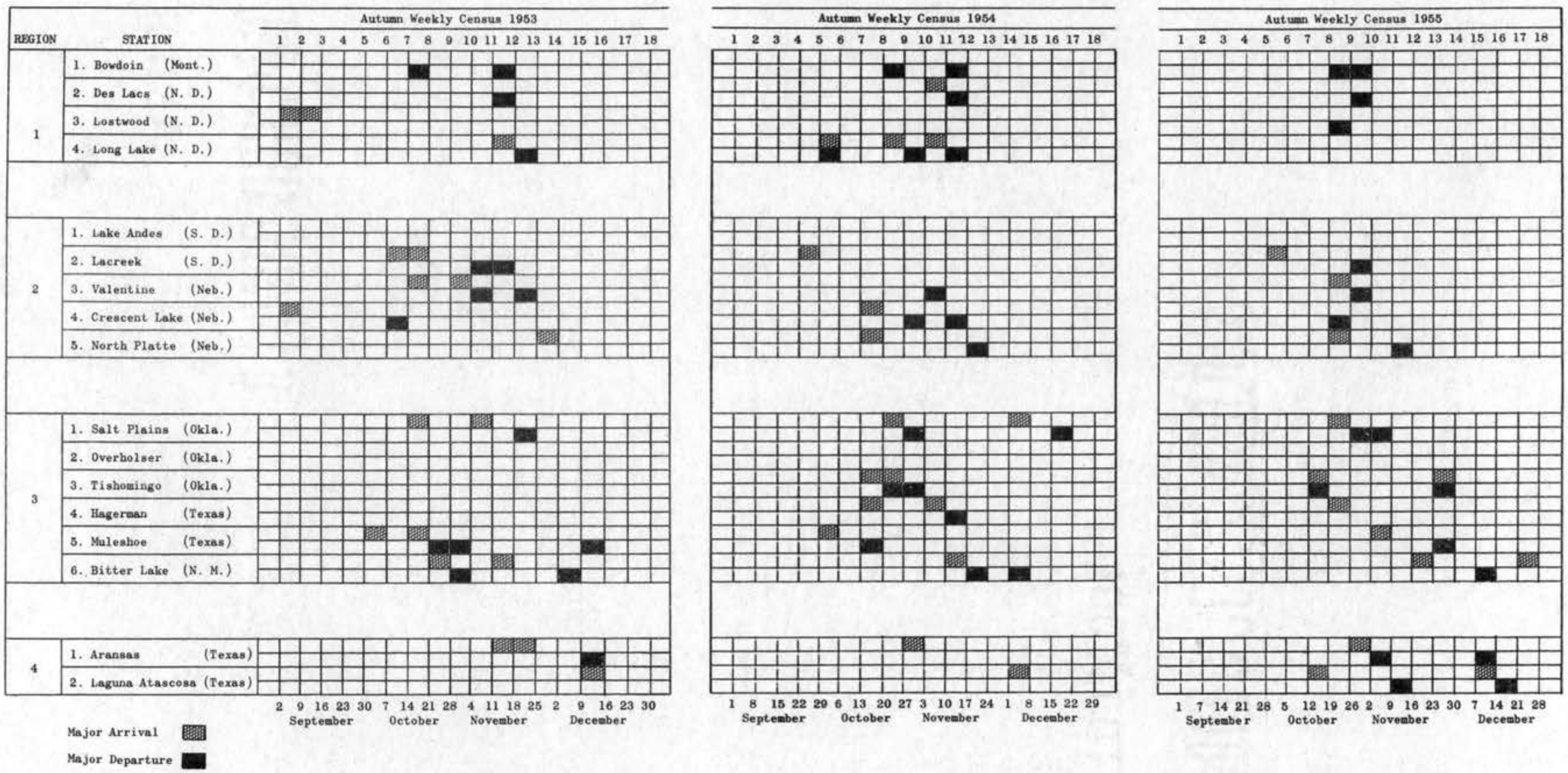


Figure 12. Major migratory flights of diver ducks in the Central Flyway, fall periods of 1953, 1954 and 1955. Any movement reflecting a change of at least 30 percent of the peak population for that particular season (eighteen weeks) was considered a major movement, (Appendix C, Table XIII).

previous to this date and one departure later. This was the year winter arrived in the northern regions nearly one month early. These conditions prevailed until the close of the period, December 31. Migratory flights in Regions III and IV were less concentrated. The Gulf Coast had seven major migratory flights, the greatest number for the three year study.

CHAPTER VII

RELATION OF WEATHER TO MIGRATION

Daily weather conditions at each of the seventeen waterfowl census stations were studied for each 122-day migratory period of 1953, 1954, and 1955. Ten weather factors were considered. Weather conditions during periods of mass migration were compared with conditions during periods of no migratory movement. Mass movements of total waterfowl, geese, dabbler ducks, and diver ducks were investigated. Refuge waterfowl counts are made weekly; therefore, the exact day of migratory movement was not known. Any change in population which was at least thirty per cent of the peak population for that season was identified as a major movement. Changes in weather factors during the seven days when the movement occurred were analyzed and mean climatological conditions were noted.

A stable population was difficult to define. In addition to varied sizes of the census stations, different census methods were employed by refuge managers. It was apparent that small shifts in population should be disregarded. At first, any population change of no more than five per cent of the peak population was considered a stable condition. By using this standard, it was found that Region II had a larger number of stable periods than Region I; and Regions III and IV had nearly three times the number of the first region. Such a condition might be expected, since waterfowl stop to rest and feed for progressively longer periods of time as they move closer to their wintering grounds. A graduated standard was established to obtain a more uniform number of stable population periods for each region. Stable conditions, as related to percentage of peak population for each station, were set at five per cent for Region I; four per cent, Region II; three per cent, Region III; and two per cent, Region IV. This method provided the following stable periods of population: total waterfowl, 207; geese, 65; dabbler ducks, 176; and diver ducks, 79. By employing a standard sampling procedure, the waterfowl and dabbler duck stable population periods for study were reduced to 104 and 88, respectively.

Temperature

Daily temperature records, listing maximum, minimum, and mean values, were related to periods of migratory movement. Maximum daily temperature is the highest temperature recorded for the 24-hour period. Minimum daily temperature is the lowest temperature recorded for a similar period of time. The United States Weather Bureau at present uses the following formula to determine the mean (average) daily temperature: maximum + minimum ÷ 2. The daily mean is the average of the highest and lowest temperatures recorded during the 24-hour period. In relating temperature to migration, primary consideration was given to the kind of temperature change during the seven-day period when migratory movement or population stability occurred. Temperature was classed as: rising, falling, variable, or stable.

Maximum Temperature

Analysis of the 39 major arrivals of total waterfowl revealed that 54.4 per cent of the flights occurred when the temperature was stable in the area of the birds' destination. Remainder of the arrivals were evenly distributed among periods of rising, falling, and variable temperature (Table 4). Of the 49 periods of major migratory departure, 55.1 per cent occurred when the daily maximum temperature was falling. Movements during periods of rising, variable, and stable temperature were greatly reduced. In 104 instances of no migratory movement between weekly census counts, 60.6 per cent of the periods had stable temperature conditions. Only 10.6 per cent had rising temperature, 14.4 per cent, falling temperature and 14.4 per cent, fluctuating temperatures. The foregoing data indicate that a general falling temperature is a significant factor in the migratory departure of waterfowl. Once the birds have departed, they apparently continue their flight until they arrive in an area with stable temperature. Periods when no migration occurred were characterized by high incidence of stable temperature.

The relationship of goose populations and daily maximum temperature is not as strong as reported for total waterfowl. Of the 58 major arrivals, 34.4 per cent occurred in periods of stable temperature. Falling temperature was evident 27.6 per cent of the time; whereas, arrivals with rising temperature occurred 19.0 per cent of the periods (Table 5). As with total waterfowl, migratory departure of geese occurred more frequently with falling temperature, 43.2 per cent of the periods; however, the number of departure periods with variable temperature, 35.2 per cent, was sizeable. A seven-day census period with variable temperatures would indicate a drop in temperature with a following rise or a series of dropping and rising temperatures. Since only 10.8 per cent of the departures took place with rising temperature, one might assume the temperature drop was the significant factor in the variable temperature. Examination of the 65 periods, when no migration occurred, indicates that geese are not

Table 4. Relationship of total waterfowl populations and daily maximum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Maximum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	2	2	1	5	12.8
Falling	2	1	3	6	15.4
Variable	3	1	2	6	15.4
Stable	6	10	6	22	56.4
Total	13	14	12	39	100.0
Major Departures					
Rising	6	0	2	8	16.3
Falling	10	7	10	27	55.1
Variable	1	1	5	7	14.3
Stable	2	3	2	7	14.3
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
Rising	7	3	1	11	10.6
Falling	7	3	5	15	14.4
Variable	4	5	6	15	14.4
Stable	22	26	15	63	60.6
Total	40	37	27	104	100.0

Table 5. Relationship of goose populations and daily maximum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Maximum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	3	4	4	11	19.0
Falling	6	4	6	16	27.6
Variable	3	4	4	11	10.0
Stable	7	8	5	20	34.4
Total	19	20	19	58	100.0
Major Departures					
Rising	3	0	1	4	10.8
Falling	2	7	7	16	43.2
Variable	4	3	6	13	35.2
Stable	0	2	2	4	10.8
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
Rising	4	2	2	8	12.3
Falling	6	5	3	14	21.5
Variable	2	10	7	19	29.2
Stable	12	8	4	24	37.0
Total	24	25	16	65	100.0

as sensitive to changes in maximum temperature. Although 37 per cent of these periods had stable temperatures, the combination of the periods with falling and variable temperatures accounted for 50.7 per cent of all periods when no migration occurred.

Examination of the major movements of dabbler ducks reveals a pattern of migration similar to that of total waterfowl populations. Since a majority of waterfowl are dabbler ducks, a similar pattern of flight would be expected. It is seen, for example, in Table 6, that most of these ducks arrived during periods of stable temperature, 47.4 per cent of the periods. As with total waterfowl, major departures occurred with falling temperature, 46.3 per cent of the periods. In 53.2 per cent of the periods with no migratory flights, maximum temperatures were stable.

The relationship of diving duck populations and maximum temperature is less obvious than for the surface feeding ducks. Comparison of Tables 5 and 7 indicates migratory flights of diving ducks are surprisingly similar to those of geese. Major departures of the divers resulted when the maximum temperature was falling, 38.5 per cent of the periods, and when the maximum temperature was variable, 36.5 per cent of the periods. Stable temperatures prevail for 37.5 per cent of arrival periods, with other factors less common. Analysis of the periods with no migratory movement suggested little evidence of relationship to maximum temperature change.

Minimum Temperature

Study of minimum daily temperatures, as related to migratory movements of total waterfowl, indicated departures were more common with

Table 6. Relationship of dabbling duck populations and daily maximum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Maximum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	2	2	0	4	10.5
Falling	2	2	3	7	18.4
Variable	4	1	4	9	23.7
Stable	5	6	7	18	47.4
Total	13	11	14	38	100.0
Major Departures					
Rising	5	0	2	7	17.9
Falling	8	3	7	18	46.3
Variable	0	1	6	7	17.9
Stable	1	5	1	7	17.9
Total	14	9	16	39	100.0
Weekly Census Periods With Stable Populations					
Rising	3	2	4	9	10.2
Falling	8	3	3	14	15.9
Variable	8	3	8	19	21.6
Stable	12	23	11	46	52.3
Total	31	31	26	88	100.0

Table 7. Relationship of diving duck populations and daily maximum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Maximum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	6	4	1	11	22.9
Falling	5	2	3	10	20.8
Variable	2	5	2	9	18.8
Stable	6	5	7	18	37.5
Total	19	16	13	48	100.0
Major Departures					
Rising	2	1	1	4	7.7
Falling	6	6	8	20	38.5
Variable	4	6	9	19	36.5
Stable	4	5	0	9	17.3
Total	16	18	18	52	100.0
Weekly Census Periods With Stable Populations					
Rising	6	5	3	14	17.7
Falling	4	10	5	19	24.1
Variable	8	7	8	23	29.1
Stable	9	10	4	23	29.1
Total	27	32	20	79	100.0

falling temperature. Periods of population stability were common when the minimum temperature was likewise stable. Migratory arrivals, though slightly more frequent during periods of stable temperature, seemed to be less related to temperature factors. Data in Table 8 suggest that falling minimum temperature is a strong factor in migratory departure. This thermal change existed during 55.1 per cent of the departure periods; whereas, the minimum temperature was stable 65.4 per cent of the periods when no flights were encountered. Comparison of Tables 4 and 8 provides some evidence that minimum temperature change is more important than maximum temperature as a stimulus initiating migratory movement.

Of a total of 37 major departures of geese in the Central Flyway, 59.5 per cent were encountered during periods of falling minimum temperatures. This compares with a falling maximum temperature 43.2 per cent of the time (Tables 5 and 9). Weekly census periods with no change in goose populations had stable minimum temperatures 46.1 per cent of the periods, as compared to stable maximum temperatures 37.0 per cent of the time. The foregoing data indicates that minimum temperature may be a strong stimulus in initiating migratory departure of geese. There appeared to be little correlation between minimum temperature change and migratory arrival.

A study of the relation of minimum temperature and dabbler duck migration provides evidence of the importance of such a weather factor as a possible stimulus to migratory movement. As with geese, minimum temperature change appears to be a stronger factor than maximum temperature (Tables 6 and 10). Major departures occurred 48.7 per cent of the periods when minimum temperature was falling. In contrast, temperature was rising 10.3 per cent; variable, 12.8 per cent; and stable, 28.2 per cent of the periods of the southward movements. Periods with no

Table 8. Relationship of total waterfowl populations and daily minimum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Minimum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	4	1	1	6	15.4
Falling	4	4	2	10	25.6
Variable	2	3	4	9	23.1
Stable	3	6	5	14	35.9
Total	13	14	12	39	100.0
Major Departures					
Rising	1	0	2	3	6.1
Falling	10	5	12	27	55.1
Variable	2	0	3	5	10.2
Stable	6	6	2	14	28.6
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
Rising	3	4	0	7	6.7
Falling	7	5	6	18	17.3
Variable	3	4	4	11	10.6
Stable	27	24	17	68	65.4
Total	40	37	27	104	100.0

Table 9. Relationship of goose populations and daily minimum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Minimum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	4	5	4	13	22.4
Falling	8	7	5	20	34.5
Variable	3	4	5	12	20.7
Stable	4	4	5	13	22.4
Total	19	20	19	58	100.0
Major Departures					
Rising	0	0	1	1	2.7
Falling	4	7	11	22	59.5
Variable	2	2	2	6	16.2
Stable	3	3	2	8	21.6
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
Rising	2	2	1	5	7.7
Falling	6	6	3	15	23.1
Variable	3	5	7	15	23.1
Stable	13	12	5	30	46.1
Total	24	25	16	65	100.0

Table 10. Relationship of dabbling duck populations and daily minimum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Minimum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	4	0	0	4	10.5
Falling	4	5	2	11	28.9
Variable	1	1	7	9	23.7
Stable	4	5	5	14	36.9
Total	13	11	14	38	100.0
Major Departures					
Rising	1	0	3	4	10.3
Falling	6	5	8	19	48.7
Variable	2	0	3	5	12.8
Stable	5	4	2	11	28.2
Total	14	9	16	39	100.0
Weekly Census Periods With Stable Populations					
Rising	1	3	3	7	8.0
Falling	8	8	2	18	20.5
Variable	5	2	4	11	12.5
Stable	17	18	17	52	59.0
Total	31	31	26	88	100.0

migratory movement appeared to be associated with stable minimum temperature. This condition was present 59.0 per cent of the time, as compared with 8.0 per cent rising, 20.5 per cent falling, and 12.5 per cent variable minimum temperature. Although arrivals were slightly more common during stable temperature conditions, there was little evidence of a relationship to a minimum temperature factor.

Evidence that minimum temperature change may trigger migratory flight of diver ducks is less apparent than for the dabbler ducks. However, a comparison of maximum and minimum temperature factors (Tables 7 and 11) suggests that minimum temperature change provides a stronger stimulus than does maximum temperature. A total of 48.1 per cent of the departures occurred with a falling maximum temperature.

Average Temperature

Study of daily average temperature and migration of total waterfowl provides additional evidence of a relationship between temperature and migratory movement. Falling mean temperatures occurred during 49.0 per cent of the migratory departures compared to 17.3 per cent of the periods with stable waterfowl populations. These periods of population stability had an accompanying 60.6 per cent stable mean temperature (Table 12). Migratory arrivals were more prevalent during similar periods of stable mean temperature.

The data, relating daily average temperature to goose migration, infer that temperature change is an influencing factor in migratory movement (Table 13). However, average temperature appears less important than minimum temperature in initiating migration. Examination of Tables 9 and 13 reveals that 59.5 per cent of migratory departures

Table 11. Relationship of diving duck populations and daily minimum temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Minimum Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	3	3	0	6	12.5
Falling	3	4	2	9	18.8
Variable	2	4	7	13	27.1
Stable	11	5	4	20	41.6
Total	19	16	13	48	100.0
Major Departures					
Rising	1	2	2	5	9.6
Falling	9	7	9	25	48.1
Variable	2	3	5	10	19.2
Stable	4	6	2	12	23.1
Total	16	18	18	52	100.0
Weekly Census Periods With Stable Populations					
Rising	4	4	3	11	13.9
Falling	5	9	5	19	24.1
Variable	6	9	7	22	27.9
Stable	12	10	5	27	34.1
Total	27	32	20	79	100.0

Table 12. Relationship of total waterfowl populations and daily average temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Average Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	3	0	1	4	10.3
Falling	2	2	1	5	12.8
Variable	2	3	4	9	23.1
Stable	6	9	6	21	53.8
Total	13	14	12	39	100.0
Major Departures					
Rising	4	0	1	5	10.2
Falling	8	6	10	24	49.0
Variable	5	1	6	12	24.5
Stable	2	4	2	8	16.3
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
Rising	4	6	1	11	10.6
Falling	8	6	4	18	17.3
Variable	4	2	6	12	11.5
Stable	24	23	16	63	50.6
Total	40	37	27	104	100.0

Table 13. Relationship of goose populations and daily average temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Average Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	4	4	6	14	24.1
Falling	6	5	5	16	27.6
Variable	3	3	7	13	22.4
Stable	6	8	1	15	25.9
Total	19	20	19	58	100.0
Major Departures					
Rising	2	0	1	3	8.1
Falling	1	7	9	17	45.9
Variable	3	2	3	8	21.6
Stable	3	3	3	9	24.4
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
Rising	3	5	1	9	13.8
Falling	5	5	3	13	20.0
Variable	3	8	7	18	27.7
Stable	13	7	5	25	38.5
Total	24	25	16	65	100.0

occurred during periods of falling minimum temperature; whereas, 45.9 per cent of departures occurred with a falling average temperature. Only a small number of geese migrated with a rising or stable temperature. There appears to be no relationship between goose arrivals and average temperature.

Study of dabbler duck migration suggested that average temperature is less important than minimum temperature as an influencing factor in migratory movement. Comparison of Tables 10 and 14 reveals that surface feeding ducks departed during 48.7 per cent of the periods with minimum falling temperature as compared to 35.9 per cent of the seven-day intervals when average temperature was falling. It is seen in Table 14 that weekly census periods with stable populations of dabblers were more frequently characterized by stable average temperatures. Arrivals of dabblers from the north were more common when temperatures were stable in the area of their destination.

The migratory movements of the diving ducks seem to have little relationship to average temperature conditions. Although many of these birds departed on their southward flight when daily average temperatures were falling or variable (Table 15), periods when there were no movements and periods of migratory arrivals showed no correlation to average thermal conditions. The migratory behavior of the divers was strikingly similar to that of the geese (Tables 13 and 15).

Frontal Systems

Between air masses of contrasting character is a relatively narrow zone of discontinuity which is called a frontal surface or front (Brands, 1944). Therefore, fronts are boundaries or separations between air masses.

Table 14. Relationship of dabbling duck populations and daily average temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Average Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
<u>Major Arrivals</u>					
Rising	3	0	0	3	7.9
Falling	2	3	2	7	18.4
Variable	1	2	5	8	21.1
Stable	7	6	7	20	52.6
Total	13	11	14	38	100.0
<u>Major Departures</u>					
Rising	4	0	2	6	15.4
Falling	4	3	7	14	35.9
Variable	4	1	6	11	28.2
Stable	2	5	1	8	20.5
Total	14	9	16	39	100.0
<u>Weekly Census Periods With Stable Populations</u>					
Rising	2	4	5	11	12.5
Falling	8	7	2	17	19.4
Variable	3	0	6	9	10.2
Stable	18	20	13	51	57.9
Total	31	31	26	88	100.0

Table 15. Relationship of diving duck populations and daily average temperatures, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Average Temperature	Number of Cases 1953	1954	1955	Total	Percent of Total
<u>Major Arrivals</u>					
Rising	5	3	0	8	16.6
Falling	5	5	2	12	25.0
Variable	1	6	7	14	29.2
Stable	8	2	4	14	29.2
Total	19	16	13	48	100.0
<u>Major Departures</u>					
Rising	2	2	0	4	7.7
Falling	7	5	7	19	36.6
Variable	5	5	9	19	36.6
Stable	2	6	2	10	19.1
Total	16	18	18	52	100.0
<u>Weekly Census Periods With Stable Populations</u>					
Rising	4	4	5	13	16.5
Falling	6	10	4	20	25.3
Variable	6	6	6	18	22.8
Stable	11	12	5	28	35.4
Total	27	32	20	79	100.0

All fronts can be divided into two major classes: cold fronts and warm fronts.

A cold front is a surface of discontinuity along which a wedge of cold air is underrunning and forcing warm air upward. In advance of the front, barometric pressure is falling, but begins to rise as the front passes. The temperature falls and the wind shifts from a southerly direction to a westerly or northerly direction (Kimble, 1955). Heavy precipitation and often thunderstorms are associated with a cold front. After the passage of the front, precipitation ceases, cloudiness decreases and visibility increases.

The warm front is a surface of discontinuity along which warm air flows over a mass of cold air. This warm air gradually displaces the cold air mass at the surface. The barometric pressure falls with the approach of the warm front and may show little change or only a slow fall after passage. Wind, which is from the south, tends to veer to the southwest. Steady drizzle or light rain frequently precedes the advance of a warm front. Although some clearing may take place after frontal passage, overcast sky and poor visibility are common (Halpine and Taylor, 1956). Warm fronts are less common in the fall months. Those that occur in the Central Flyway form most often in the southern part of the United States in conjunction with maritime tropical air from the Gulf of Mexico. These tropical air masses move poleward over the continent and become increasingly stable as the lower layers of air become cooled (Brands, 1944).

In this investigation of the relation of waterfowl migration to the passage of frontal systems, the seven-day interval between each census was classified into one of three categories, based on the presence of a cold front, a warm front, or the absence of a frontal system. Study of total waterfowl migration revealed that arrivals, departures, and periods of no migratory movement, were similar in their relation to frontal systems (Table 16). The fact that 74.4 per cent of the arrivals from the north, 73.5 per cent of the departures to the south, and 63.5 per cent of the stable population periods, all occurred during an interval when a cold front passed, implies no relationship to this factor. Examination of goose migration and frontal systems provided similar results (Table 17).

In the Central United States, cold air masses advance southeastward from Canada. They move at varying speeds, generally from 20 to 30 miles an hour (Fisher, 1958). In the fall and winter months, there is a cyclic flow of cold fronts from the northwest. In the northern states, these fronts are more frequent and, in some instances, two or three may move through the area in the course of a week. Because of the frequency of cold fronts, one might expect a high percentage during periods when waterfowl did not migrate.

A further study of frontal systems, as related to migration of dabbler ducks (Table 18), and diver ducks (Table 19), provided a pattern almost identical to that of total waterfowl and geese. The preceding data implies that frontal systems are unrelated to migratory movements of waterfowl. However, the fact that a positive correlation appeared to exist between temperature drop and migration caused the investigator to study the relative strengths of the cold fronts. The strength of a frontal system depends primarily on the difference in temperature between air masses. With a relatively large temperature contrast, the frontal surface grows strong and produces much turbulent weather. With a small contrast, the frontal surface may be weaker and less distinct

Table 16. Relationship of total waterfowl populations and frontal systems, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Frontal System	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Front	1	2	2	5	12.8
Cold	11	9	9	29	74.4
Warm	1	3	1	5	12.8
Total	13	14	12	39	100.0
Major Departures					
No Front	2	0	0	2	4.1
Cold	12	9	15	36	73.5
Warm	5	2	4	11	22.4
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
No Front	8	10	8	26	25.0
Cold	29	21	16	66	63.5
Warm	3	6	3	12	11.5
Total	40	37	27	104	100.0

Table 17. Relationship of goose populations and frontal systems, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Frontal System	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Front	2	1	2	5	8.6
Cold	15	14	13	42	72.4
Warm	2	5	4	11	19.0
Total	19	20	19	58	100.0
Major Departures					
No Front	1	0	2	3	8.1
Cold	7	10	12	29	78.4
Warm	1	2	2	5	13.5
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
No Front	5	2	0	7	10.8
Cold	16	22	16	54	83.1
Warm	3	1	0	4	6.1
Total	24	25	16	65	100.0

Table 18. Relationship of dabbler duck populations and frontal systems, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Frontal System	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Front	1	1	1	3	7.9
Cold	10	8	11	29	76.3
Warm	2	2	2	6	15.8
Total	13	11	14	38	100.0
Major Departures					
No Front	1	1	0	2	5.1
Cold	9	5	13	27	69.2
Warm	4	3	3	10	25.7
Total	14	9	16	39	100.0
Weekly Census Periods With Stable Populations					
No Front	7	7	8	22	25.0
Cold	22	20	16	58	65.9
Warm	2	4	2	8	9.1
Total	31	31	26	88	100.0

Table 19. Relationship of diver duck populations and frontal systems, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Frontal System	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Front	2	1	0	3	6.3
Cold	15	12	13	40	83.3
Warm	2	3	0	5	10.4
Total	19	16	13	48	100.0
Major Departures					
No Front	2	0	1	3	5.8
Cold	11	12	15	38	73.0
Warm	3	6	2	11	21.2
Total	16	18	18	52	100.0
Weekly Census Periods With Stable Populations					
No Front	3	2	2	7	8.9
Cold	18	21	17	56	70.8
Warm	6	9	1	16	20.3
Total	27	32	20	79	100.0

(Fisher, 1958). For the purpose of this study, any cold front that resulted in a drop in the daily mean temperature of less than 10° F. was classed as weak and a drop greater than this amount was considered a strong front. Table 20 contains the results of this investigation. Of 36 periods of migratory departure of total waterfowl, when cold fronts passed, 63.9 per cent were classed as strong and 36.1 per cent were weak. Conversely, during periods of population stability of total waterfowl, 36.9 per cent were strong and 63.6 per cent were weak. Migratory arrivals were more common during periods of passage of a strong cold front. Data for dabbler ducks were nearly identical to those for total waterfowl. The foregoing figures indicate a strong cold front is related to the migratory departure of waterfowl, particularly, surface feeding ducks. Evidence of a relationship of a strong cold front and the migration of geese and diver ducks is less convincing. Whereas geese departed during 69 per cent of the periods which had accompanying strong cold fronts, 55.6 per cent of the periods with stable populations also had a strong front. Diver duck migration appeared to be unrelated to the passage of a front. Strong fronts were about as common when the birds did not migrate as when they departed for the south.

Barometric Pressure

The heating and cooling of the atmosphere are the primary causes of weather changes. Because land heats and cools more rapidly than oceans, vast areas of unequal temperature join each other and bring development of semi-permanent high and low pressure areas. When a part of the earth's surface becomes warmer than the surrounding region, a low pressure area develops and the air rises. Conversely, a high pressure forms from overflow aloft from low pressure areas or by cooling of the earth's surface.

Table 20. Relationship of waterfowl migration and passage of a cold front, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Strength of Front	Total Waterfowl		Geese		Dabbler Ducks		Diver Ducks	
	Total	Percent	Total	Percent	Total	Percent	Total	Percent
Major Arrivals								
Weak Front	13	44.8	18	42.9	12	41.4	25	62.5
Strong Front	16	55.2	24	57.1	17	58.6	15	37.5
Total	29	100.0	42	100.0	29	100.0	40	100.0
Major Departures								
Weak Front	13	36.1	9	31.0	6	22.2	16	42.1
Strong Front	23	63.9	20	59.0	21	77.8	22	57.9
Total	36	100.0	29	100.0	27	100.0	38	100.0
Periods of Population Stability								
Weak Front	42	63.6	24	44.4	37	63.8	27	48.2
Strong Front	24	36.9	30	55.6	21	36.2	29	51.8
Total	66	100.0	54	100.0	58	100.0	56	100.0

As cool air contracts, air from above flows downward, increasing the total mass above the earth's surface and, thereby, producing a high pressure (Brands, 1944). These permanent pressure systems are responsible for our prevailing westerly and trade winds. Fluctuations in the size and shape of these permanent pressure systems give rise to development of wandering low and high pressure areas along their boundaries. These migratory pressure systems follow a general course from west to east, carried along by the prevailing westerlies (Blair, 1942). In their eastward movement, highs and lows often follow each other in regular succession. On the average, migratory highs and lows travel about 500 miles every 24 hours in summer and 700 miles a day in winter (Fisher, 1958). As these pressure systems move under the influence of the westerlies, air within each system is also circulating. In the Northern Hemisphere, air moves into a low from all directions, forming a counter-clockwise circulation; whereas, the air currents radiate outward from the center of a high pressure area, assuming a clockwise circulation. Thus, wind on the east side of a low pressure area would come from the southeast and be warm and wind on the west would come from the northwest and be cooler. Conversely, winds on the east side of a high pressure system would come from the northwest and on the west side, air currents would move from the southeast. It is apparent that the change in the pressure systems results in changing weather. The question has arisen concerning the relationship of changes in atmospheric pressure and a possible effect upon migration of birds. In this study, an attempt has been made to relate migratory movements to changes in pressure. Each census period has been classified as having rising, falling, or stable barometric pressure.

The 49 analyzed major departures of total waterfowl indicated 77.5

per cent of the movements were associated with periods of barometric change. In 40.8 per cent of the periods, a rising pressure was observed and falling pressure was encountered in 36.7 per cent of the departure periods. Only 22.5 per cent of the time was the pressure stable (Table 21). In contrast, arrivals were more common (48.8 per cent) during periods of stable pressure, and equally divided between falling and rising pressure, each 25.6 per cent. The periods of no migratory movement were characterized by pressure which was 46.2 per cent stable, 31.7 per cent falling, and 22.1 per cent rising. These data imply there is a higher incidence of barometric pressure change during periods of migratory departure than periods when the birds failed to migrate. The arrival data imply that these birds fly into an area of greater pressure stability.

The relationship of atmospheric pressure change and migration of geese is similar to that for total waterfowl. Of the 37 major periods of departure, 83.7 per cent occurred during a pressure change with 45.9 per cent of the movements during a barometric pressure rise. Less change in pressure occurred during periods of no migration. Data related to arrivals revealed less relationship to pressure factors (Table 22).

Records of dabbler ducks provided evidence of a stronger relationship to pressure than do the total waterfowl or goose records. Of 39 departures, 89.8 per cent were associated with a definite change in pressure, with 51.3 per cent associated with a rising pressure. Stable pressure was present only 10.2 per cent of the periods. In contrast to this, 46.6 per cent of the periods with no migration had stable pressure. As with total waterfowl, arrivals were more common during stable periods (Table 23).

The evidence of a relationship of diver duck migration and barometric pressure is less obvious. Although 80.7 per cent of the departures occurred with a strong pressure change, 63.3 per cent of the periods with

Table 21. Relationship of total waterfowl populations and barometric pressure, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Barometric Pressure	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	5	0	5	10	25.6
Falling	5	3	2	10	25.6
Stable	3	11	5	19	48.8
Total	13	14	12	39	100.0
Major Departures					
Rising	6	4	10	20	40.8
Falling	11	1	6	18	36.7
Stable	2	6	3	11	22.5
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
Rising	10	6	7	23	22.1
Falling	12	11	10	33	31.7
Stable	18	20	10	48	46.2
Total	40	37	27	104	100.0

Table 22. Relationship of goose populations and barometric pressure, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Barometric Pressure	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	6	3	6	15	25.9
Falling	8	5	8	21	36.2
Stable	5	12	5	22	37.9
Total	19	20	19	58	100.0
Major Departures					
Rising	2	4	11	17	45.9
Falling	5	5	4	14	37.8
Stable	2	3	1	6	16.3
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
Rising	5	10	8	23	35.4
Falling	6	6	4	16	24.6
Stable	13	9	4	26	40.0
Total	24	25	16	65	100.0

no movement had a change in pressure. The data indicate these birds frequently arrive during periods of stable barometric pressure (Table 24).

In the middle latitudes of the Northern Hemisphere, most low pressure systems are associated with fronts (Neuberger and Stephens, 1948). The lows are formed along a stationary front where two contrasting air masses oppose each other. Since this study gave evidence of a relationship between the passage of a strong cold front and migration of total waterfowl and dabbler ducks, it is undoubtedly true that the pressure relationship is a factor closely allied with the passage of a frontal system. With the approach of a cold front, the pressure falls and then rises after the front has passed. Since the pressure records indicate a greater departure of geese, dabbler and diving ducks with rising barometric pressure, the foregoing data would suggest a greater percentage of these birds make their migratory departure after the front has passed the census station. Careful study of the data indicates that the number of periods with a rising pressure were not significantly greater than the number of periods with a falling pressure. Consequently, the waterfowl appeared to depart about as often before arrival of a cold front as after frontal passage.

Since the census data were grouped into weekly periods, population changes that occurred during each census period were not recorded regularly. In all probability, the influence of the passage of fronts upon waterfowl movements was masked by the lack of precise data on the times of major arrivals and departures.

Surface Wind

Wind, defined as air moving parallel to the earth's surface, is usually the result of horizontal differences in air pressure. Two basic

Table 23. Relationship of dabbler duck populations and barometric pressure, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Barometric Pressure	Number of Cases 1953	1954	1955	Total	Percent of Total
<u>Major Arrivals</u>					
Rising	5	2	4	11	28.9
Falling	3	2	3	8	21.1
Stable	5	7	7	19	50.0
Total	13	11	14	38	100.0
<u>Major Departures</u>					
Rising	6	4	10	20	51.3
Falling	8	2	5	15	38.5
Stable	0	3	1	4	10.2
Total	14	9	16	39	100.0
<u>Weekly Census Periods With Stable Populations</u>					
Rising	12	6	6	24	27.3
Falling	5	12	6	23	26.1
Stable	14	13	14	41	46.6
Total	31	31	26	88	100.0

Table 24. Relationship of diver duck populations and barometric pressure, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Barometric Pressure	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
Rising	1	5	4	10	20.8
Falling	8	3	4	15	31.3
Stable	10	8	5	23	47.9
Total	19	16	13	48	100.0
Major Departures					
Rising	6	6	12	24	46.1
Falling	6	7	5	18	34.6
Stable	4	5	1	10	19.3
Total	16	18	18	52	100.0
Weekly Census Periods With Stable Populations					
Rising	10	8	12	30	38.0
Falling	4	12	4	20	25.3
Stable	13	12	4	29	36.7
Total	27	32	20	79	100.0

rules concerning relationship of pressure and wind are: (1) the direction of air flow is from regions of higher pressure to regions of lower pressure

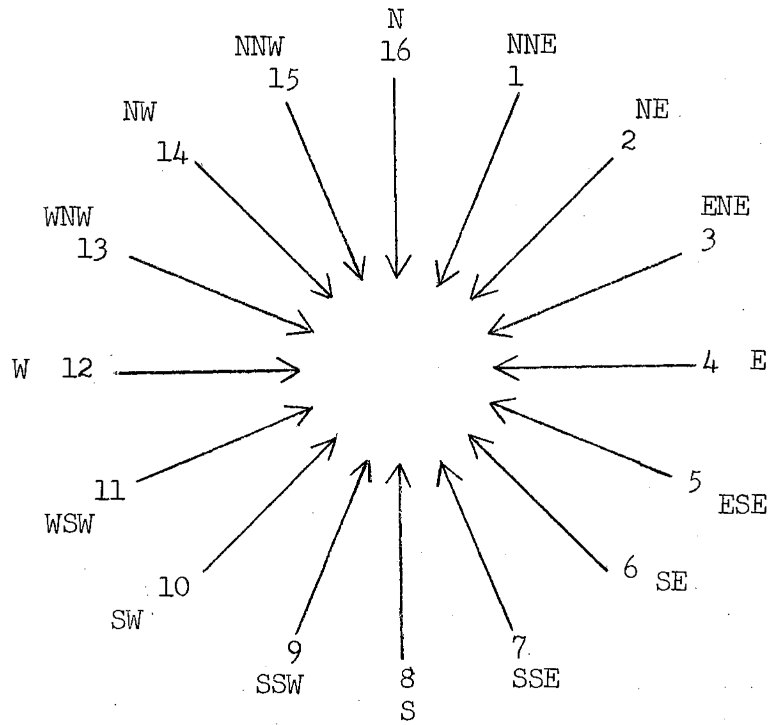


Figure 13. Sixteen principal wind directions recorded by the United States Weather Bureau.

and (2) the velocity of air flow depends on the pressure gradient or rate of pressure change (Finch, et. al., 1942). In this study, wind direction was recorded on the sixteen points of a compass at $22\frac{1}{2}°$ intervals, as given by the weather bureau (Figure 13). The prevailing wind direction was determined for each day of the study. Four flight conditions, based on prevailing wind direction, were defined as follows: tailwind, NW to NE wind (compass points 14, 15, 16, 1 and 2); headwind, SE to SW (compass points 6, 7, 8, 9, and 10); crosswind, ENE to ESE and WSW to WNW (compass points 3,4,5, and 11, 12, 13); and variable wind direction. The latter condition was characterized by absence of a prevailing wind direction during the census period. Each seven-day interval between waterfowl population county was classified in one of these four categories. The mean wind velocity for each census period was derived from analysis of daily mean velocity, and then expressed in miles per hour.

A study of the relation of wind to total waterfowl imigration revealed prevailing tailwinds existed during 40.8 per cent of the periods of major departures for the south. Headwinds prevailed 24.9 per cent of these periods. Crosswinds were 16.3 per cent and variable winds, 18.0 per cent. In contrast, stable waterfowl populations were observed when 15.4 per cent of the periods had tailwinds, 36.5 per cent headwinds, 23.1 per cent crosswinds, and 25.0 per cent variable winds. Most of the major arrivals occurred during periods of headwinds, 33.3 per cent, or variable winds, 30.8 per cent (Table 25). The foregoing data indicate departures of waterfowl occurred more often during periods of prevailing tailwinds, than during corsswinds or headwinds. Flight continued into the arrival area where a headwind prevailed or variable wind direction occurred. Periods of stable waterfowl populations were likewise characterized by a more frequent occurrence of headwinds or variable winds. Analysis of wind velocity provides inadequate evidence of a relationship to migratory flight. In this case, the method employed, which utilized mean wind speed for a seven-day interval, tends to have a leveling effect upon the data, thereby, eliminating short periods of high or low wind velocity which may have significance.

Evidence that weather factors do not have a strong influence on the movements of geese is further supported by data on wind direction and migratory flight. Comparison of data during migration and periods of no

Table 25. Relationship of total waterfowl populations and surface wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

	Number of Cases								
	1953		1954		1955				
Wind Direction	No.	Mean Wind Speed (m.p.h.)	No.	Mean Wind Speed (m.p.h.)	No.	Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	2	(10)	4	(12)	2	(14)	8	(13)	20.5
Crosswind	1	(15)	2	(8)	3	(10)	6	(10)	15.4
Headwind	6	(9)	3	(8)	4	(13)	13	(9)	33.3
Variable	4	(11)	5	(10)	3	(9)	12	(10)	30.8
Total	13		14		12		39		100.0
Major Departures									
Tailwind	7	(10)	7	(13)	6	(13)	20	(12)	40.8
Crosswind	3	(12)	2	(8)	3	(11)	8	(11)	16.3
Headwind	7	(12)	1	(10)	4	(13)	12	(12)	24.9
Variable	2	(10)	1	(8)	6	(10)	9	(10)	18.0
Total	19		11		19		49		100.0
Weekly Census Periods With Stable Populations									
Tailwind	3	(9)	8	(11)	4	(11)	16	(10)	15.4
Crosswind	8	(10)	6	(8)	10	(10)	24	(9)	23.1
Headwind	15	(10)	14	(11)	9	(11)	38	(10)	36.5
Variable	14	(11)	9	(10)	3	(11)	26	(10)	25.0
Total	40		37		27		104		100.0

Table 26. Relationship of goose populations and surface wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Wind Direction	1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	4	(8)	7	(9)	5	(13)	16	(10)	27.6
Crosswind	2	(12)	5	(8)	5	(11)	12	(10)	20.7
Headwind	7	(11)	3	(10)	6	(12)	16	(11)	27.6
Variable	6	(11)	5	(8)	3	(7)	14	(9)	24.1
Total	19		20		19		58		100.0
Major Departures									
Tailwind	1	(14)	4	(12)	5	(13)	10	(13)	27.0
Crosswind	1	(12)	4	(8)	3	(11)	8	(10)	21.6
Headwind	4	(10)	2	(9)	1	(18)	7	(11)	19.0
Variable	3	(8)	2	(9)	7	(10)	12	(10)	32.4
Total	9		12		16		37		100.0
Weekly Census Periods With Stable Populations									
Tailwind	6	(9)	6	(13)	6	(12)	18	(11)	27.7
Crosswind	5	(9)	4	(11)	5	(10)	14	(10)	21.5
Headwind	9	(10)	2	(13)	2	(16)	13	(11)	20.0
Variable	4	(11)	13	(11)	3	(12)	20	(11)	30.9
Total	24		25		16		65		100.0

movement reveals no significant difference (Table 26).

Migration records of dabbler ducks reveal a similarity between periods of stable populations and periods of major arrivals. During migratory departure, 30.8 per cent of the periods had a tailwind; 21.8 per cent had a headwind. In contrast, 13.6 per cent of the periods of no migration had tailwinds, and 39.8 per cent, headwinds (Table 27). Although this pattern has some similarity to the total waterfowl pattern, the evidence of a wind relationship to the migration of dabbler ducks is less obvious.

Analysis of wind and diver duck migration provides no evidence of a relationship. Periods of major arrivals, major departures, and stable populations were not significantly different in respect to wind direction and speed (Table 28). As already observed with other weather factors, the diving ducks did not appear strongly affected by weather variables.

Precipitation

During the fall migratory period, rainfall encountered in the Central Flyway is principally of the cyclonic type and, therefore, associated with the passage of low pressure areas. The front half of the cyclone is warm and often contains moist air which ascends over cold air, usually producing a large area of steady rainfall. In the rear part of the cyclone, cold air undercuts warm moist air and a belt of squalls with heavy rains results (Brands, 1944). Low pressure systems of this type are cyclic and migrate through the study region. These storms are more numerous and better developed during the fall and winter months. In this investigation, each census period was identified as having one of the following: no precipitation, rain only, rain and snow, and snow only.

In the study of the relationship of total waterfowl to migration,

Table 27. Relationship of dabbler duck populations and surface wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Wind Direction	1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	2	(10)	2	(12)	2	(13)	6	(12)	15.8
Crosswind	2	(9)	2	(8)	2	(9)	8	(9)	21.1
Headwind	5	(9)	2	(7)	4	(13)	11	(10)	28.9
Variable	4	(11)	5	(11)	4	(9)	13	(10)	34.2
Total	13		11		14		38		100.0
Major Departures									
Tailwind	4	(8)	3	(13)	5	(11)	12	(13)	30.8
Crosswind	3	(10)	2	(6)	3	(10)	8	(9)	21.8
Headwind	4	(9)	1	(10)	3	(11)	8	(10)	21.8
Variable	3	(9)	3	(7)	5	(10)	11	(9)	25.6
Total	14		9		16		39		100.0
Weekly Census Periods With Stable Populations									
Tailwind	3	(9)	6	(11)	3	(11)	12	(11)	13.6
Crosswind	1	(10)	6	(9)	10	(10)	17	(10)	19.3
Headwind	19	(10)	12	(9)	4	(12)	35	(10)	39.8
Variable	8	(12)	7	(10)	9	(10)	24	(11)	27.3
Total	31		31		26		88		100.0

Table 28. Relationship of diver duck populations and surface wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

	Number of Cases								
	1953		1954		1955			Mean Wind Speed	
Wind Direction	No.	Mean Wind Speed (m.p.h.)	No.	Mean Wind Speed (m.p.h.)	No.	Mean Wind Speed (m.p.h.)	Total	(m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	3	(7)	2	(11)	3	(11)	8	(9)	16.7
Crosswind	1	(11)	3	(10)	1	(14)	5	(11)	10.4
Headwind	8	(11)	5	(10)	4	(12)	17	(11)	35.4
Variable	7	(9)	6	(11)	5	(8)	18	(9)	37.5
Total	19		16		13		48		100.0
Major Departures									
Tailwind	4	(11)	6	(13)	7	(13)	17	(13)	32.7
Crosswind	3	(9)	4	(8)	2	(10)	9	(9)	17.3
Headwind	3	(8)	4	(10)	3	(8)	10	(9)	19.2
Variable	6	(11)	4	(7)	6	(10)	16	(10)	30.8
Total	16		18		18		52		100.0
Weekly Census Periods With Stable Populations									
Tailwind	6	(9)	6	(8)	4	(11)	16	(9)	20.3
Crosswind	8	(8)	12	(9)	5	(11)	25	(9)	31.6
Headwind	6	(10)	2	(8)	4	(13)	12	(11)	15.2
Variable	7	(10)	12	(9)	7	(10)	26	(10)	32.9
Total	27		32		20		79		100.0

some form of precipitation occurred during 59.0 per cent of the periods of major arrivals and 69.4 per cent of the departure periods. It should be noted, however, that 64.4 per cent of the periods with stable waterfowl populations had precipitation (Table 29). A further check was made of a possible relationship of migration to the quantity of precipitation. It was found that periods of arrival, departure, and population stability were very similar, in this respect; thus, no significant relationship was apparent.

Analysis of the migratory movement of geese revealed that departure periods had less precipitation than periods of arrivals, and also less than periods of no migration (Table 30). The data for dabbler and diver ducks (Tables 31 and 32) are similar to total waterfowl records.

It does appear significant that snow occurred more often during periods of migratory departure than during periods of population stability. In each category of waterfowl studied, this condition was present. For example, 34.7 per cent of the total waterfowl departures occurred during census periods when snowfall was encountered. Only 8.6 per cent of the stable population periods had snowfall. Since precipitation occurred about as frequently during periods of no migration, as during periods of departure, the investigator suspected that temperature may have been the actual underlying factor. Further analysis revealed that periods with departures had a higher frequency of freezing temperatures than did the periods of population stability. From the preceding data, no significant relationship could be found between precipitation and the migratory movements of waterfowl.

Sky Cover

Considerable controversy has arisen concerning migration as related

Table 29. Relationship of total waterfowl populations and incidence of precipitation, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Precipitation	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Precipitation	3	8	5	16	41.0
Rain Only	7	3	5	15	38.5
Rain and Snow	1	3	1	5	12.8
Snow Only	2	0	1	3	7.7
Total	13	14	12	39	100.0
Major Departures					
No Precipitation	4	6	5	15	30.6
Rain Only	9	1	7	17	34.7
Rain and Snow	4	3	2	9	18.4
Snow Only	2	1	5	8	16.3
Total	19	11	19	49	100.0
Weekly Census Periods With Stable Populations					
No Precipitation	16	15	6	37	35.6
Rain Only	19	21	18	58	55.8
Rain and Snow	2	1	2	5	4.8
Snow Only	3	0	1	4	3.8
Total	40	37	27	104	100.0

Table 30. Relationship of goose populations and incidence of precipitation, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Precipitation	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Precipitation	6	8	8	22	37.9
Rain Only	10	8	6	24	41.4
Rain and Snow	2	4	4	10	17.3
Snow Only	1	0	1	2	3.4
Total	19	20	19	58	100.0
Major Departures					
No Precipitation	1	1	3	5	13.5
Rain Only	4	6	4	14	37.9
Rain and Snow	1	4	5	10	27.0
Snow Only	3	1	4	8	21.6
Total	9	12	16	37	100.0
Weekly Census Periods With Stable Populations					
No Precipitation	6	13	7	26	40.0
Rain Only	13	10	5	28	43.1
Rain and Snow	0	2	3	5	7.7
Snow Only	5	0	1	6	9.2
Total	24	25	16	65	100.0

Table 31. Relationship of dabbler duck populations and incidence of precipitation, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Precipitation	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Precipitation	3	5	7	15	39.5
Rain Only	7	4	4	15	39.5
Rain and Snow	1	2	2	5	13.2
Snow Only	2	0	1	3	7.8
Total	13	11	14	38	100.0
Major Departures					
No Precipitation	4	6	4	14	35.9
Rain Only	6	1	7	14	35.9
Rain and Snow	2	1	1	4	10.3
Snow Only	2	1	4	7	17.9
Total	14	9	16	39	100.0
Weekly Census Periods With Stable Populations					
No Precipitation	11	13	5	29	33.0
Rain Only	18	16	18	52	59.1
Rain and Snow	1	2	3	6	6.8
Snow Only	1	0	0	1	1.1
Total	31	31	26	88	100.0

Table 32. Relationship of diver duck populations and incidence of precipitation, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Precipitation	Number of Cases 1953	1954	1955	Total	Percent of Total
Major Arrivals					
No Precipitation	3	7	9	19	39.6
Rain Only	14	7	1	22	45.8
Rain and Snow	1	1	2	4	8.3
Snow Only	1	1	1	3	6.3
Total	19	16	13	48	100.0
Major Departures					
No Precipitation	5	9	7	21	40.4
Rain Only	5	7	7	19	36.5
Rain and Snow	3	2	2	7	13.5
Snow Only	3	0	2	5	9.6
Total	16	18	18	52	100.0
Weekly Census Periods With Stable Populations					
No Precipitation	10	12	4	26	32.9
Rain Only	15	18	12	45	57.0
Rain and Snow	1	2	3	6	7.6
Snow Only	1	0	1	2	2.5
Total	27	32	20	79	100.0

to sky cover. Some ornithologists maintain that clear skies are required for mass migration; whereas, an equal number hold that major movements may occur under completely overcast skies. In this investigation, consideration was given to the amount of sky cover throughout each migratory period. United States Weather Bureau records designate sky cover in tenths for each day. Conditions for the day and night hours are given separately. The mean sky cover was determined for each census period by combining the mean sky cover for each day and computing the average. Since the exact date of migratory departure and arrival was not available, the analysis had to relate to an entire census period. The investigator is aware that the use of this method would tend to eliminate the possibility of a census period with mean sky cover of either extreme, one-tenth or ten-tenths. Thus, a study of arrival, departure, and stable population periods provides only a general comparison of mean conditions.

Records of total waterfowl movements, as related to amounts of sky cover, indicate a majority of major arrivals occurred during periods when the mean sky cover ranged from two-tenths to five-tenths. Periods of departures had a mean ranging from two-tenths to seven-tenths. Most of the stable population periods rated between one-tenth to six-tenths cloudiness (Table 33). Data for sky cover and goose migration indicated a similar pattern. Periods of major departure of geese did tend to have greater cloud cover, ranging from four-tenths to eight-tenths (Table 34). Examination of records for dabbler ducks (Table 35), and diver ducks (Table 36), provides evidence of a similar pattern to that of geese and total waterfowl.

The results of this study suggest that waterfowl of all types tend to depart on their southward migratory flight during weekly periods when mean sky cover is greater than that of periods with stable populations.

Table 33. Relationship of total waterfowl populations and cloud cover, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Cloud Cover in Tenths	Number of Major Arrivals				Percent Total	Number of Major Departures				Percent Total	Weekly Census Periods With Stable Populations				Percent Total
	1953	1954	1955	Total		1953	1954	1955	Total		1953	1954	1955	Total	
0	0	2	1	3	7.7	0	1	0	1	2.0	1	4	2	7	6.8
1	0	1	0	1	2.6	2	0	1	3	6.1	8	3	1	12	11.5
2	3	1	4	8	20.5	2	1	2	5	10.3	5	7	2	14	13.5
3	0	1	1	2	5.1	3	3	3	9	18.4	6	3	5	14	13.5
4	3	2	4	9	23.1	3	3	4	10	20.4	6	5	8	19	18.5
5	3	6	1	10	25.7	1	0	2	3	6.1	5	9	1	15	14.4
6	1	1	1	3	7.7	2	1	4	7	14.3	6	4	3	13	12.5
7	2	0	0	2	5.1	5	0	2	7	14.3	1	2	1	4	3.8
8	1	0	0	1	2.5	0	2	1	3	6.1	1	0	3	4	3.8
9	0	0	0	0	0.0	1	0	0	0	2.0	1	0	1	2	1.9
10	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Total	13	14	12	39	100.0	19	11	19	49	100.0	40	37	27	104	100.0

Table 34. Relationship of goose populations and cloud cover, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Cloud Cover in Tenths	Number of Major Arrivals				Percent Total	Number of Major Departures				Percent Total	Weekly Census Periods With Stable Populations				Percent Total
	1953	1954	1955	Total		1953	1954	1955	Total		1953	1954	1955	Total	
0	0	2	1	3	5.2	0	0	0	1	2.7	1	1	0	2	3.1
1	3	1	1	5	8.6	1	1	0	2	5.4	0	2	1	3	4.6
2	6	3	2	11	19.0	1	0	0	1	2.7	4	3	1	8	12.3
3	1	2	1	4	7.0	0	2	1	3	8.1	2	3	3	8	12.3
4	2	4	4	10	17.2	3	2	4	9	24.4	4	6	3	13	20.0
5	3	4	3	10	17.2	1	3	3	7	18.9	7	7	2	16	24.6
6	0	1	4	5	8.6	1	2	1	4	10.8	2	3	2	7	10.8
7	3	3	2	8	13.8	2	1	2	5	13.5	2	0	3	5	7.7
8	1	0	0	1	1.7	0	1	3	4	10.8	1	0	1	2	3.1
9	0	0	1	1	1.7	0	0	1	1	2.7	1	0	0	1	1.5
10	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Total	19	20	19	58	100.0	9	12	16	37	100.0	24	25	16	65	100.0

Table 35. Relationship of dabbler duck populations and cloud cover, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Cloud Cover in Tenths	Number of Major Arrivals				Percent Total	Number of Major Departures				Percent Total	Weekly Census Periods With Stable Populations				Percent Total
	1953	1954	1955	Total		1953	1954	1955	Total		1953	1954	1955	Total	
0	0	0	1	1	2.6	0	0	0	0	0.0	3	4	2	9	10.2
1	2	1	0	3	7.8	2	0	0	2	5.1	7	3	1	11	12.5
2	2	2	4	8	21.1	0	1	1	2	5.1	6	2	3	11	12.5
3	1	2	1	4	10.5	4	3	5	12	30.8	3	5	2	10	11.4
4	3	2	5	10	26.4	4	2	2	8	20.8	2	5	4	11	12.5
5	3	4	3	10	26.4	1	1	2	4	10.8	7	8	4	19	21.6
6	0	0	0	0	0.0	2	1	2	5	12.8	2	3	5	10	11.4
7	2	0	0	2	5.2	1	0	3	4	10.3	0	1	3	4	4.5
8	0	0	0	0	0.0	0	1	1	2	5.1	0	0	1	1	1.1
9	0	0	0	0	0.0	0	0	0	0	0.0	1	0	1	2	2.3
10	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Total	13	11	14	38	100.0	14	9	16	39	100.0	31	31	26	88	100.0

Table 36. Relationship of diver duck populations and cloud cover, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Cloud Cover in Tenths	Number of Major Arrivals				Percent Total	Number of Major Departures				Percent Total	Weekly Census Periods With Stable Populations				Percent Total
	1953	1954	1955	Total		1953	1954	1955	Total		1953	1954	1955	Total	
0	1	1	2	4	8.3	0	1	0	1	1.9	0	0	0	0	0.0
1	2	3	1	6	12.5	1	1	0	2	3.9	2	2	1	5	6.3
2	5	3	5	13	27.1	2	1	3	6	11.5	8	4	1	13	16.5
3	4	0	1	5	10.4	4	6	4	14	26.9	5	1	2	8	10.1
4	3	3	4	10	20.8	3	2	3	8	15.4	2	6	4	12	15.2
5	2	4	0	6	12.5	2	3	2	7	13.5	5	12	4	21	26.6
6	1	0	0	1	2.1	1	2	3	6	11.5	1	6	4	11	13.9
7	1	1	0	2	4.2	3	1	2	6	11.5	2	1	3	6	7.6
8	0	1	0	1	2.1	0	0	0	0	0.0	0	0	0	0	0.0
9	0	0	0	0	0.0	0	1	1	2	3.9	2	0	1	3	3.8
10	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0
Total	19	16	13	48	100.0	16	18	18	52	100.0	27	32	20	79	100.0

Likewise, less cloudiness was observed during periods of arrival than during periods of departure.

Upper Air Wind

Although weather at the earth's surface may be a factor in initiating migratory movement of waterfowl, it is apparent that once the migration is under way, weather aloft will either hinder or aid flight. The investigator sought to relate migratory flight to upper air wind direction and speed.

Measurements of upper air conditions are obtained by soundings with radiosondes or use of pilot balloons and a theodolite. Since only larger weather stations make upper air soundings, weather-aloft records were obtained for only ten of the seventeen waterfowl census stations. From microfilm copies of Form WBAN 33, Summary of Constant Pressure Data, and WBAN 22, Winds Aloft Summary Form, wind direction and speed were obtained for each 1,000 feet above surface level. Because most waterfowl migrate below the 7,000 foot level (Lincoln, 1935), conditions were not studied above this altitude. Wind direction was recorded in the manner employed for surface wind, using the sixteen point system (Figure 13). The prevailing wind direction was determined for each day of the study period, and from this, each census period was classified as providing one of four flight conditions: tailwind, crosswind, headwind, and variable wind direction. This method of classification has been discussed in an earlier section of this report on surface winds (p. 99). The mean wind velocity for each census period was derived from analysis of daily mean velocity and expressed in miles per hour.

In the Central States, the upper winds are mainly from the southwest, west, and northwest (Finch, et al., 1942). One would, therefore, expect a

Table 37. Relationship of total waterfowl populations and upper air wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Upper Air Wind Direction	1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	3	(29)	5	(22)	1	(31)	9	(27)	26.5
Crosswind	4	(22)	3	(20)	7	(25)	14	(22)	41.2
Headwind	4	(22)	1	(20)	1	(34)	6	(25)	17.6
Variable	1	(20)	3	(22)	1	(9)	5	(20)	14.7
Total	12		12		10		34		100.0
Major Departures									
Tailwind	6	(22)	4	(34)	6	(31)	16	(29)	35.6
Crosswind	6	(27)	5	(27)	5	(29)	16	(27)	35.6
Headwind	1	(13)	0	(0)	4	(20)	5	(18)	11.1
Variable	4	(25)	2	(20)	2	(16)	8	(20)	17.7
Total	17		11		17		45		100.0
Weekly Census Periods With Stable Populations									
Tailwind	13	(18)	8	(29)	6	(20)	27	(22)	26.5
Crosswind	12	(25)	6	(22)	9	(20)	27	(22)	26.5
Headwind	7	(18)	13	(20)	8	(25)	28	(20)	27.4
Variable	7	(20)	9	(20)	4	(22)	20	(20)	19.6
Total	39		36		27		102		100.0

higher percentage of crosswinds and tailwinds to be encountered during the fall migratory flight. Comparison of upper air winds (Table 37) with surface winds (Table 25) for total waterfowl, substantiates this assumption. Additional evidence is provided by a similar comparison of surface and upper air winds during migration of geese, dabbler and diver ducks. Migration records of total waterfowl revealed that 35.6 per cent of the departure periods had tailwinds and 35.6 per cent crosswinds. In contrast, periods with no migration had 26.5 per cent tailwind and 26.5 per cent crosswind (Table 37). Although this difference does not appear to be significant, a similar relationship was observed for dabbler ducks (Table 39) and diver ducks (Table 40). Data for the geese (Table 38) revealed little difference between periods of migratory departure and periods of no migration. There were noticeable differences in the percentage of headwinds at departure periods, compared with periods of population stability. In each case, headwinds were less common at the time of migratory departure. The data do not reveal the reason for this. The fact, that passage of a strong frontal system and a high percentage of surface tailwinds are more common during major departures, suggests to the investigator that the upper air pattern may be linked with these other weather factors.

Winds change in velocity with altitude. Since the frictional force decreases with elevation, wind velocity will increase as altitude increases (Petterssen, 1941). This is supported, in part, by a comparison of surface and upper air wind data of this study. Analysis of upper wind velocity provided inadequate evidence of a relationship to migratory flight. As explained earlier, the use of mean wind velocity, for a census period, tends to have a leveling effect on extreme conditions. It is noticeable, however, that the velocity of tailwinds was greater than that for crosswinds or headwinds.

Table 38. Relationship of goose populations and upper air wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Upper Air Wind Direction	1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	3	(29)	4	(27)	4	(25)	11	(27)	21.2
Crosswind	5	(29)	6	(20)	7	(25)	18	(25)	34.6
Headwind	7	(20)	1	(20)	3	(18)	11	(20)	21.2
Variable	2	(20)	7	(18)	3	(20)	12	(20)	23.0
Total	17		18		17		52		100.0
Major Departures									
Tailwind	4	(25)	4	(29)	6	(27)	14	(27)	37.9
Crosswind	1	(18)	4	(25)	6	(29)	11	(27)	29.7
Headwind	1	(22)	0	(0)	2	(27)	3	(25)	8.1
Variable	3	(20)	4	(22)	2	(25)	9	(22)	24.3
Total	9		12		16		37		100.0
Weekly Census Periods With Stable Populations									
Tailwind	7	(27)	11	(31)	5	(25)	23	(29)	35.9
Crosswind	6	(25)	7	(22)	6	(31)	19	(25)	29.7
Headwind	7	(13)	2	(20)	3	(25)	12	(18)	18.8
Variable	4	(18)	5	(22)	1	(13)	10	(20)	15.6
Total	24		25		15		64		100.0

Table 39. Relationship of dabbler duck populations and upper air wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Upper Air Wind Direction	Number of Cases: 1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
<u>Major Arrivals</u>									
Tailwind	3	(29)	2	(16)	2	(31)	7	(25)	18.4
Crosswind	6	(25)	5	(24)	9	(27)	20	(25)	52.6
Headwind	3	(22)	0	(0)	2	(27)	5	(25)	13.2
Variable	1	(20)	4	(22)	1	(9)	6	(20)	15.8
Total	13		11		14		38		100.0
<u>Major Departures</u>									
Tailwind	5	(22)	3	(36)	6	(29)	14	(29)	35.9
Crosswind	4	(34)	3	(25)	6	(29)	13	(29)	33.3
Headwind	1	(13)	0	(0)	3	(20)	4	(18)	10.3
Variable	4	(20)	3	(20)	1	(16)	8	(20)	20.5
Total	14		9		16		39		100.0
<u>Weekly Census Periods With Stable Populations</u>									
Tailwind	8	(18)	7	(29)	6	(22)	21	(22)	24.4
Crosswind	9	(25)	11	(22)	10	(22)	30	(22)	34.9
Headwind	6	(22)	6	(18)	9	(20)	21	(20)	24.4
Variable	7	(20)	7	(20)	0	(0)	14	(20)	16.3
Total	30		31		25		86		100.0

Table 40. Relationship of diver duck populations and upper air wind direction and speed, Central Flyway, fall migratory periods of 1953, 1954, and 1955.

Upper Air Wind Direction	Number of Cases 1953 No.	1953 Mean Wind Speed (m.p.h.)	1954 No.	1954 Mean Wind Speed (m.p.h.)	1955 No.	1955 Mean Wind Speed (m.p.h.)	Total	Mean Wind Speed (m.p.h.)	Percent of Total
Major Arrivals									
Tailwind	3	(18)	4	(20)	3	(25)	10	(20)	20.8
Crosswind	8	(22)	5	(22)	7	(27)	20	(25)	41.7
Headwind	5	(20)	0	(0)	3	(18)	8	(20)	16.7
Variable	3	(18)	7	(27)	0	(0)	10	(22)	20.8
Total	19		16		13		48		100.0
Major Departures									
Tailwind	7	(29)	8	(31)	8	(29)	23	(29)	46.0
Crosswind	3	(25)	5	(25)	7	(25)	15	(25)	30.0
Headwind	1	(22)	1	(22)	1	(16)	3	(20)	6.0
Variable	4	(22)	4	(22)	1	(20)	9	(22)	18.0
Total	15		18		17		50		100.0
Weekly Census Periods With Stable Populations									
Tailwind	8	(20)	9	(25)	3	(18)	20	(22)	25.6
Crosswind	7	(22)	7	(22)	5	(31)	19	(25)	24.4
Headwind	6	(18)	6	(22)	6	(20)	18	(20)	23.1
Variable	5	(22)	10	(22)	6	(18)	21	(20)	26.9
Total	26		32		20		78		100.0

Atmospheric Stability

Air is said to be stable if it resists vertical displacement. In a stable atmosphere, a small volume of air, displaced upward or downward, experiences forces which act to restore it to its original level (Sutton, 1961). Unstable air favors vertical displacement and sets up vertical air currents. A third state, called conditional instability, refers to air which is stable when not saturated, and unstable when saturated (Brands, 1944). Inasmuch as unstable atmosphere will produce turbulence, it may have some effect upon migratory flight. In this investigation, the upper air was classed as stable, conditionally unstable, or unstable, for each day of the study periods. Data for this study were obtained from microfilm copies of Form WBAN 33, Summary of Constant Pressure Data. Atmospheric stability was determined by plotting (on a pseudo-adiabatic chart) temperatures at each fifty millibar level, from surface to the 700 millibar level. The air is absolutely stable if its lapse rate is less than the moist adiabatic rate. Unstable air has a lapse rate greater than the dry adiabatic rate. Air in which the temperature curve shows the atmospheric lapse rate to lie between the dry adiabatic and moist adiabatic lapse rates is considered conditionally unstable (Halpine and Taylor, 1956). In Figure 14, three hypothetical temperature curves are plotted. Curve 1 represents stable air; Curve 2, conditionally unstable air; and Curve 3, unstable air.

In this investigation, each day of the study period was rated on a three point system, with 1 as stable; 2, conditionally unstable; and 3, unstable. The mean stability for each weekly census period was derived by averaging the daily mean stabilities. Since the atmosphere is stable most of the time and any unstable condition is of short duration, this

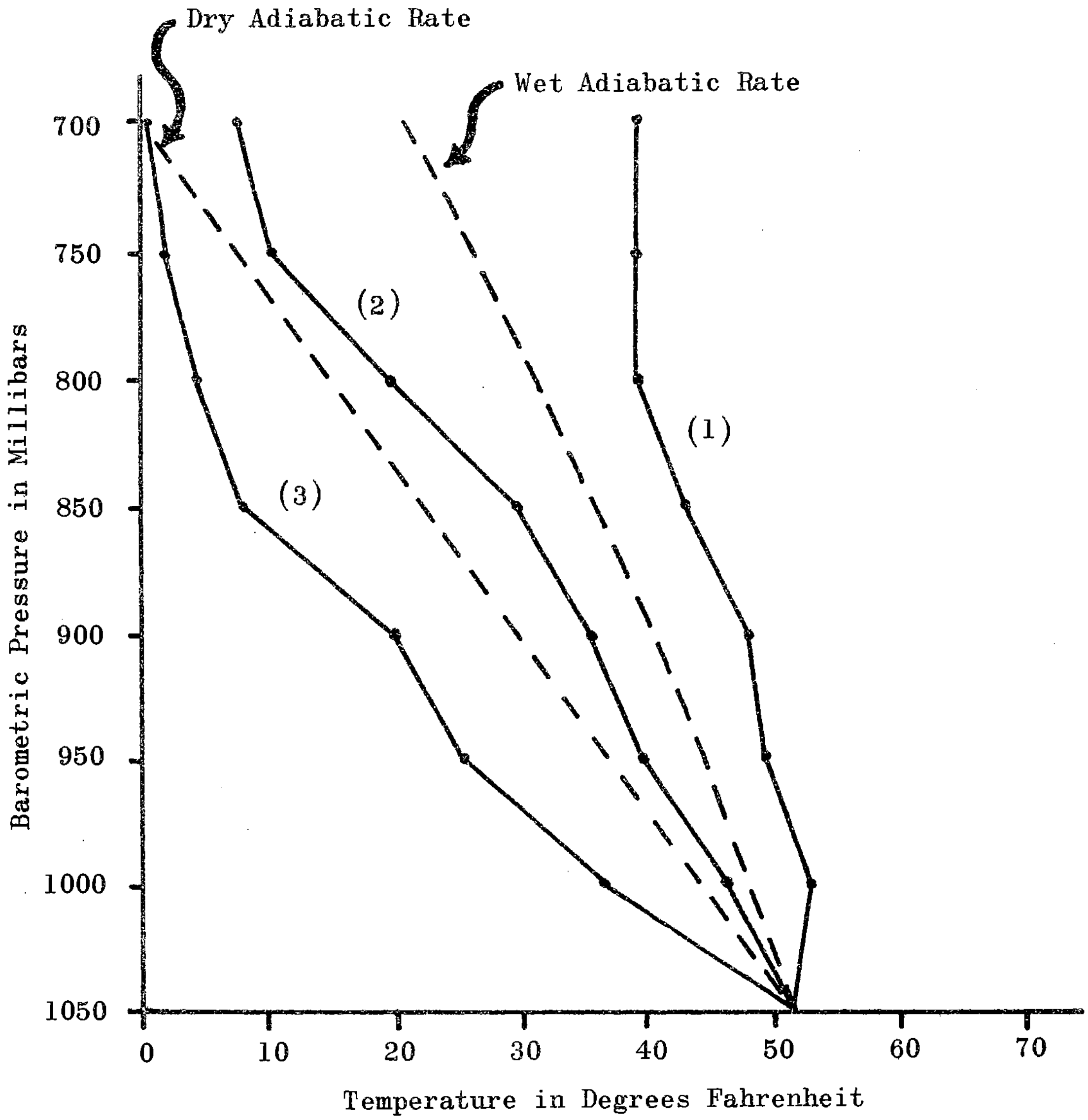


Figure 14. Three hypothetical temperature curves plotted to demonstrate stability conditions of air. (1) stable air, (2) conditionally unstable air, (3) unstable air.

method, which gave a mean stability for a seven-day census period, gave misleading results. Unstable periods were absent from the records. Periods of major arrivals, major departures, and population stability were classed as generally stable. From the knowledge gained by this study, it is apparent that in order to relate migration to atmospheric stability, it is necessary to have daily census data and to be able to pin-point exact times of migratory arrivals and departures. Only then may one relate the movement of waterfowl to such a rapidly changing weather factor as atmospheric stability.

CHAPTER VIII

ANALYSIS OF RESULTS

Waterfowl migrations encountered entirely different climatic conditions during the fall seasons of 1953, 1954, and 1955. The 1953 season was generally mild with drought conditions at the beginning of the period, followed by rains which provided adequate water levels on refuge impoundments. The 1954 season was unusually warm and extreme drought conditions prevailed in much of the Central Flyway. Rains that came failed to correct the drought damage to refuges in the southern part of the flyway. Because of the above-normal temperatures, water areas in even the northern most regions remained open until the latter part of December. The autumn migratory period of 1955 was unusual in that winter arrived nearly two months early in the northern regions of the flyway. In this same year, all regions were warm in September and October. About November 1, cold weather arrived in all the states north of the Red River. Water areas which froze early in November did not re-open during the remainder of the fall season. Heavy snowfall and blizzards were common in the northern regions. These three fall seasons provided contrasting climatological conditions for this study.

Patterns of Waterfowl Migration in the Central Flyway

In this study of fall migration of waterfowl it was found in all of the three seasons studied that large populations of birds were already in Montana and North Dakota by September 1. Populations built-up until mid-October when general southward migration occurred. Nearly all birds had left the area by December 1. South Dakota and Nebraska waterfowl reached peak numbers approximately two weeks later than the waterfowl in northern states. Major southward departures from Region II began two weeks later than in Region I. Oklahoma, North Texas, and Eastern New Mexico received their first large flights from the north the first week of November. Populations built-up until the end of the study period, December 31. Waterfowl began to arrive on the Texas Gulf Coast about November 1 in 1953 and 1954, but in 1955 the birds never appeared in the proportions found during the two previous years.

Study of the major waterfowl flights, for each of the three years, revealed that the mass movements in the two northern regions were concentrated in a few weekly periods (Figure 9). Mass flights in Region III were less concentrated. No definite pattern of arrival on the Gulf Coast was evident. Comparison of the three years of study indicated that 1953 was a year with two periods of mass flights in the northern border states and, as the birds moved south, major flights were less concentrated in any particular time period. The 1954 season provided a more leisurely pattern of migration, undoubtedly related to the very mild season. Major flights in 1955 were concentrated into a brief time period, in nearly all regions of the flyway. The arrival of early winter weather in the northern regions coincided with mass migration.

Migration of geese, as observed in this study, was entirely different from that of total waterfowl. Montana, North Dakota, and South Dakota had only small numbers of geese. Region III, Oklahoma and North Texas, received high populations of wintering geese, but the Texas Gulf Coast had a population build-up only in the unusual year of 1955. As indicated earlier in this report, most geese either moved through the northern states without stopping or they remained only a few days in the area, never permitting a population build-up. Patterns of migration indicated that major flights of geese occurred earlier than flights of total waterfowl. In Oklahoma and North Texas, where many geese winter, major arrivals began the second week in October and peak numbers were reached by the middle of November. In contrast, major flights of total waterfowl occurred about November 1 and peak numbers were not reached until late December. Comparative data for major flights of geese and total waterfowl indicate a greater scattering of goose flights during the migratory season. Only in Region II of the year 1955 were the flights concentrated within a short time interval; this coincided with the arrival of early winter weather.

The dabbler duck migration, as observed by study of five representative species: mallard, pintail, gadwall, baldpate, and shoveller, was almost identical to that of total waterfowl. Since these ducks comprise the major part of waterfowl population in Regions I, II, and III, such a similarity of patterns would be expected. The marked difference between the migrations of 1954 and 1955 are apparent in Figure 11. A scattering of major flights was observed during the extremely warm autumn of 1954. In 1955 the southward movements were concentrated in a brief time period in each of the regions of the Central Flyway. The early arrival of winter weather in the northern states coincided with major dabbler movements from the Canadian border to the Gulf Coast of Texas.

The migration of diver ducks was analyzed by considering the combined movements of four representative species: redhead, ring-neck, canvasback, and lesser scaup. The divers built-up to peak populations and departed south about the same time as dabblers in the northern states of Montana, North Dakota, South Dakota, and Nebraska. The divers, however, appeared to by-pass Region III, Oklahoma and North Texas, in their southward migrations (Figure 8). Large numbers commonly appeared on the Texas Gulf Coast. This study does not attempt to explain the scarcity of divers in Region III. It may be that the diver ducks flew over Oklahoma and North Texas without stopping, or upon arriving in South Dakota and Nebraska, they veered to the East, along the tributaries of the Mississippi River, and then proceeded down the Mississippi Flyway to the Gulf. They could then follow along the coast to the Aransas and Laguna Atascosa Refuges of Region IV.

Migration patterns of divers were similar in 1953 and 1954. Sizeable populations moved through Montana, North Dakota, South Dakota, and Nebraska; very few appeared in Oklahoma, North Texas, and New Mexico. However, large populations built-up in Region IV on the Texas Gulf Coast. The 1955 pattern was similar to the two previous years for Regions I, II, and III, but the birds never appeared on the refuges of the Texas Gulf Coast. Since the numbers of diving ducks were extremely low in Region III (Figure 8), the wintering populations of these birds in 1955 were not located by the refuge managers of the Central Flyway. Region IV had a peak population of 750,647 divers in 1953; 459,995 in 1954, but only 11,574 in 1955.

Compared with dabbler ducks, the diving ducks revealed a more general scattering of major flights. Figures 10 and 12 indicate that the geese and diving ducks were similar in this respect.

Relation of Weather to Waterfowl Migration

Study of the literature failed to provide a clear concept of the relation of weather to migration of birds. Some investigators maintained that certain climatological conditions provide the stimulus for migration, but others found no relationship. Another group of investigators stated that although weather may not be a stimulus triggering migration, it either aids or hinders flight after the migratory movement is under way. Those that found a weather relationship, did not agree on the critical weather factor involved. It was the purpose of this study to analyze these weather variables in relation to the autumn migration of waterfowl in the Central Flyway.

Eight separate weather factors were studied and related to the migratory movements of total waterfowl, geese, dabbler ducks, and diver ducks. Comparative data were obtained from periods of major movements of birds and periods of no migration. A major movement was defined as any change in bird census which was at least 30 per cent of the peak population for that season. A graduated standard was established for determining a stable population. Any census change of no more than five per cent of peak population was considered a stable population for stations in Region I. In the other areas of the flyway, the standards were four per cent in Region II, three per cent in Region III, and two per cent in Region IV. Because waterfowl stop to rest and feed for progressively longer periods of time as they approach their wintering grounds, the use of a graduated standard provided a uniform number of stable population periods for each region of the Central Flyway.

Temperature and Waterfowl Migration

Total waterfowl records indicated migratory departures coincided with falling maximum temperatures. Arrivals were frequently associated with stable temperatures in the area of the birds' destination. Periods when the waterfowl failed to migrate were characterized by a stable maximum temperature. The pattern of dabbler duck migration was similar to that of total waterfowl. Although migrations of geese and diving ducks appeared related to a drop in maximum temperature, evidence was not as strong as in the case of dabbler ducks and total waterfowl.

A falling minimum temperature appeared to be more important than a falling maximum temperature as a stimulus for migratory departure of waterfowl. In the four categories studied, total waterfowl, geese, dabbler ducks, and diver ducks, most departures occurred during periods of falling minimum temperature. In each case, the periods of no migratory movements had a higher incidence of stable temperatures. Arrivals appeared to be unrelated to temperature conditions in the area of the birds' destination.

All waterfowl departed more frequently during weekly periods of a falling average temperature and usually failed to migrate during periods of a stable average temperature. Arrivals of total waterfowl and dabbler ducks were more common during periods of stable average temperatures in the area of the birds' destination. Data for geese and diver ducks provided no evidence of a relationship. Average temperature appears to be less related to migration than either maximum or minimum temperatures.

This study agrees with the observations of Bellrose and Sieh (1960) that falling temperature is related to the migratory departure of waterfowl. Although this investigation revealed a relationship with a change in maximum, minimum, and average daily temperatures, a falling minimum temperature appeared to be a more critical factor. Some investigators have noted a relationship to falling temperature, but believe that availability of food is the significant factor. They maintain that only when food is hard to reach because of ice and snow are major flights of birds observed coincident with a drop in temperature (Milne and Milne, 1958, Svärdson, 1953). The results of this study do not agree. The general freeze-up dates for each refuge were considered and only the waterfowl flights, occurring before these dates, were analyzed. Adequate quantities of food were available on the refuges.

Frontal Systems and Migration

Study of relation of waterfowl migration to passage of a frontal system indicated geese, dabbler ducks, and diver ducks responded in a similar manner. Most of the arrivals from the north and departures to the south occurred during a period of the passage of a cold front. However, examination of the periods when waterfowl failed to migrate provided evidence of nearly as many cold fronts as the number occurring with migratory movement. A further study, concerning the strength of fronts, disclosed that a strong cold front, one with a drop in the daily mean temperature of more than 10° F., was related to the migratory departure of dabbler ducks, but unrelated to geese and diver duck departures (Table 20).

Although some investigators, including McClure (1954), Lasky (1957), and Baird, et al. (1958), maintained that a cold front was associated with migration of passerine birds, Bellrose and Sieh (1960) found only one of three spectacular waterfowl flights associated with a cold front. It is apparent from the present study that the passage of a cold front *per se* is unrelated to migratory movement of waterfowl. A strong cold front did coincide with the migratory departure of total waterfowl and dabbler ducks.

Since most of this study dealt with waterfowl counts taken at seven-day intervals, thus preventing identification of exact dates of arrivals and departures, the validity of the data might be questioned. At one census station, Lake Overholser, Oklahoma, the investigator made daily census counts. Analysis of these records correspond with the findings obtained from the entire flyway data. At Lake Overholser, most departures of total waterfowl occurred with a strong cold front; whereas, most of the cold fronts passing the census station, during periods of no migratory movements, were weak. Data for geese revealed no relation to frontal systems.

Barometric Pressure and Migration

In general, migratory departures of total waterfowl occurred more often during periods of changing barometric pressure than during periods of stable pressure. Although more than fifty per cent of the periods with no migration had a changing pressure, there was a greater tendency toward stable conditions. A higher incidence of stable pressure was evident during periods of arrivals. Similar relationships were observed for geese, dabbler and diver ducks. Study of Lake Overholser daily records agreed with the entire flyway data. Since pressure change is associated with frontal systems and attending storms, it might be assumed that migratory flights were triggered by these storm systems. However, evidence from this study is not strong enough for this conclusion.

Analysis of the migratory movements, as related to the kinds of pressure change, revealed that major departures of all waterfowl occurred only slightly more often with a rising barometric pressure than with a falling pressure. This indicates that neither a rising nor a falling barometric pressure is an important factor directly related to waterfowl migration. The results of this study agree with Lack (1960a) that pressure appears to have no direct influence on migration. As observed by Bellrose and Sieh (1960), ducks migrated during high and low pressure.

Surface Wind and Migration

Examination of direction of surface wind and incidence of migration indicated a possible relationship only with data of total waterfowl migratory flights. Departures occurred more often during periods of prevailing tailwinds than during periods with headwinds, crosswinds, or winds from variable directions. In contrast, periods of population stability had a higher incidence of headwinds than tailwinds. Migratory arrivals appeared to be unrelated to wind direction at the birds' destination. Study of goose, dabbler duck, and diver duck migratory flights indicated wind direction was not related to movements of these birds. The percentage of periods with tailwinds, headwinds, crosswinds, and variable winds was not significantly different during major departures, major arrivals or periods of no migration. Data from daily records at Lake Overholser agreed with flyway data. Total waterfowl departures were more common during periods of prevailing tailwinds, but goose departures appeared to be unrelated to wind direction.

The investigator is unable to explain the possible relationship of total waterfowl departures to the incidence of tailwinds and no such relationship for the dabbler ducks. Since dabbler ducks comprise the larger part of total waterfowl populations, one would expect to find a similar relationship. This was observed with most of the other weather factors. Since wind direction did not appear to be related to the migratory flights of geese, dabbler and diver ducks, and because of the existence of conflicting evidence for total waterfowl flights, this study does not provide proof that wind direction is important to waterfowl migration.

Results of this investigation agree with Cooke (1910), Thomson (1953), and Bellrose (1958). Hochbaum (1944, 1955) observed ducks moving with favoring winds and also against headwinds that grounded smaller birds. As suggested by Lack (1960), the significant factor is not wind direction, but possibly some other associated weather element, such as temperature. Wind velocity data were inadequate for an analysis of this factor. In this case, the method employed, utilizing mean wind speed for a seven-day interval, tended to have a leveling effect upon the data, thereby eliminating short periods of high or low wind velocity which may have been significant. A weather factor, as changeable as wind velocity, cannot be analyzed by the procedures used in this particular study.

Precipitation and Migration

There appeared to be no relationship between incidence of precipitation and migration of waterfowl. Precipitation was about as common during periods of no migration as during periods of major arrivals and departures. Further study, relating migration to amounts of precipitation, suggested no significant relationship.

The literature provides only a few references concerning the effect of precipitation on migration. Bagg (1956) and McClure and Yoskii (1957) observed a reduced volume of passerine migration during periods of precipitation. However, Phillips (1911) reported unusual Canada goose flights which appeared to coincide with a stormy period of heavy precipitation.

As noted earlier in this report, it did appear significant for all categories of waterfowl that snowfall occurred more often during periods of major departures than during periods of no migration. Further analysis indicated freezing temperatures were encountered more often during periods of departure. Since falling temperatures have been found to be related to migratory movements, temperature may have been the actual underlying factor.

Jones and Gilmore (1955) found snow more important than temperature in triggering fall departure of the pink-footed goose from Iceland to Great Britain. Bellrose and Sieh (1960) also noted that three mass flights of ducks coincided with snowfall. The data in the present investigation neither prove nor disprove that a relationship exists between waterfowl migration and the incidence of snowfall.

Sky Cover and Migration

The literature fails to present conclusive evidence of the effect of sky cover on migratory movement. Approximately as many observers maintain migration can occur with overcast skies as those who believe clear skies are necessary.

Because this study did not provide exact dates of migratory departures and arrivals, the analysis had to relate to an entire census period. The results provided only a general comparison of mean sky conditions occurring during migratory flights. Waterfowl of all types appeared to depart on their southward flights under greater cloud cover than existed when these birds failed to migrate. Less cloud cover was observed during arrival periods than during periods of departures. Geese appeared to be less affected than ducks by overcast skies.

The findings of Hochbaum (1955) at Delta, Manitoba and Bellrose and Sieh (1960) in the Mississippi Flyway agree that mass waterfowl migration occurred under overcast skies. These observations together with the results of this study tend to discredit the hypothesis of Nisbet (1957) that birds must have clear skies for purpose of proper orientation.

Upper Air Wind and Migration

Prevailing wind directions and velocities aloft were studied to the

7,000 foot elevation above surface level. In autumn and winter, the winds aloft are mainly from the west and northwest in Central United States. One would, therefore, expect a high incidence of tailwinds and crosswinds during all census periods of the autumn migration. This fact is evident from data previously presented. Study of total waterfowl data indicated a higher incidence of tailwinds and crosswinds during periods of migration. In addition, fewer headwinds were encountered during periods of departure than during periods of population stability. Similar relationships were observed for dabbler and diver ducks. Wind direction was unrelated to goose migration.

These upper air conditions may be related to the passage of a frontal system. Because a strong cold front did occur more frequently with migratory departures of waterfowl, the upper air pattern may be linked with the passage of the frontal system. Higher incidence of tailwinds and fewer headwinds at departures may suggest that these waterfowl depart more frequently after the passage of a cold front. The fact that geese did not respond to the passage of a frontal system, may explain the lack of a relationship between migration and upper air wind direction.

Some investigators, including McMillan (1940) and Newman (1952) suggest that birds may seek out a wind at some level aloft that is coincident with the direction of migration and, thereby, take advantage of a tailwind. A combined study of surface and upper air winds indicated a tailwind could be located at some level 63 per cent of the departure periods. A headwind was present at some level only 24 per cent of the departure periods.

Analysis of upper air wind velocity provided inadequate evidence of a relationship to migratory movement of waterfowl.

Atmospheric Stability and Migration

This investigation necessitated the use of mean atmospheric stability for each weekly census period. Because an unstable atmosphere is of short duration, use of mean stability figures failed to list any unstable periods. The data indicated a stable atmosphere existed during periods of major arrivals and major departures in addition to periods of no migration. It is apparent, in order to study such a changing weather factor as atmospheric stability, one must have daily census data and thereby identify exact times of migratory movements.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Bird migration has been extensively studied in the United States and Europe; however, the relation of weather to migratory flights has not been thoroughly investigated. Those who have considered this problem do not agree concerning the relationship of various weather factors to migration.

The objective of this investigation was to study the autumn migration of waterfowl in the Central Flyway of the United States and determine if a relation existed between migratory flights and climatological conditions.

Procedures

1. Four study regions, representative of the different climatological zones of the Central Flyway, were selected as areas for collecting data.

2. Seventeen census stations, distributed within these regions and each located near a United States weather station, were chosen for waterfowl population counts.

3. Census data were obtained from each station for the autumn periods of 1953, 1954, and 1955.

4. Each census station was visited to observe waterfowl habitat conditions and to identify migration routes.

5. Weather records, for the immediate area of each census station, were

obtained from the National Weather Records Center, Asheville, North Carolina.

6. Waterfowl census data and weather records were placed on IBM punch cards and programmed for reduction of data by the Oklahoma State University Computer Center.

Major Findings

1. Patterns of total waterfowl migration indicated that peak populations occurred in mid-October in Region I, about the first of November in Region II, and the last of December in Regions III and IV. Major migratory arrivals occurred during the first week of November in wintering areas of Regions III and IV.

2. Mass movements of waterfowl were concentrated in two or three separate periods for Regions I and II. In Regions III and IV the major movements were scattered during the migratory season.

3. Patterns of goose migration indicated small population build-up in Regions I and II, large wintering populations in Region III, Oklahoma and North Texas, and a population build-up in Region IV, only in the unusual year of 1955.

4. Major flights of geese occurred earlier in the season than did major flights of ducks. Major goose arrivals began in Region III by the second week of October. Major flight patterns indicated a more scattered distribution for geese than for ducks during the migratory season.

5. Patterns of migration were nearly identical for dabbler ducks and total waterfowl.

6. Migration patterns indicated diver ducks did not use the refuges in Region III in appreciable numbers during fall migration. Large populations were recorded in Regions I, II, and IV. Diver ducks which normally winter on the Texas Gulf Coast never arrived in appreciable numbers in 1955. Their location was unknown to refuge personnel.

7. The autumn migration of 1953 was characterized by two or three definite migratory pulsations. A more leisurely southward movement with a scattering of migratory flights occurred in 1954, and 1955 had one mass movement with nearly all birds leaving northern regions approximately one month early. The 1955 mass movement was observed throughout the flyway from the Canadian border to the Gulf Coast of Texas.

8. Major southward departures of all types of waterfowl, geese, dabbler and diver ducks, coincided with falling temperature.

9. Falling minimum temperature was more closely related to migration than were falling maximum temperature or falling average temperature.

10. Temperature relation to migration was not as strong for geese and diver ducks as it was for dabbler ducks.

11. Migratory arrivals appeared to be unrelated to temperature at the birds' destination.

12. Passage of a frontal system, as such, was unrelated to waterfowl migration. The passage of a strong cold front coincided with the migratory departures of dabbler ducks, but not for geese and diver ducks.

13. Barometric pressure change appeared to be unrelated to migratory movement of waterfowl.

14. Direction of surface wind was unrelated to the migration of all types of waterfowl. The relationship to wind velocity could not be analyzed by the methods employed in this study.

15. Precipitation, per se, was not related to waterfowl migration. However, snowfall was more common during periods of departure of all waterfowl than during periods when no migration occurred.

16. Cloud cover was greater during periods of departure than during periods of no migration. Greater cloud cover was observed during the migration of geese than during the migration of ducks.

17. There was a higher incidence of upper air tailwinds and crosswinds during the periods of major departures than during the periods of no migration of ducks. Goose migration appeared to be unrelated to direction of upper air winds.

18. The methods employed in this study did not permit analysis of the relations of atmospheric stability to migration of waterfowl.

Suggestions for Further Study

Daily population counts should be made so that the exact time of each major migratory flight can be determined. Each census station should be located near a first class weather station. In addition, the personnel taking the census should keep a record of weather conditions during the period when the census is taken. Methods employed for taking waterfowl counts should be as nearly uniform as possible. With data of this nature, the following would be possible:

1. To determine if dabbler ducks depart with a headwind before the

arrival of a strong cold front or with a tailwind after the passage of a strong cold front.

2. To determine the relationship of migration to wind velocity and atmospheric stability.

3. To re-study the relation of migration to barometric pressure, wind direction, and precipitation and, thereby, determine if the methods employed in this study were sensitive enough to identify such a relationship.

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APPENDIX A

Table 1. Coding system for IBM punch card data processing.

Columns	Data
1	Region of study
2	Census station
3, 4, 5, 6, 7, 8, 9	Population of total waterfowl
10, 11, 12, 13, 14	Population of geese
15, 16, 17, 18, 19, 20, 21	Population of ducks
22, 23, 24, 25, 26, 27, 28	Population of dabbler ducks
29, 30, 31, 32, 33, 34, 35	Population of diver ducks
36	Month
37, 38	Day
39	Year
40, 41, 42	Maximum temperature
43, 44	Minimum temperature
45, 46	Average temperature
47, 48	Departure from normal temperature (in degrees)
49, 50, 51, 52	Rainfall (to one-hundreth inch)
53, 54, 55	Snowfall (to one-tenth inch)
56, 57	Wind direction (16 point system)
58	Census period
59, 60	Wind speed (miles per hour)
61, 62	Sky cover (in tenths)
63, 64, 65, 66, 67	Millibars of barometric pressure (to one tenth)
68	Frontal system
69, 70	Time of passage of frontal system
71, 72	Prevailing direction of upper air wind, night (16 point system)
72, 74	Average speed of upper air wind, night (meters per second)
75, 76	Direction of upper air wind, day (16 point system)
77, 78	Speed of upper air wind, day (meters per second)
79	Atmospheric stability, night
80	Atmospheric stability, day

APPENDIX B

Table 2. Weekly census for total waterfowl in Regions 1 and 2 of the Central Flyway, 1953, 1954, and 1955.

	Region I			Region II		
Census Period	1953	1954	1955	1953	1954	1955
1	159,294	252,880		87,343	110,305	17,775
2	169,264	287,047	101,813	98,593	127,956	136,910
3	214,233	312,567	138,163	119,718	140,730	177,385
4	162,381	354,163	169,499	109,831	146,240	186,335
5	236,999	361,428	196,986	107,066	163,120	198,995
6	266,406	384,169	273,336	112,509	183,275	180,860
7	301,981	269,267	351,972	143,934	200,635	193,750
8	211,825	281,392	347,425	202,959	328,770	240,370
9	204,613	184,166	146,772	270,969	359,406	333,910
10	154,444	138,984	24,347	462,164	354,705	553,275
11	207,847	169,470	14,463	346,339	269,365	346,392
12	35,657	141,768	465	360,423	247,746	75,255
13	5,153	104,616		144,243	212,732	138,785
14	4,196	11,400		141,445	126,861	61,100
15				81,930	29,295	67,275
16				76,745	21,957	31,175
17				61,253	13,095	24,275
18				61,203	11,455	28,225

Table 3. Weekly census for total waterfowl in Regions 3 and 4 of the Central Flyway, 1953, 1954, and 1955.

	Region III			Region IV		
Census Period	1953	1954	1955	1953	1954	1955
1	204	2,864	945		446	2,367
2	1,871	1,640	1,266	125	2,324	1,188
3	2,853	1,365	1,362	2,710	3,373	1,661
4	4,545	2,306	2,470	3,991	3,099	2,033
5	5,781	4,738	3,735	8,129	3,218	2,296
6	9,598	9,784	10,288	17,861	2,594	10,214
7	22,834	21,451	26,781	25,205	10,579	28,562
8	43,423	26,397	60,146	29,176	22,344	32,723
9	74,596	46,173	90,454	69,998	41,456	178,337
10	87,003	68,056	180,174	220,315	115,854	152,703
11	107,627	115,862	335,640	387,306	196,956	74,160
12	180,914	139,626	507,659	543,707	201,675	98,451
13	239,425	147,107	540,271	496,864	247,464	96,302
14	288,321	135,526	612,223	446,649	397,940	57,047
15	311,393	153,514	697,447	421,583	746,844	56,824
16	296,110	165,938	655,575	1,485,856	891,092	132,779
17	288,318	157,876	709,213	1,476,523	847,202	147,775
18	314,269	176,430	798,394	1,304,849	836,532	222,298

Table 4. Weekly census for geese in Regions 1 and 2 of the Central Flyway, 1953, 1954, and 1955.

	Region I			Region II		
Census Period	1953	1954	1955	1953	1954	1955
1	0	3,500		6	10	0
2	2,800	3,500	909	6	11	85
3	3,000	3,510	709	6	10	85
4	2,856	4,010	673	6	20	85
5	4,686	6,410	1,125	163	250	185
6	6,207	3,739	1,875	1,349	950	1,085
7	5,386	2,492	951	3,724	1,150	625
8	2,628	1,313	1,310	4,774	1,110	770
9	3,061	1,350	1,554	4,274	1,446	775
10	1,708	1,688	641	5,194	1,645	3,850
11	2,001	1,125	1,535	3,369	2,080	4,552
12	453	1,651	75	1,434	1,910	1,755
13	56	218		1,789	1,661	1,810
14	0	100		2,060	625	1,300
15				856	25	1,225
16				2,550	5	125
17				600	0	75
18				600	0	75

Table 5. Weekly census for geese in Regions 3 and 4 of the Central Flyway, 1953, 1954, and 1955.

	Region III			Region IV		
Census Period	1953	1954	1955	1953	1954	1955
1	3	0	150		0	0
2	3	0	150	0	0	0
3	3	0	0	0	0	0
4	78	0	0	37	0	0
5	198	70	181	0	0	0
6	3,488	1,540	2,416	453	0	796
7	11,275	5,840	6,692	707	78	510
8	18,607	9,513	11,478	604	2,083	1,318
9	23,076	14,899	22,450	985	1,235	2,397
10	23,386	19,548	33,917	2,883	5,699	14,252
11	26,466	33,886	34,640	5,486	6,401	13,159
12	42,316	38,495	47,288	3,839	6,401	15,312
13	35,770	38,655	15,828	8,015	7,696	20,079
14	36,492	30,496	13,362	8,065	8,117	18,590
15	31,004	34,069	12,067	9,843	8,146	17,786
16	28,027	33,050	11,707	8,261	10,778	21,929
17	23,122	29,221	13,107	8,738	11,798	20,991
18	21,810	25,212	11,911	3,393	12,518	23,822

Table 6. Weekly census for dabbler ducks in Regions 1 and 2 of the Central Flyway, 1953, 1954, and 1955.

	Region I			Region II		
Census Period	1953	1954	1955	1953	1954	1955
1	15,560	171,120		44,925	48,375	8,475
2	91,965	187,079	70,550	46,600	57,975	75,050
3	116,645	201,879	88,250	63,650	69,775	98,250
4	114,125	227,201	104,680	62,400	73,725	120,500
5	139,515	250,801	108,380	66,100	101,025	134,500
6	159,001	246,515	175,780	76,200	120,750	119,550
7	218,086	159,840	248,890	96,750	141,250	131,550
8	175,567	182,080	238,090	128,750	250,250	166,800
9	161,357	132,100	111,560	127,700	270,250	220,800
10	137,140	100,885	8,820	274,650	278,700	320,850
11	158,760	126,460	10,340	169,800	144,275	111,050
12	31,550	129,320	390	198,002	164,200	40,150
13	4,862	96,305		78,002	142,600	40,050
14	4,184	11,300		75,852	112,050	33,150
15				60,302	23,950	25,550
16				55,077	18,550	25,550
17				55,052	12,150	23,050
18				55,002	11,075	27,050

Table 7. Weekly census for dabbler ducks in Regions 3 and 4 of the Central Flyway, 1953, 1954, and 1955.

	Region III			Region IV		
Census Period	1953	1954	1955	1953	1954	1955
1	70	2,308	411		285	1,814
2	439	671	634	46	2,000	643
3	768	725	834	2,440	3,003	681
4	1,105	1,318	1,042	3,332	2,500	726
5	1,800	2,454	1,819	7,680	2,798	1,845
6	2,836	5,765	3,507	15,924	1,857	8,325
7	4,953	12,344	11,957	18,272	6,845	26,601
8	11,270	13,433	35,346	20,022	9,367	25,847
9	38,917	25,737	45,482	29,697	13,072	169,652
10	53,980	42,643	118,287	108,959	31,478	126,237
11	70,595	77,255	282,605	230,199	82,174	57,525
12	125,312	96,057	441,627	235,162	87,374	79,360
13	187,965	104,967	507,348	184,596	129,770	71,550
14	234,397	95,931	580,786	134,646	229,770	33,961
15	258,042	109,182	662,250	107,491	303,620	34,486
16	247,278	123,741	626,016	722,708	416,844	103,531
17	242,444	112,210	682,218	716,408	399,401	123,014
18	267,439	136,413	764,648	699,560	390,033	195,646

Table 8. Weekly census for diver ducks in Regions 1 and 2 of the Central Flyway, 1953, 1954, and 1955.

	Region I			Region II		
Census Period	1953	1954	1955	1953	1954	1955
1	4,280	22,240		2,862	4,770	850
2	30,660	37,260	19,190	3,912	4,820	4,225
3	41,890	44,160	23,290	4,387	4,820	3,800
4	42,160	57,763	38,430	4,775	5,545	4,300
5	56,300	60,263	59,030	5,800	12,100	5,650
6	66,720	76,425	72,010	8,800	15,100	13,800
7	62,900	80,620	84,280	11,550	19,350	24,600
8	27,568	73,970	90,180	27,050	31,875	33,250
9	33,528	43,800	30,350	29,635	39,475	43,500
10	42,828	35,070	4,010	51,610	36,975	39,400
11	42,375	40,150	1,500	21,650	22,825	9,200
12	2,951	10,390	0	15,002	20,500	100
13	110	8,050		102	12,500	50
14	10	0		552	6,100	0
15				551	513	0
16				501	100	0
17				501	43	0
18				501	28	0

Table 9. Weekly census for diver ducks in Regions 3 and 4 of the Central Flyway, 1953, 1954, and 1955.

	Region III			Region IV		
Census Period	1953	1954	1955	1953	1954	1955
1	0	0	0		30	0
2	0	0	0	0	52	0
3	0	0	0	24	37	0
4	0	1	0	0	0	8
5	2	18	0	35	0	25
6	34	80	3	156	0	300
7	230	209	456	4,201	2,739	323
8	624	979	986	6,201	11,013	5,005
9	490	1,751	3,210	38,147	30,058	5,896
10	1,024	1,009	2,466	100,542	77,834	11,574
11	921	1,105	2,580	150,365	107,528	2,523
12	1,322	1,863	2,181	302,416	107,528	2,527
13	2,000	1,264	4,843	303,244	108,291	3,478
14	1,528	1,205	3,070	303,244	158,296	3,448
15	1,189	1,225	5,120	303,173	433,311	3,473
16	804	1,053	1,620	754,147	459,995	6,243
17	979	692	2,070	750,647	459,850	2,192
18	1,352	357	8,007	601,000	408,385	1,451

APPENDIX C

Table 10. Peak populations of waterfowl at the seventeen census stations for 1953, 1954, and 1955.

Station	Peak Population 1953	1954	1955
Region 1			
1. Bowdoin N. W. R.	222,868	356,165	317,931
2. Des Lac N. W. R.	37,532	40,710	27,166
3. Lostwood N. W. R.	35,210	20,790	26,159
4. Long Lake N. W. R.	41,057	42,816	
Region 2			
1. Lake Andes N. W. R.	123,345	147,825	202,240
2. La Creek N. W. R.	67,824	75,300	59,875
3. Valentine N. W. R.	263,610	252,760	304,825
4. Crescent Lake N. W. R.	25,850	27,225	17,675
5. North Platte N. W. R.	61,000	44,275	41,000
Region 3			
1. Salt Plains N. W. R.	42,460	24,730	51,030
2. Lake Overholser	10,000	3,000	10,000
3. Tishomingo N. W. R.	58,500	74,050	73,950
4. Hagerman N. W. R.	97,245	59,267	46,723
5. Muleshoe N. W. R.	129,583	81,319	701,462
6. Bitter Lake N. W. R.	45,728	25,036	69,969
Region 4			
1. Aransas N. W. R.	77,696	84,314	85,220
2. Laguna Atascosa N. W. R.	1,420,983	864,702	162,113

Table 11. Peak populations of geese at the seventeen census stations for 1953, 1954, and 1955.

Station	Peak Population 1953	1954	1955
Region 1			
1. Bowdoin N. W. R.	6,625	6,410	1,811
2. Des Lac N. W. R.	32	36	44
3. Lostwood N. W. R.	0	62	90
4. Long Lake N. W. R.	571	388	
Region 2			
1. Lake Andes N. W. R.	1,450	125	900
2. La Creek N. W. R.	2,824	700	2,000
3. Valentine N. W. R.	800	700	300
4. Crescent Lake N. W. R.	1,750	800	3,000
5. North Platte N. W. R.	600	500	750
Region 3			
1. Salt Plains N. W. R.	15,100	7,019	10,020
2. Lake Overholser	200	350	80
3. Tishomingo N. W. R.	21,000	21,400	32,950
4. Hagerman N. W. R.	15,310	20,510	6,120
5. Muleshoe N. W. R.	601	700	702
6. Bitter Lake N. W. R.	124	89	129
Region 4			
1. Aransas N. W. R.	7,338	6,848	16,947
2. Laguna Atascosa N. W. R.	2,900	6,150	7,075

Table 12. Peak populations of dabbler ducks at the seventeen census stations for 1953, 1954, and 1955.

Station	Peak Population 1953	1954	1955
Region 1			
1. Bowdoin N. W. R.	160,000	230,000	230,000
2. Des Lac N. W. R.	32,700	30,200	16,360
3. Lostwood N. W. R.	29,560	10,250	16,500
4. Long Lake N. W. R.	40,650	42,600	
Region 2			
1. Lake Andes N. W. R.			
2. La Creek N. W. R.	54,000	56,500	44,000
3. Valentine N. W. R.	190,000	217,000	252,000
4. Crescent Lake N. W. R.	15,750	18,250	8,750
5. North Platte N. W. R.	50,000	25,250	30,100
Region 3			
1. Salt Plains N. W. R.	23,100	8,500	35,700
2. Lake Overholser			
3. Tishomingo N. W. R.	38,000	55,000	40,500
4. Hagerman N. W. R.	82,000	38,400	40,365
5. Muleshoe N. W. R.	126,250	80,000	688,500
6. Bitter Lake N. W. R.	43,492	24,638	64,875
Region 4			
1. Aransas N. W. R.	73,799	70,020	70,460
2. Laguna Atascosa N. W. R.	665,300	407,950	160,138

Table 13. Peak populations of diver ducks at the seventeen census stations for 1953, 1954, and 1955.

Station	Peak Population 1953	1954	1955
Region 1			
1. Bowdoin N. W. R.	56,000	75,000	80,000
2. Des Lac N. W. R.	8,510	9,800	6,390
3. Lostwood N. W. R.	6,690	3,320	6,620
4. Long Lake N. W. R.	2,401	290	
Region 2			
1. Lake Andes N. W. R.			
2. La Creek N. W. R.	10,000	5,200	12,000
3. Valentine N. W. R.	41,000	25,000	34,000
4. Crescent Lake N. W. R.	2,750	6,250	3,250
5. North Platte N. W. R.	500	7,500	200
Region 3			
1. Salt Plains N. W. R.	875	1,310	2,210
2. Lake Overholser			
3. Tishomingo N. W. R.		1,000	100
4. Hagerman N. W. R.	470	105	530
5. Muleshoe N. W. R.	95	84	600
6. Bitter Lake N. W. R.	964	1,203	7,917
Region 4			
1. Aransas N. W. R.	2,194	9,435	5,299
2. Laguna Atascosa N. W. R.	754,100	450,560	6,275

VITA

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Doctor of Philosophy

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