california CONDORS:

status of the recovery effort

jared verner

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The Author

JARED VERNER, a research wildlife biologist, is in charge of the Station's endangered species research unit at Fresno, California. He was educated at Washington State University (B.S., wildlife management, 1957), Louisiana State University (M.S., zoology, 1959), and the University of Washington (Ph.D., zoology, 1963). Before joining the Forest Service in 1976, he was professor of ecology at Illinois State University.

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Disturbance and high mortality related to human activity have apparently caused the decline of the condor population to about 50 birds. Failure to reproduce successfully is now the central problem; inadequate food supply near nest sites, lack of nest sites in new concentration areas, and pesticide accumulation in condor tissues are possible causes. Low reproductive rate hinders the recovery effort. Results of population modeling indicate that a minimum of eight nesting attempts each year is needed to maintain a population of at least 50; field data indicate that an average of only 1.8 young were produced per year from 1966 through 1976. Principal recommendations include analysis of vegetation structure in the condor range by aerial photographic interpretation; attempts to mark condors for life; standardization of counting procedures; and approval and funding of the proposal to rear condors in captivity.

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Retrieval Terms: California condor, endangered species, survival, natural history, population dynamics, population modeling.

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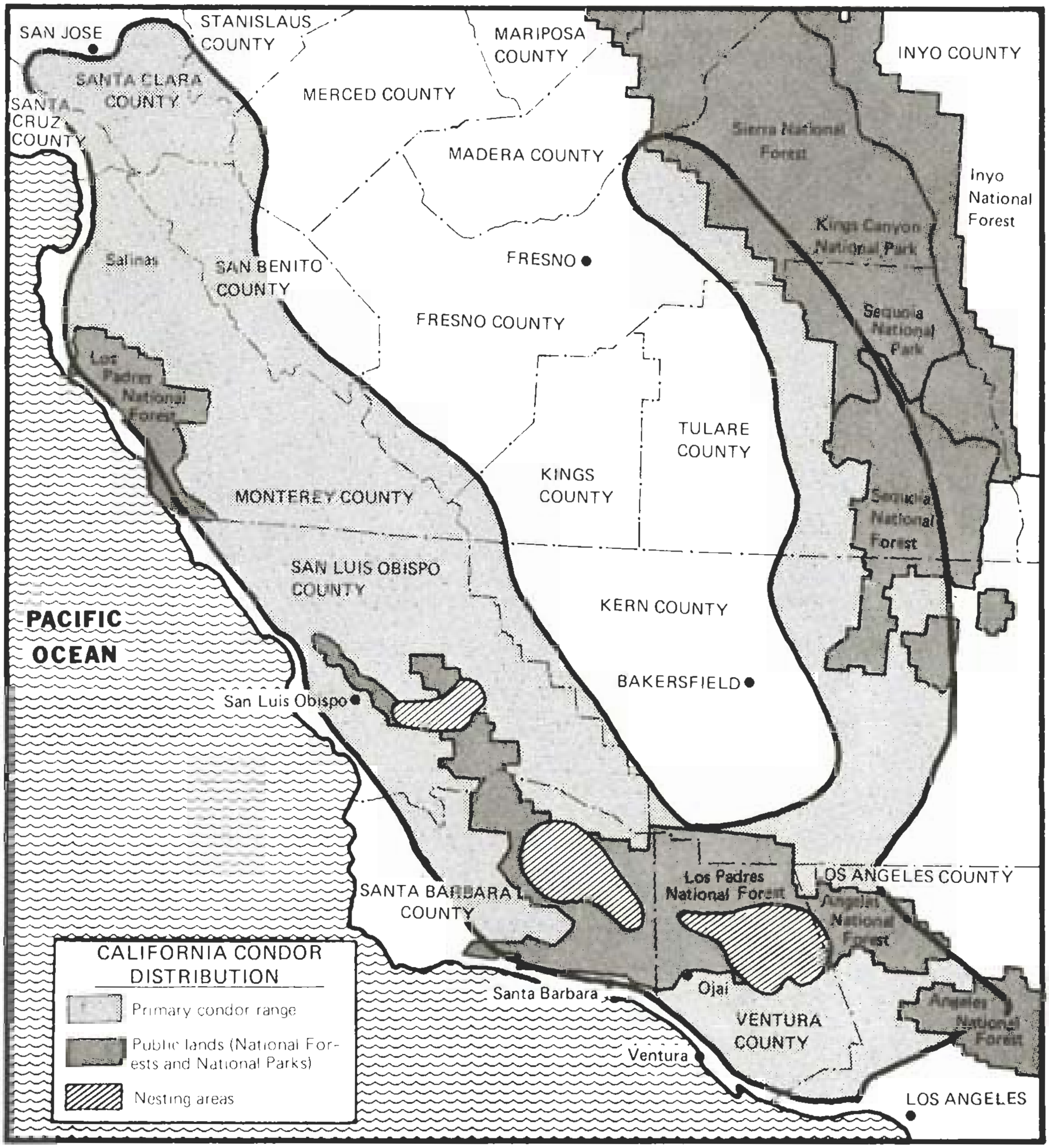

SAN JOSE
STANISLAUS COUNTY
MARIPOSA COUNTY
INYO COUNTY
SANTA CLARA COUNTY
SANTA CRUZ COUNTY
MERCED COUNTY
MADERA COUNTY
Sierra National Forest
Inyo National Forest
Kings Canyon National Park
Salinas
SAN BENITO COUNTY
FRESNO
FRESNO COUNTY
Sequoia National Park
Los Padres National Forest
TULARE COUNTY
KINGS COUNTY
MONTEREY COUNTY
Sequoia National Forest
SAN LUIS OBISPO COUNTY
KERN COUNTY
PACIFIC OCEAN
BAKERSFIELD
San Luis Obispo
Los Padres National Forest
LOS ANGELES COUNTY
SANTA BARBARA COUNTY
Angeles National Forest
CALIFORNIA CONDOR DISTRIBUTION
Primary condor range
Public lands (National Forests and National Parks)
Nesting areas
Santa Barbara
Ojai
VENTURA COUNTY
Angeles National Forest
Ventura
LOS ANGELES

In Brief...

In the California condor recovery effort, key life history features pose problems for the population, in its present declining trend. Most important are delayed onset of first reproduction, and low reproductive potential. The condors today are restricted to certain mountainous regions of southern California and are thought by some authorities to be divided into two subpopulations with little or no intermixing of birds. Adults weigh about 9 kg and have a wing span of about 2.9 m. Subadults are distinguishable until about age 5, but only the age class from 3 to 3½ years old can be distinguished with much reliability. First breeding probably occurs no earlier than age 6 and no later than age 10. The single egg typically is laid on the floor of a cliff-face cavity, usually in early March. The young may remain in the nest cave through October, or even later, and the adults may continue to care for their young well into the following spring. No unequivocal data have shown that a given pair breeds more often than every other year.

although the possibility of annual breeding may not be ruled out, particularly with ideal conditions.

California condors apparently are carrion feeders exclusively, showing a preference for deer and calf carcasses. Feeding sites must provide ample clearance for landing and takeoff. Condors regularly drink from and bathe in freshwater pools.

Available data show that the population has been declining for the past 125 years, at least, and that probably fewer than 50 birds survive today. Abnormally high mortality, largely attributable to human activities, probably accounted for the decline over most of the specified time period, but today, failure of most condors to breed successfully is the principal reason the population has not stabilized. An annual count of California condors, in October, was initiated in 1965, but it still has not been possible to obtain an accurate estimate of the remaining birds, nor will it be until at least a portion of the population has been individually marked for field recognition. Even trends in the condor population may not be inferred from the annual counts, because counting procedures have not been held constant. Data from high counts of groups of birds, however, suggest about a 30 percent decline in numbers from the early 1940's to the mid-1960's and another 36 percent decline from the mid-60's to December 1976.

Nesting success for the years 1939-41 was about 65 percent; in 1966-68 it was only 45 percent. Since 1969, however, virtually every suspected nesting effort succeeded. Unfortunately, annual production of fledged young has not been sufficient to maintain the population. Never more than three young were produced in any year since 1966; annual average from 1966 through 1976 was only 1.8 young fledged.

Adult sex ratio among living condors is unknown. In museum specimens males outnumber females in a ratio of 60:40.

Results of population modeling indicate that the annual survival rate of adults, throughout the species' history, must have been about 95 percent, and that of subadults (to age 6) about 87 percent, for the condor to have persisted to modern times. These values yield an expected mean longevity of 16.9 years and a maximum longevity of 80 years, beginning with a hypothetical group of 100 dependent young alive in mid-October. If the model assumes a possible bias in the sex ratio of 60 males to 40 females, and a possible long-term average of 75 percent nesting success, a minimum of eight nesting attempts must be made each year to maintain a population of at least 50 condors.

Active efforts to do something about the reduction in abundance and distribution of California condors date from 1939. Most sources of mortality directly attributable to human activities have been eliminated or significantly reduced, as have sources of disturbance at nesting, feeding, and roosting sites. A formal recovery plan has been drafted and approved. A viable public education program is in operation. Supplemental feeding of condors near suitable nest sites has been in effect since 1971. Data have been gathered to suggest that biological concentration of pesticide metabolites may be responsible for recent failure of the condors to breed successfully. And, finally, a formal proposal has been made by the California Condor Recovery Team to erect artificial nest sites in southern Kern County and to begin, as soon as possible, a captive rearing program with the long-term goal of returning reared birds to the wild population.

Major recommendations offered in this report to extend the recovery effort are these: (1) Analyze vegetation structure in the condor range to provide baseline data in the event of significant, future shifts in principal use areas of condors. Similar data from past aerial photography should be sought for comparison. (2) Explore the possibility of individually marking condors for life by use of tattoos. Marked birds are essential if data are to be obtained on movement patterns, absolute population size, age at first reproduction, frequency of breeding by individual birds, and sex ratio. (3) Strive to perfect a method for identification of the sex of captured birds. (4) Employ more seasonal help for field observations, particularly to assist in establishing whether condor breeding efforts fail because of eggshell thinning or because adults fail to initiate nesting activities. (5) Standardize the mid-October counting procedures and rigorously maintain them for an indefinite number of years. (6) Strive to identify the source of any substance toxic to condors by exhaustive assay of all levels in the condor's food web. (7) Approve and fund as soon as possible the Contingency Plan proposal for erection of artificial nest sites. (8) Approve and fund as soon as possible the Contingency Plan proposal to begin rearing condors in captivity, for later release to the wild. If pesticide accumulation is, in fact, the reason for recent failure of condor breeding activity, captive rearing may be the only way to purge birds of their pesticide loads in time to save the population. Captive rearing, if undertaken, should be carried out where birds are to be released, perhaps using a mobile rearing facility.

The California condor (*Gymnogyps californianus*) is among those North American bird species most threatened with extinction. Several agencies (notably the U.S. Fish and Wildlife Service, Forest Service, and Bureau of Land Management; the California Department of Fish and Game; and the National Audubon Society) have invested heavily in resources and personnel in the effort to stabilize the dwindling condor population. Available evidence shows unquestionably that the California condor population has been markedly restricted in distribution and has declined steadily in numbers at least since the early part of the last century. These trends continue today in spite of many programs undertaken to turn the situation around.

Earlier studies identified inordinate mortality as the primary agent in decreasing the number of condors—mortality in large part attributable to human activity (Koford 1953, Miller and others 1965). Steps taken to eliminate most such causes of mortality are realistic and apparently have been largely successful. A secondary factor identified in the condor problem was undue disturbance of the birds by human activities. Disturbances were thought to contribute to abandonment of traditional nesting and roosting areas and even to abandonment of active nests, thus reducing annual production of young condors. Again, measures taken to secure the condors from such disturbances are thought to be adequate and effective (Sanford R. Wilbur, pers. commun.). The decline continues, however, because in recent years few pairs of condors have even attempted to nest.[1] The reasons for this are unknown, although considerable recent evidence points to pesticide accumulation as a causative agent.

This paper first summarizes those life history features germane to population management. Based on this information and on past and present conjecture about population size, some simple models of population dynamics are then presented as a means of improving our ability to determine from censuses any trends in condor population size. An annotated list of the various facets of the recovery effort follows, and, finally, suggestions are made for enlargement of both research and management activities associated with the California condor recovery effort.

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[1] Wilbur, Sanford R. *The California condor, 1966-1974, with a look at its past and future.* (Manuscript in preparation)

Life History

range

The condors today are restricted to a roughly U-shaped range in southern California. The left arm of the U extends northward into the Coast Range Mountains from Santa Barbara to about the boundary between San Luis Obispo and Monterey Counties. From August through December, nonbreeders extend the Coast Range distribution northward to the vicinity of San Jose. The base and right arm of the U extend from the northern fringes of the greater Los Angeles area into the western foothills of the Sierra Nevada Mountains. Yearlong occupancy extends into the Tehachapi Mountains to a point almost as far north as Bakersfield. Nonbreeders range northward in the west Sierran foothills from May through September to about the southern Madera County Line, somewhat northeast of Fresno. Three nesting areas are recognized—the Hi Mountain-Beartrap region east of San Luis Obispo, the Sisquoc area north of Santa Barbara, and the Sespe-Piru area in east-central Ventura County and adjacent Los Angeles County. The Sespe-Piru has long been known as the principal nesting area of California condors.

Two features of condor distribution and seasonal movements have potential significance to effective management for recovery of the population. First, condors occupying the Coast Range area may comprise a subpopulation separate from those breeding in the Sespe-Piru and ranging northward along the western foothills of the Sierras (Wilbur[1] and pers. commun., Wilbur and others[2]). The division between these presumed subpopulations apparently straddles the boundary between Santa Barbara and Ventura Counties. No condors have been marked to test the subpopulation hypothesis unequivocally, but no condors have been seen crossing this boundary in either direction, even though trained observers have spent much time at strategic vantage points. Moreover, the relative numbers of birds observed in the two segments of the range do not change seasonally or from year to year.

Second, nonbreeders from the Sespe-Piru and western Sierra region formerly ranged northward from the breeding area during the May-September period, and returned to the Sespe-Piru for the winter and spring. As birds reached breeding age,

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[2] Wilbur, Sanford R., W. D. Carrier, B. K. Muldowney, J. C. Borneman, and W. H. Radtkey. 1974. *California condor recovery plan.* (Available on request from Sanford R. Wilbur, Fish and Wildlife Service, 1190 E. Ojai Ave., Ojai, Calif. 93023.)

they remained to nest in the Sespe-Piru. A reduction in available winter food supply in the Sespe-Piru area may have caused some nonbreeders to shift their wintering range to southern Kern County. This region lacks suitable nest sites, however; a fact which suggests certain stimuli necessary to pair formation and nest site selection may be lacking at the critical time.[1]

physical characteristics

Adult condors weigh approximately 9 kg and have a wing span of about 2.9 m. Plumage is black except on the underwing linings and the edges of the upper secondary coverts, where it is white. The head and neck are naked: the skin on the neck area is gray, but on the head it is yellowish-orange, grading into reddish posteriorly. A large ruff occurs where feathering begins on the neck, and a perched bird may use its ruff to protect its retracted, naked neck. No evident sexual dimorphism in size or plumage exists. Five or six years are required for a bird to attain adult plumage (Koford 1953). Wilbur (pers. commun.) observes that birds 5 years old are essentially indistinguishable from adults, and most subadult age classes cannot be identified with certainty. Among subadults, the one age class that can be most reliably distinguished is the so-called "ring-necked" stage of birds from 3 to 3½ years old.

age at first breeding

Because subadult birds have never been observed as members of breeding pairs, Koford (1953) concluded that age at first reproduction in California condors is *at least* 6 years. Wilbur (pers. commun.) believes the age is more likely to be at least 8 years, based on knowledge of the age at first breeding among other large bird species with long prereproductive periods, as well as the fact that a California condor in the National Zoological Park was 12 years old when it laid its first egg (Dixon 1924). At best, then, our estimate of the mean age is only an intelligent guess, and an error in this guess of only 1 year profoundly affects our ability to assess accurately whether or not condor reproduction is sufficient to maintain the population (compare Cole 1954), as will be shown later in this paper. Furthermore, the key element is not the youngest age at which reproduction occurs among the condors, but the average age of the first *successful* reproduction. In most bird species for which an analysis of breeding success in relation to age has been possible, there is significantly lower success in the first breeding effort than in later efforts, as described by Lack (1966). We can reasonably assume that the condors also improve with experience.

nesting habits

Territoriality evidently is not highly developed among California condors. Territorial encounters have been noted only infrequently, even when several nonbreeding birds roosted near active nests (Koford 1953). Active nests have been located within 1.6 km of each other.

Nest site selection may be a prolonged process, lasting weeks or even months (Sibley 1969). "The main physical requirements for a condor nesting site seem to be: location in cavity in rock (or large tree trunk), suitable roosting perches nearby, fairly easy approach from the air, space below for taking off, protection from storms, winds and direct sunshine, space enough to hold two full-grown condors, level soft area where walls are about two feet apart, and perches available for the young bird when it leaves the nest" (Koford 1953). Most nest caves face either northeasterly or southwesterly (Carrier 1971).

Koford's (1953) observations suggest a breeding phenology as follows:

1. Laying of the single egg extends from February 10 to mid-April, and most laying occurs in early March.
2. Incubation requires 42 days (43 according to

Carrier 1971; possibly up to 60 days, as in the Andean condor, *Vultur gryphus,* according to Wilbur, pers. commun.). It is shared by the sexes, and may continue to late May or early June, depending on laying date.

3. Nestlings are fed by both parents, and the young remain in the nest approximately 20 weeks. Young from late-hatched eggs thus may be in the nest through October. (Koford's figure 10, p 87, suggests young in the nest into December).

4. Young leave the nest long before they can fly, finding perching sites on ledges, rock outcrops, or trees near the nest cavity. There they remain to be fed by their parents for about another 10 weeks, while they are unable to fly long distances; they may change perching sites occasionally. (One juvenile was still within 1.6 km of the nest 10 weeks after leaving the nest. It had changed perches several times and at the age of 201 days was still within 300 m of the nest. It could fly only about 100 m at a time, but not without losing altitude. At 47 weeks it could fly and soar reasonably well, as it was identified among other birds at a watering site. The date was March 21 of the spring following the year it hatched.)

The duration of a successful nesting effort by a pair of condors is a negative factor in efforts to effect recovery of the population, with most condor experts in agreement that a given pair could rear, at most, only one young every other year. This conclusion is based on observations of adults continuing to feed young well into their second year, apparently because an effective social hierarchy makes it difficult for very young birds to obtain much food at carcasses where older, more dominant birds are feeding (Koford 1953, Carrier 1971, Wilbur[1] and pers. commun., Wilbur and others[2]). Carrier and Wilbur have also seen adults feeding young of the previous year, at the nest site, well into the spring (Wilbur, pers. commun.).

Annual nesting may occur, however. Finley (1908) states that "Even under favorable circumstances, each pair of condors will raise but one offspring a year." Koford (1953) reported consecutive use of "nest 5" in 1940 and 1941; the circumstances are not clear, however. The young in 1940 was not seen after it left the nest. It may have perished, so that the pair was free to nest again in 1941; a second pair may have used the nest site in 1941; or possibly the same pair successfully reared the 1940 young to independence in time to renest in 1941. Certainly the best evidence for annual nesting is Sibley's (1970) report of a relatively isolated pair of condors at Hi Mountain, San Luis Obispo

County. Four different sites in a small area were used over a 4-year period. Young were reared at least to the flying stage each year. Sibley (pers. commun.) confirmed his interpretation of this observation as follows: "I feel 100 percent confident that the same pair nested four years running and that each year they successfully fledged the young... I have pushed the interpretation that abundant local food . . . allowed for a more rapid development of the young bird." Nevertheless, the successful production of young in each of any two consecutive years still remains to be proved for free-living condors.

Whether or not annual breeding is possible for a pair of condors remains a question of obvious significance to any management program for condor recovery. In any event, it is clear that optimum conditions in nesting areas must be maintained *continuously* in view of the protracted period of nest site selection and the extraordinarily long nesting cycle.

food habits

California condors apparently are carrion feeders exclusively. Ninety-five percent of their food is derived from cattle, sheep, ground squirrels, deer, and horses, and they show a clear preference for deer and calves (Koford 1953). Clearance for landing and takeoff is important, so preference is shown for carcasses in short vegetation on ridges. Breeding birds return to the vicinity of the nest after foraging, and according to Wilbur,[1] they probably obtain most of their food within 50 km of the nest. Nonbreeders typically roost near carcasses upon which they have been feeding. Atmospheric conditions suitable for soaring generally limit condor foraging activity to warmer periods of the day. Considering travel time to and from roosts or nest sites, some birds may have only 2 or 3 hours a day of actual search time over suitable foraging areas (Koford 1953). Moreover, because soaring condors probably observe one another closely and follow a descending bird to a newly discovered carcass, a declining population may in itself lessen foraging success when carcasses are scarce or widely scattered.

Condors regularly drink from and bathe in freshwater pools. The importance of suitable pools that provide easy access and takeoff, and situated within convenient distance of foraging areas, was emphasized by Koford (1953) and Carrier (1971). Miller and others (1965) questioned the importance of fresh water because the condor's size and diet make dehydration unlikely. The special importance of water to these carrion feeders, however, may lie in its use for cleansing the feathers.

Population Dynamics

population trends

During the first half of the 1800's, when the nation's westward expansion was beginning, California condors were distributed northward at least to what is now central Washington, and perhaps even into British Columbia (Jewett and others 1953, Wilbur 1973), and as far south as Baja California. The history of the decline in the number of condors and the restriction of their range has been analyzed recently by many authorities (for example, Koford 1953, Miller and others 1965, Carrier 1971, Wilbur 1973, Wilbur[1], and Wilbur and others[2]), all of whom agree at least in that human activities of various sorts have been primarily responsible. All aspects of this problem need not be summarized here; suffice it to say that wanton shooting, egg collecting, specimen collecting for scientific purposes, general disturbance of nesting areas, and possibly inadvertent poisoning through rodent control projects probably were most important in the decline of the condor population from 1850 to 1950.

Koford (1953) was the first to provide an estimate of total condor numbers based on carefully documented counts by competent observers. His field work covered 400 observation days between March 1939 and June 1941; 80 observation days between February and July 1946; and 15 additional observation days up to the time he prepared his manuscript. The procedure gave the total number of birds counted in different areas at the same time and resulted in a high count of 42 birds on March 26, 1941 (22 at Tejon Ranch and 20 in the Sespe area). An alternate procedure of summing high counts from various widely separated areas over longer periods yielded a high of 43 birds in a 10-day period. Because not all birds would be accounted for by these procedures, Koford increased his counts by about 50 percent, for a final estimate of 60 birds as the total condor population in 1941. No empirical basis was established for the 50 percent added; the value apparently was only an informed judgment.

The next effort to estimate condor numbers was that of Miller and others (1965), based on extensive field work by the McMillan brothers from February 1963 into the summer of 1964. The means of population estimation in that report was comparable to Koford's and yielded high counts of 22 birds at Simi Valley in mid-April 1963, 24 birds at Tejon Flats on October 26, 1963, and 22 birds near Apache Potrero on August 23, 1964. Using data of this sort, in combination with adjustments for adults known to be

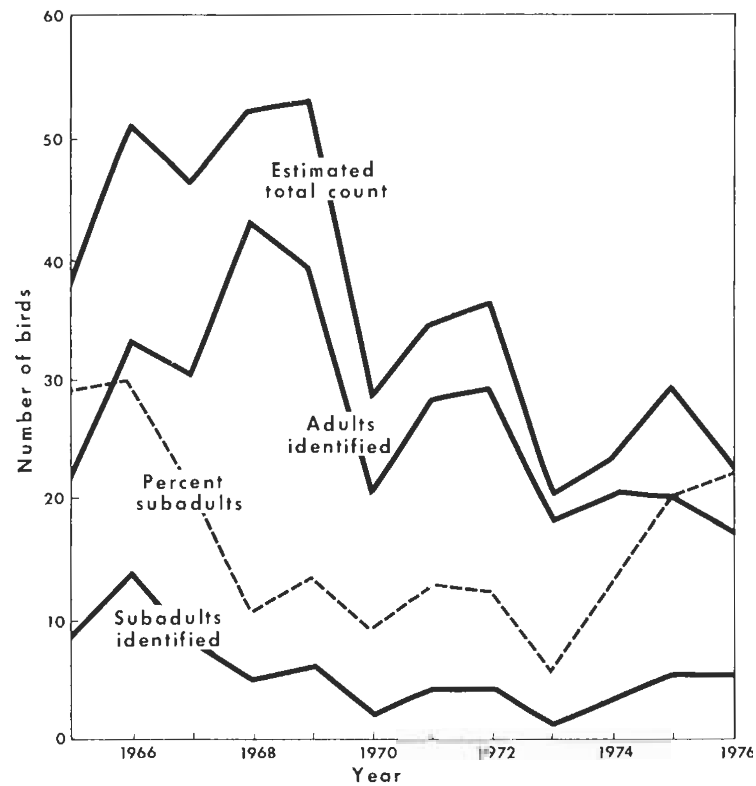

Figure 1—Results of annual condor census (1965-76) show sharp declines in numbers in 1970 and 1973, but these are probably due to procedural changes in the census (see text). For years when counts were made on two or more days, the values were taken from the day with the highest count in each category. The estimated total count includes birds not seen well enough to permit age determination; counts for adults and subadults include only individuals specifically identified as to age class. Percent of subadults = subadults identified / adults identified + subadults identified.

omitted because they were near nest sites, and adding 50 percent to compensate for other birds not in count areas, Miller and his coworkers reached a total population estimate of 42 birds for 1964. This represents a decline of about 30 percent in 23 years.

As a direct result of the study by Miller and others (1965) a condor census was established in mid-October 1965 and has been repeated annually since then. Trained observers at strategic locations, using standard forms, report as fully as possible on the age, activity, and direction of travel of each condor observed. Data from all observation stations are collated in an effort to eliminate duplication in sightings of birds. Details of census conditions (*table 1*) and count estimates (*fig. 1*) were taken from Mallette and Borneman (1966), Mallette and others (1967, 1970, 1972, 1973), Sibley and others (1968, 1969), Carrier and others (1972), and Wilbur (pers. commun.).

Unfortunately, the census procedures originally established in 1965 have not been maintained, so trends in condor numbers (*fig. 1*) cannot be taken as real indicators of population changes. For example, the numbers of observers and observation stations have never been the same in any 2 years of the census (*table 1*). In 1970 the number of stations was reduced by about 78 percent by eliminating all stations with a record of few or no sightings in previous years. The estimated total count of condors (total sightings minus probable duplications, as determined by collating records from different stations) in 1970 was down 66 percent from the year before (*fig. 1*). The number of counting stations was reduced again in 1973, by about 80 percent, and carcasses were placed at the remaining stations to attract more birds to them. The estimated total count in 1973 dropped about 44 percent from the previous year. Indeed, estimated total counts over the years are significantly correlated with the number of counting stations (Spearman's rank order correlation: $r_s = 0.81$, $P<0.01$).

Thus, results of the annual condor census are of no value in determing whether or not the condor population has responded in any way to management activities to date. The census could be useful, however, if procedures were standardized and maintained for several years. At least trends in numbers of subadult and adult age classes could be investigated without biases introduced by procedural changes. Such trends ought to be as reliable indicators of population changes as the high single and high cumulative counts now used as evidence.

The method by which count data should be translated into an estimate of the total condor population for any given year, and the reliability of the estimate, have been much in question. The key to this issue lies in establishing an index for estimating what proportion of the total population is likely to be missed by a given census technique. Obviously no such index is available, nor is it reasonable to assume one may be established in the near future, unless at least a portion of the population is permanently marked for individual recognition.

The magnitude of the decline in the condor population since 1940, when Koford (1953) did most of his field work, has been debated because condor biologists now believe that Koford underestimated the size of the population in 1940-41 and that Miller

Table 1—*Conditions of annual condor census, initiated in 1965*

Date of census (October)		Number of observers[1]	Number of stations[1]	Number of stations reporting birds[1]	Observing conditions
Year	*Day*				
1965	16, 17	98, 91	69, 61	16, 16	Good
1966	18, 19	133, 133	65, 65	15, 23	Good
1967	17, 18	130, 130	69, 69	19, 21	Good
1968	16, 17	137, 136	66, 66	18, 20	Good
1969	15	94,	51	27	Good
1970	21, 22	45, 43	16, 16	11, 8	Fair to poor
1971	13, 14	45, 45	18, 18		Good to poor
1972	11, 12	50, 50	20, 20		Good to fair
1973	2, 3	9, 9	4, 4	4, 3	Good
1973	25, 26	11, 10	5, 5	4, 3	Good to fair
1974	16, 17	25, 25	9, 9	7, 8	Good
1975	21	80	41	16	Good
1976	13, 14	36, 36	12, 12	9, 11	Good

[1] Separate totals are given for each day of the census.

and others (1965) underestimated the 1963-65 population. Details of the basis for this debate are provided in Sibley and others[3] and Wilbur.[1] Biologists Sibley, Carrier, Borneman, and Wilbur all have had access to a growing file of condor sighting cards, which includes cards for all sightings in Koford's original field notes. Thorough study of these records, combined with comparisons of high single counts, data on numbers of known nestings per year, and the assumption that the coastal birds comprise a separate subpopulation, all point compellingly to the conclusion that the condor population in 1940 probably consisted of at least 100 birds (Sibley and others,[3] Wilbur,[1] Wilbur and others[2]). Data gathered by Miller and others (1965) indicate a population decline by that time of about 30 percent (that is, about 70 birds remaining). More recently, authorities (Sibley and others,[3] Carrier 1971, Wilbur,[1] Wilbur and others[2]) interpret censuses and yearlong sightings, carefully studied, to indicate a population of about 50 birds. That number was reaffirmed by Wilbur (pers. commum.) in December 1975 but was revised to about 45 birds in December 1976. In any event, there is little question that the population has declined since Koford's (1953) studies made in the early 1940's.

[3] Sibley, Fred C., W. Dean Carrier, and John C. Borneman. *Population decline of the California condor.* (Manuscript in preparation.)

An indication of population vitality more important than total population size is annual reproduction, which is well summarized by Wilbur.[1] From nest site visitation from 1966-69 and nesting area observations since 1969, annual production of fledged young (1966-76) has been estimated for the coastal subpopulation and the Sespe subpopulation, as follows (Wilbur, pers. commun.):

Year:	*Coast*	*Sespe*
1966	1	2
1967	1 (2?)	2
1968	1	1
1969	1	1
1970	0	2
1971	0	2
1972	1	1
1973	0	0
1974	0	1
1975	0	1
1976	1	1

The decline indicated is supported by estimates of subadult birds in the total population, estimated for the 7 years from 1968 to 1974 as 10,10,13, 8, 8, 6, and 4. The indicated decrease of 60 percent among the subadult population is far larger than the decline likely among adults during the same period (in an estimated total population in 1968 of 61, with 51 adults, and in 1975 of 50, with 46 adults, the decline among adults was only 10 percent).

The condor population in 1946 was estimated to include from 15 to 20 subadults (Koford 1953), or 25 to 33 percent of the estimated total population. Thirteen nesting attempts (nine succeeded) were documented by Koford over the years 1939-41 and 1946, and he suggested that the population in the early 1940's included 20 adult pairs, 10 breeding per year, with perhaps as many as 5 young surviving each year. Miller and others (1965) estimated that subadults comprised almost 33 percent of the condor population; their study did not include searching for active nests. Their estimates of annual productivity were based on sightings of presumed yearlings; however, according to Sibley (1968), new knowledge of the molt pattern of condors suggests that the estimates may have included some older birds among the counts of yearlings. Wilbur[1] concluded from analysis of the study by Miller and others that no valid comparisons are possible beyond the probability that about 2.5 young were fledged annually in the mid-sixties and that at least seven pairs were reproductively active (not all in the same year). In summary, it seems safe to conclude that data on breeding activity and population age structure point to declining production of young condors. Indeed, if the above estimates of annual production are close, then low reproductive performance by the population as a whole was a significant factor in the population's decline as far back as the 1940's. As will be noted later, in the section Population Modeling, about five or six fledglings must be alive in October to maintain a population of 50 condors.

A weak point in determination of the population's reproductive performance each year is the method of establishing the number of breeding attempts. In a spring visit to canyons containing historic nesting sites, the presence of paired birds is noted, but without follow-up to determine whether or not the birds are actually using one of the sites. The canyons are visited again, late in the fall usually, to search for dependent young. This procedure is followed in part for want of enough personnel to spend the time watching nest sites, and in part to reduce the risk that human interference will cause loss of egg or young or cause the adults to desert the nest. Unfortunately, however, the procedure does not determine when, in the normal breeding cycle, failure occurs, so there is no way to evaluate properly the possible role of pesticides in lowering breeding success. It seems to me that a cautious observer, stationed with a spotting scope on a canyon rim a considerable distance from potential nest sites, could learn whether or not condors were using any of those sites, without unduly disturbing the birds.

nesting success

Information on nesting success for the years 1939-41 and 1966-68 has been summarized by Sibley (1968), based on Koford (1953) and Sibley's own field work. Of 11 known nesting attempts during the 1939-41 period, 7 (65 percent) succeeded, but only 12 of 22 (45 percent) succeeded in 1966-68. Causes of nest failure varied, but disturbance of adults at the nest has been conceded to be important. Of 10 known nest failures, 7 showed egg loss, and 3 showed loss of young. Wilbur[1] (and pers. commun.) has found that since 1969 virtually every suspected nesting effort succeeded. Few useful conclusions can be extracted from these data, except that nesting success can be very high among condors if optimum conditions are maintained, particularly seclusion from disturbance near the nest site, and suitable food sources within easy flight distance of the nest.

sex ratio

Population sex ratio is unknown, as the sexes are not distinguishable in the field and no one has captured the birds for close, on-site examination and release. Sex ratio among museum specimens in adult plumage is approximately 60:40 in favor of males (Koford 1953; Wilbur,[1] and pers. commun.). Although there is no way to determine whether or not this is a fair indication of sex ratio among breeding adults, the possibility exists that among birds of breeding age males outnumber females. Males may be more likely than females to be collected, however, perhaps because they are more likely to approach humans or because they spend less time in parental care (Koford, pers. commun.). A 60:40 sex ratio among adult condors could mean as few as 17 or 18 females of breeding age and only 8 or 9 breeding efforts per year.

Population Modeling

Modeling hypothetical condor populations can provide information useful for a number of critical management decisions; the validity of the conclusions drawn from such models hinges, of course, on the accuracy of the population data utilized. Koford (1953) modeled population age structure on the assumptions of (1) 95 percent and (2) 90 percent annual survivorship, estimating (1) 24 percent and (2) 40 percent subadults. Mean longevities were (1) 20 years and (2) 10 years. These values were translated into numbers based on population estimates of 59 in 1946 and 41 in 1964 (Miller and others 1965), but no significant conclusion emerged.

A more thorough and sophisticated approach to mathematical modeling of the California condor population by Mertz (1971) led to conclusions that may have important management implications:

1. Renesting the year following nest failure has only a slight positive effect on potential for population growth, as expected in a species with long maturation time and low reproductive rate (compare Cole 1954, Lewontin 1965).
2. In a declining population, a shorter maturation time accelerates the rate of decline.
3. In a growing population, a shorter maturation time accelerates growth, but only slightly.
4. The effect of senescence is small unless adult survival rate is high and the postreproductive period is short. The first condition is essential for the condor; the second, though not determined, is unlikely.
5. A change in adult survival rate has a significantly greater effect on population growth potential than a comparable change in subadult survival rate.
6. "Despite the uncertainties associated with the evolution of low reproductive rates, a few requisites are apparent. One is the requirement for a very stable environment—stable in the subjective sense that it must be remarkably free from factors which could cause catastrophic decimation of population numbers. Condors simply do not have the capacity to recoup their numbers quickly following a population crash. For the same reasons, condors would seem to require reasonably permanent geographic ranges; they are incapable of rapidly filling an environment after colonization. Another requirement necessitated by low reproduction is a remarkable freedom from ongoing forms of mortality."

Most points covered in item 6 are obvious, and condor biologists have long been aware of them. But points 1 to 5 are not so obvious and may be vital to effective management of the condor population.

Mertz' paper is less useful than it might have been

if data now available on such matters as numbers, breeding activity, and age structure had been available to him. For example, Mertz reasoned—I believe correctly—that adult survival rate must exceed that of subadults. With this assumption, his calculations showed that "the California condor population cannot withstand an annual adult survival which averages less than about 78 percent. If 50 percent is adopted as a reasonable value for preadult survival, then annual adult survival must average at least 86 percent. In fact, adult survival may have to be much higher than these values, considering that the basic condor life history assumes maximum reproduction." The last sentence holds the key, because at least in recent years the condor population has not demonstrated maximum reproduction, that is, each adult pair breeding every other year. The studies by Sibley, Carrier, and especially Wilbur, as cited earlier in this report, convince me that the condors have not approached maximum reproduction for many years.

replacement reproductive rate

Recruitment into a breeding population must at least equal annual losses if the population is not to decline. On this basis, I have modeled several hypothetical condor populations to estimate (1) the numbers of dependent young (nestlings or fledglings) that must be alive each October to maintain the population, (2) the expected proportions of recognizable subadults among volant birds, (3) the effect of separate subpopulations on maintenance-level reproduction, and (4) the impacts on maintenance-level reproduction resulting from changes in survival rates among subadults as opposed to those among adults. The modeled populations were fitted to an October-to-October cycle because that cycle coincides with the period of the annual condor census, and because the absolute number of dependent young birds alive in October probably can be assessed more accurately than the absolute number of any other age class.

The estimate of 50 condors (Wilbur,[1] and pers. commun.) was used to derive age structures of three hypothetical populations. Available data on annual reproduction led me to doubt whether there is more than one surviving bird in each prereproductive age class. Accordingly, on the assumptions of prereproductive periods of 6, 8, and 10 years, models have been designed for stable populations of 44 adults and 6 subadults, 42 adults and 8 subadults, and 40 adults and 10 subadults. Five different rates of mean annual survival (91, 93, 95, 97, and 99 percent) were selected and modeled for adult birds. The real adult survival rate probably lies within this range (Koford



Table 2—*Mean annual losses among adult condors, as a function of adults in population and annual survival rate.*

Adult population	Annual losses of adults at annual adult survival rate of . . .				
	91 pct.	93 pct.	95 pct.	97 pct.	99 pct.
	Single, panmictic population				
40	3.60	2.80	2.00	1.20	0.40
42	3.78	2.94	2.10	1.26	.42
44	3.96	3.08	2.20	1.32	.44
	Two subpopulations				
8	.72	.56	.40	.24	.08
34	3.06	2.38	1.70	1.02	.34

1953, Mertz 1971, and Wilbur[1]). The expected numbers of annual losses from the breeding population for the various models are shown in *table 2*.

Three possible survival rate schedules of subadults were examined in the models. These were selected to provide increasing survival rate with increasing age, leading to mean annual survival rates of subadults, from age 0.5 to 6.5 years, of approximately 85, 87 and 89 percent (*table 3*). Note that even with an average annual survival rate of 89 percent, fewer than half of the dependent young alive in October would be expected to live to 6.5 years of age. Birds older than 6.5 years were assumed to survive at the same rate as adult birds for each population modeled. Values in *tables 2* and *3* were used to calculate the minimum numbers of dependent young that must be alive in October to maintain condor populations with different numbers of adults and various subadult and adult survival rates (*tables 4 and 5*).

A primary goal of the California Condor Recovery Team is to maintain the condor population at 50 birds, with annual reproduction at 4 (Wilbur and

Table 3—*Annual (October to October) condor survival rates selected for various subadult age classes, to lead to all-age mean subadult annual survival rates of approximately 85, 87, and 89 percent*

Item	Survival rates to yield all-age mean of . . .		
	85 pct.	87 pct.	89 pct.
Age class, years:	*Percent*		
0.5 to 1.5	80	82	84
1.5 to 2.5	82	84	87
2.5 to 3.5	84	86	90
3.5 to 4.5	86	88	91
4.5 to 5.5	88	91	91
5.5 to 6.5	90	91	91
Percent of original population of dependent young alive at age 6.5	37.5	43.2	49.6

Table 4—*Numbers of dependent young needed in mid-October to maintain a population of 50 condors as a function of adult and subadult survival rates and age at first reproduction.*

Adult (A) and and subadult (S) survival rates (percent)		Dependent young needed if age at first reproduction is . . .		
		6 years (44 adults)	8 years (42 adults)	10 years (40 adults)
A = 91	S = 85	10.55	12.16	13.99
	S = 87	9.17	10.57	12.16
	S = 89	7.99	9.21	10.59
A = 93	S = 85	8.21	9.06	9.98
	S = 87	7.13	7.87	8.67
	S = 89	6.21	6.86	7.55
A = 95	S = 85	5.86	6.20	6.54
	S = 87	5.10	5.39	5.69
	S = 89	4.44	4.69	4.95
A = 97	S = 85	3.52	3.57	3.61
	S = 87	3.06	3.10	3.14
	S = 89	2.66	2.70	2.73
A = 99	S = 85	1.17	1.14	1.11
	S = 87	1.02	.99	.96
	S = 89	.89	.86	.84

others[2]). The modeling (*tables 4* and *5*) suggests that this rate of reproduction will suffice only if the adult survival rate approaches 97 percent per year. As discussed below, I believe 97 percent to be possible, but suspect that a value of 95 percent is more likely as a long-term average.

Needed reproduction based on two subpopulations is compared in *table 5* with that based on a single, panmictic population. Minimum essential reproductive output, for all condors collectively, differs according to the survival rate combinations. Eight of the fifteen combinations require more total young if the subpopulation theory is correct, and these include most of the survival rate combinations that I believe are realistic for California condors. The difference exists because at these mean survival rates, fractions of condors are calculated to disappear from the population each year, but replacement figures must show the next whole number above any given fraction. The actual minimum essential reproduction thus hinges on whether or not the subpopulation theory is valid.

The fact that death of fractions of condors requires whole-number replacements, in the simplistic models developed here, has another implication for population management. The survival rates modeled are inconsistent with a stable condor population of 50 birds. If too few offspring are produced, the

Table 5—*Number of dependent young needed in mid-October to maintain two condor subpopulations, totalling 50 birds, as a function of adult and subadult survival rates*[1]

Adult (A) and subadult (S) survival rates (percent)		Dependent young needed for two subpopulations		Dependent young needed, in whole numbers	
		8 adults	34 adults	Two subpopulations	One population
A = 91	S = 85	2.32	9.87	13	13
	S = 87	2.01	8.56	12	11
	S = 89	1.75	7.46	10	10
A = 93	S = 85	1.73	7.33	10	10
	S = 87	1.50	6.46	9	8
	S = 89	1.31	5.55	8	7
A = 95	S = 85	1.18	5.02	8	7
	S = 87	1.03	4.36	7	6
	S = 89	.89	3.80	5	5
A = 97	S = 85	.68	2.89	4	4
	S = 87	.59	2.51	4	4
	S = 89	.51	2.19	4	3
A = 99	S = 85	.22	.92	2	2
	S = 87	.19	.80	2	1
	S = 89	.16	.70	2	1

[1] Age at first reproduction is assumed to be 8 years; a total of 42 adults is assumed.

population obviously declines; production of enough to compensate for annual losses, on the other hand, will be too many for all survival rate combinations except those calling for 99 percent annual survivorship among adults. There, stable populations of fewer than 50 birds could result, but at every other percentage the population would increase to some number less than 100 birds before it stabilized (*fig. 2*). Thus if condor reproduction can be increased enough to compensate for annual losses, we should actually expect to observe a slow increase in numbers until a balance is reached between whole-number loss and whole-number replacement.

Differences in subadult survival rate have little effect on stable population size (*fig. 2*). Indeed, minimum numbers of dependent young needed in mid-October to maintain the condor population (*table 4*) increase an average of 4.83 with a decline in adult survival rate from 97 to 93 percent, over the range of subadult survival rates from 85 to 89 percent. A comparable decline in subadult survival rate, from 89 to 85 percent over the range of adult survival rates from 93 to 97 percent, requires an average increase of only 1.52 dependent young needed in mid-October. Of course the important implication of this result is that loss of an adult condor from the population is about three times more detrimental than the loss of a subadult.

The frequencies of immature age groups in the

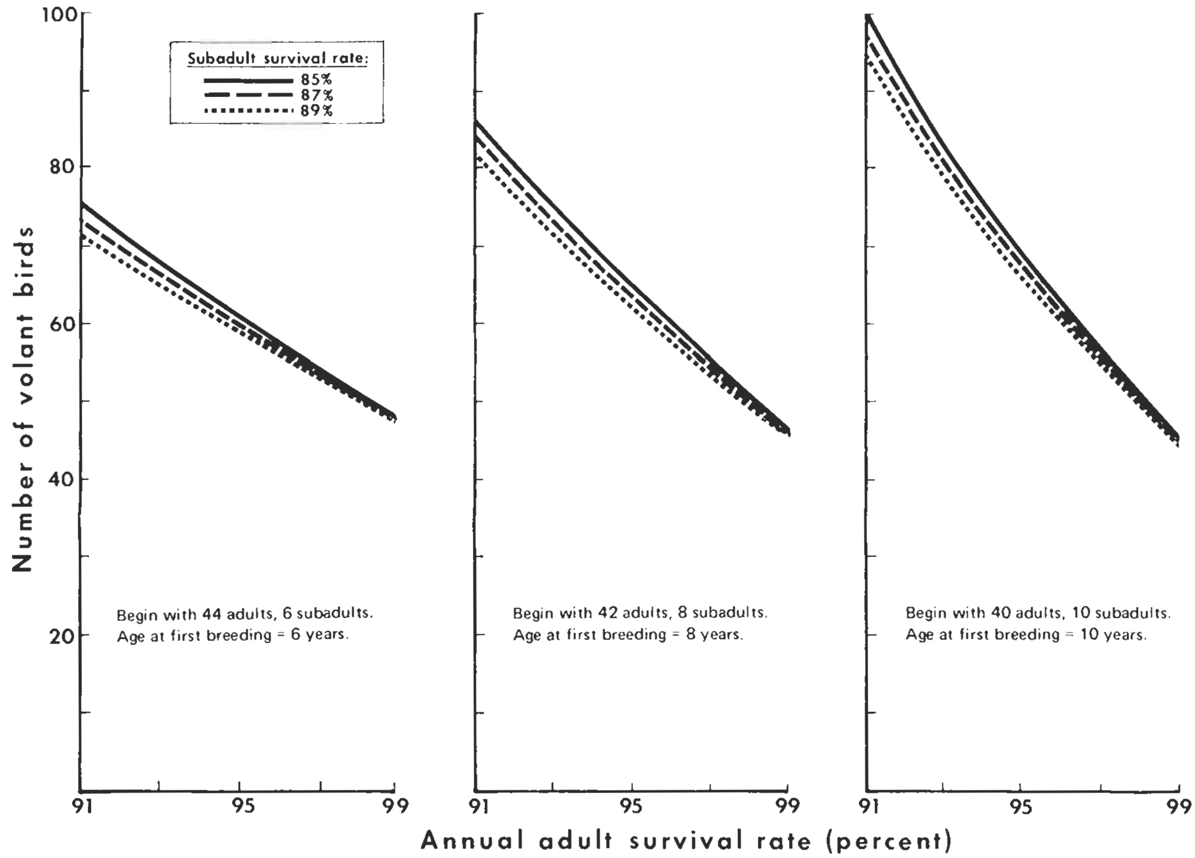

Figure 2—The number of volant birds in a stable population of the California condor is shown as a function of the assumed survival rates of subadults and adults. Curves are shown for three assumptions of the proportion of subadults to adults and the age at first breeding for initial populations of 50 birds.

population might be indicative of trends in population size, as suggested by Koford (1953) and Mallette and others (1970). Mertz (1971) affirmed this but cautioned that "for age distribution to be very informative, we should need some estimate of the prereproductive survivorship curves for successful condor populations." My modeling indicates that application of age distribution data in condor management depends even more on knowledge of adult survival rate than it does on knowledge of subadult survival rate. The percent of recognizable subadults (age classes 1.5, 2.5, 3.5, and 4.5 years) in a *stable* condor population declines sharply with increasing adult survival rate (*fig. 3*), dropping from about 33 to 36 percent subadults to about 5 to 7 percent subadults as adult survival rate climbs from 91 to 99 percent. Varying the subadult survival rates affects the expected percentages of recognizable subadults so minimally as to be immeasurable with the imprecise censusing techniques available for condors (*fig. 3*). Even knowledge of the percentage in the total population of the 3.5-year age class, the one most easily distinguished, is of little value without knowledge of adult survival rate.

Unless more is known about trends in the various age classes, knowledge of age ratios is of practically no value in assessing the vitality of a population. The modeling done here is for stable populations. If both age groups (subadults and adults) were declining at the same rate, the same age ratios as expected in a stable population would apply; so also if both age groups were increasing at the same rate. On the other hand, if the adult segment were declining at a faster rate than the subadult segment, there would be an increasing trend in the ratio of subadults to adults, and this might be interpreted as a healthy sign for the population.

In the absence of solid data on total numbers of

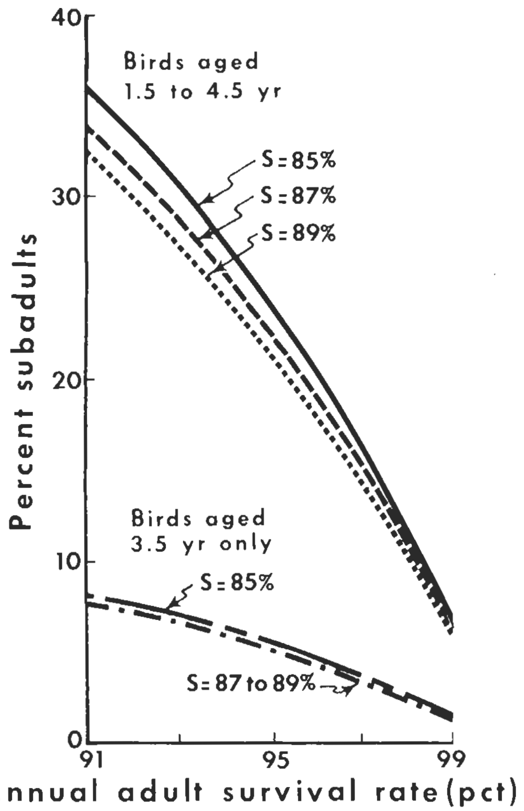

Figure 3—The proportion of subadults to adults among volant birds in stable California condor populations in October is shown as a function of adult and subadult survival rates.

birds in each age group, the best approach still seems to be to compare, from year to year, such data as high counts for a single day and total numbers of sightings in different areas over longer time periods. This is the approach that has led current condor biologists to conclude that the population today is probably less than half the size it was in 1940 and perhaps only two-thirds the size it was in 1965.

Figure 3 may be used to obtain a better estimate of real adult survival rate among California condors. Earlier estimates of the percentage of immatures in the condor population range from 25 to 33 percent (Koford 1953, Miller and others 1965). These estimates correspond to a stable population with adult survival rates from 92 to 94 percent (*fig. 3*). Even during the early period of the annual condor census, subadults comprised nearly 30 percent of the confirmed sightings (*fig. 1*). If these percentages accurately reflect condor population age structure in past years, then the population should have increased if adult survivorship were even as high as 95 percent. Because all indications are that the population has declined, it seems safe to conclude that adult survival rate, at least over the period 1940-70, averaged less than 94 percent.

Survivorship

Hypothetical survivorship curves may be constructed from assumed subadult and adult survival rates, as Koford (1953) did. The models used here start with 100 dependent young alive in October and project numbers of survivors in subsequent Octobers; so results may have more direct application to the annual condor census. Curves thus generated (*fig. 4*) provide information about mean and maximum longevity (*table 6*), and about the percentages of subadult age classes in the volant population (*fig. 3*). Expected percentages of different age classes in an October population, as calculated from survivorship curves, did not differ from comparable estimates derived from modeling for replacement production.

Data on mean longevity of condors fortify earlier statements about minimum possible combinations of subadult and adult survival rates. Note, for example, that adult/subadult survival rates of 91/85 percent, 91/87 percent, and 91/89 percent yield mean longevities so low (*table 6*) that an average pair would not survive long enough to rear two young, given the widely accepted assumption that it normally takes 2 years to rear a young to independence. This limita-

Table 6—*Mean and maximum longevity as a function of adult and subadult condor survival rates, modeled from initial populations of 100 dependent young alive in October*

Adult (A) and subadult (S) survival rates (percent)		Longevity	
		Mean	Maximum
		Years	
A = 91	S = 85	9.2	45
	S = 87	9.6	46
	S = 89	9.9	48
A = 93	S = 85	11.6	56
	S = 87	12.1	58
	S = 89	12.5	60
A = 95	S = 85	16.3	77
	S = 87	16.9	80
	S = 89	17.4	83
A = 97	S = 85	27.6	126
	S = 87	28.4	130
	S = 89	29.1	135
A = 99	S = 85	86.7	367
	S = 87	88.3	381
	S = 89	89.7	395

tion holds regardless of whether reproduction begins at 6, 8, or 10 years of age. Even assuming 1.5 years to be the usual time required to rear a condor to independence, first breeding at age 8, and mean longevity of 15.5 years, the average pair of condors could attempt to breed only four times before dying. With 75 percent success in rearing young to independence, the pair would produce three offspring; an incredible 97.4 percent mean annual survival rate would be necessary if these birds were to reach mean longevity of 15.5 years. Thus longevity among California condors probably evolved to be in excess of 15.5 years, indicating an adult survival rate of about 95 percent. Only with successful breeding beginning at age 6, and/or with annual reproduction an occasional or regular event, might these estimates be appreciably lower.

This question is explored in greater depth in *table 7*. Obviously, the values shown must exceed 100 percent if the population is to survive, given the assumptions specified. It is easy to identify those combinations of survival rates, sex ratio, and age at first breeding that are possible with biennial reproduction. Given a reasonable expectation of no more than 75 percent nesting success, an adult survival rate of 91 percent is impossible for all conditions except a 50:50 sex ratio, first breeding at age 6, and annual subadult survivorship of at least 89 percent. The assumptions of a 60:40 sex ratio and first breeding at age 8 require an adult survival rate of 95 percent for all three subadult survival rates tested. Identical conclusions result from comparing minimum numbers of dependent young required to maintain various adult populations (*table 4*). In summary, both modeling approaches attempted here suggest that minimum feasible rates for long term survival of California condors probably have averaged about 95 percent among adults and about 85 to 87 percent among subadults.

Thus if the population were stable today we should observe from 22 to 24 percent subadults in the volant population (*fig. 3*). This proportion has not been observed in recent years, probably because reproductive output by the population has declined. And as most data point compellingly to a decline in the number of adults as well, the prospect is even

Table 7—*Attainable percentage of the minimum number of breeding pairs required to maintain the condor population, as a function of adult and subadult survival rates, sex ratio, and age at first reproduction*[1]

Adult (A) and subadult (S) survival rates (percent)		Percentage of minimum by age at first reproduction and sex ratio					
		6 years		8 years		10 years	
		50m:50f	60m:40f	50m:50f	60m:40f	50m:50f	60m:40f
A = 91	S = 85	109	87	90	72	74	59
	S = 87	123	99	102	81	84	67
	S = 89	142	114	117	94	97	77
A = 93	S = 85	136	109	117	93	101	80
	S = 87	157	125	135	108	116	93
	S = 89	180	144	155	124	134	107
A = 95	S = 85	190	152	169	135	152	122
	S = 87	217	174	195	156	176	141
	S = 89	250	200	225	180	203	162
A = 97	S = 85	310	248	291	233	273	219
	S = 87	358	286	336	268	315	252
	S = 89	412	329	387	309	363	291
A = 99	S = 85	919	735	899	720	881	705
	S = 87	1060	848	1038	831	1017	814
	S = 89	1221	977	1196	957	1172	937

[1] Table values assume biennial reproduction, so would be doubled if pairs reproduced annually. Values also assume that all breeding-age pairs breed and that all successfully rear one young at least to October. Any value greater than 100 percent indicates a possible combination of survival rates, sex ratio, and age at first reproduction. With 75 percent nesting success, any value less than 133 indicates an impossible combination.

more grim than trends in age ratios might lead us to conclude.

Maximum longevity is difficult to determine from simple assumptions about adult and subadult survival rates, because estimated maximum longevity increases with the size of the original cohort of dependent young selected for modeling. Prolonged prereproductive life and the limit of 1 offspring per breeding effort suggest that the peak of reproductive value in condors coincides with mean age at first successful reproduction (compare Fisher 1958, and Wilson and Bossert 1971). This conclusion, together with theoretical development of the probable mode of evolution of senility (Williams 1957, Medawar 1957, and Hamilton 1966), leads me to suspect that the California condor is subject to senescent death, in the sense of increasing likelihood of organic failure with advancing age. Mertz (1971) concluded, from an analysis of the impact on population growth of senescent failure to breed, that condors likely evolved to maintain reproductive vigor "well past half of a century." I agree and would not be surprised if some individuals survive 75 years, a figure consistent with conclusions about probable minimum survival rates (see above). This age may not be out of line with a maximum age of perhaps 45 years reached by a captive bird,[1] since conditions of captivity may well have been conducive to early death. If very old birds (whatever that may mean) decline in reproductive vigor or are subject to senescent death, this would have the effect of reducing slightly the estimates of mean longevity as calculated from hypothetical survivorship curves. The magnitude of such an effect, however, probably would not substantially alter conclusions reached here about minimum, essential reproduction; because postreproductive birds (if present at all) should comprise a negligible percentage of the total population (*fig. 4*).

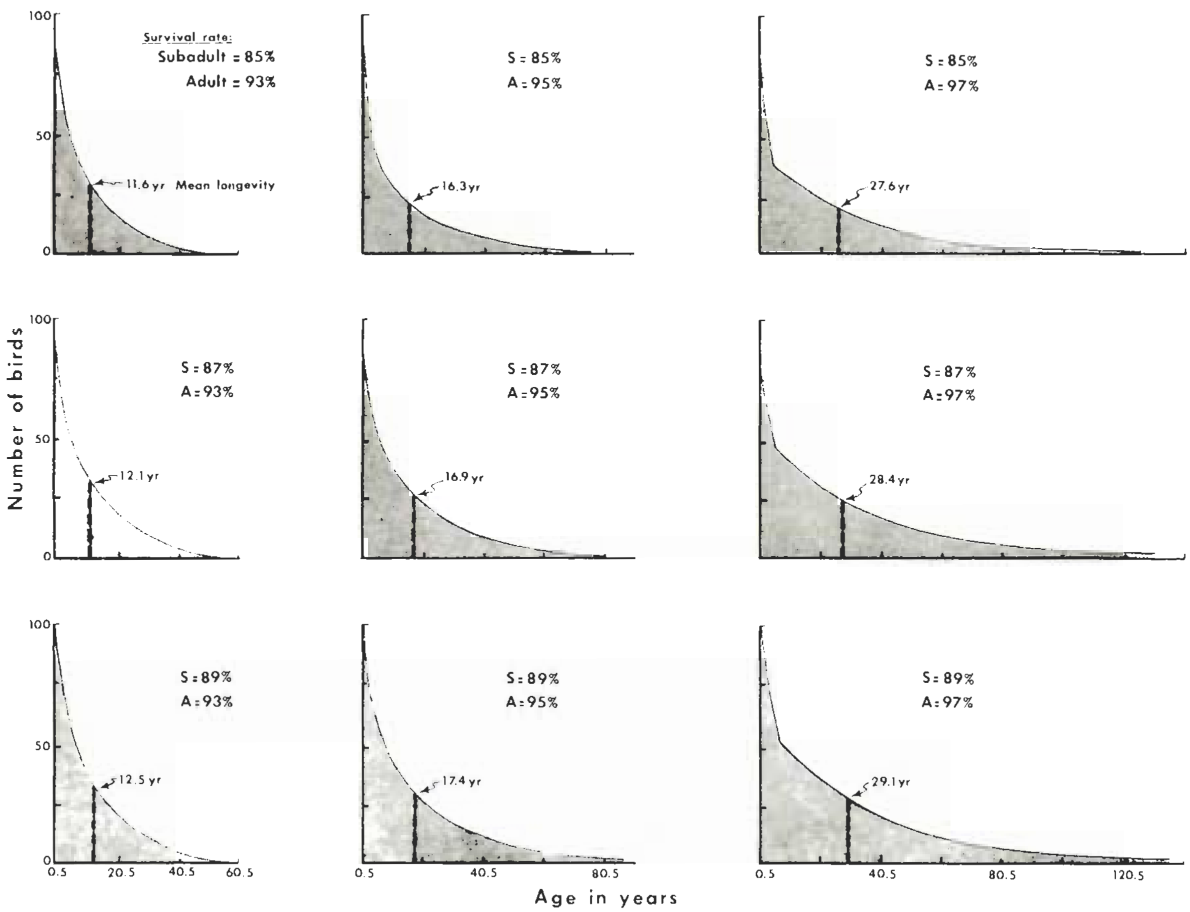

Figure 4—Survivorship curves of beginning populations in October of 100 dependent young are plotted here under varying assumptions of survival rate. (The subadult survival rate applies for the first 6 years.) Mean longevity is shown for each curve.

Current Status of the Condor Recovery Effort

Koford (1953) presents a concise chronicle of the shrinking range of California condors in the western United States, dating from about 1840. The record is, of course, scanty. But it is clear. Even though the decrease in abundance and distribution of condors was well known for nearly a century, no serious effort was undertaken to study the birds until Koford initiated his research in 1939. That work brought focus on the critical status of the condor population. Even beyond that, however, Koford's (1953) monograph on California condors is an early landmark in the development of public awareness of extinction as a fact of life during modern times, an awareness tangibly expressed in the passage by Congress, in 1973, of the Endangered Species Act.

The key developments in the condor recovery effort have implications which require discussion; these implications lead to specific recommendations made in the final section of this report.

1. The studies of Koford (1953) and Miller and others (1965) developed the factual basis for measures to protect condors from unnecessary, human-related mortality. Establishment of condor sanctuaries in the Sisquoc and Sespe-Piru areas followed. These studies also suggested the need to identify causes of disturbance of condors at their feeding sites, their roosting sites, and, especially, their breeding sites. Sibley (1969) investigated this problem and was able to specify minimum tolerable distances from sites of condor activity for disturbances.

2. The Endangered Species Act (1973) requires that a recovery team be established to draft a recovery plan for every endangered species in the United States. The California Condor Recovery Team was among the first of these teams to be established, its members representing the U.S. Fish and Wildlife Service, the U.S. Forest Service, the California Department of Fish and Game, the National Audubon Society, and the U.S. Bureau of Land Management. This team prepared a recovery plan (Wilbur and others[2]), which spells out those actions deemed most vital at this time to success of the condor recovery effort. In the plan, time schedules, responsible organizations, and cost estimates are itemized for 12 land acquisition actions, 6 investigative actions, and 21 administrative actions. Land acquisitions, protective patrols, mining and oil search closures, and closure of air space to 3000 feet above condor habitat are designed to provide maximum security of the birds from disturbance. Some objectives appear well on the

way to being achieved at this time. Other actions, proposed or ongoing, are discussed below.

3. Education of the public about all aspects of the condor problem, and particularly about condor identification, is recognized as highly important in the recovery effort. The National Audubon Society has assumed major responsibility for this task and has assigned to it a fulltime condor biologist, John C. Borneman. The education program is being pursued with vigor and success (Wilbur, pers. commun.).

4. A possible reason so few pairs of condors, in recent years, have begun breeding efforts is a lack of adequate food resources sufficiently near nesting sites to permit efficient parental foraging for a growing young (Sibley 1968, Wilbur 1972). It is difficult to document such a deficiency. No hard data are available, for example, on the mean distance from the nest that breeding birds ordinarily forage. Such information must be obtained by following marked birds.

The most thorough and most recent appraisal of food resources is that of Wilbur (1972), Wilbur[1] and Wilbur and others.[2] Wilbur finds reason to believe that "food in the vicinity of the Sespe-Piru nesting areas may be inadequate to release the reproductive function in some condors. Observations of feeding condors indicate there is a well-defined 'peck-order,' with certain individuals and pairs dominating carcasses to the almost complete exclusion of others."

A pilot project (Wilbur and others 1974) to assess the impact of supplemental feeding on breeding activity in the Sespe-Piru area began in February 1971. Results, though not conclusive, suggested that continuation of the program was warranted. Goats, road-killed deer, and other large animal carcasses are collected and frozen until needed. These are then placed within 3 to 6.5 km of known nesting sites. Different carcasses are placed far apart in an effort to assure ready access to food by subordinate condors otherwise excluded by the social hierarchy. This program is in operation over as much of the year as possible, but to date it has not been linked to any marked increase in numbers of condor pairs breeding in a given year.

5. Food supply problems motivated Cowles' (1958) suggestion that effective fire prevention, by allowing secondary succession, may make some areas unsuitable for foraging; under these conditions habitats might support fewer deer, or meadows might grow up to dense shrub cover not allowing ready landing and takeoff. Miller and others (1965) were critical of Cowles' idea because it came at a time when deer numbers were high, and it tended to paint an unwarranted picture of starving condors. In a later paper, Cowles (1968) pressed the issue again, making

the provocative point that condor food habits necessarily may have changed in recent years because shrub closure of traditional feeding sites may have forced the birds into extensively grazed lands where most of their food today consists of large animal carcasses. Perhaps carcasses of small animals, such as rabbits and squirrels, comprised an important part of the condor diet prior to effective fire suppression. Such animals are small enough that some of their bones would be ingested by the condors, providing a source of calcium for eggshell production. Bones of larger animals could not, of course, be ingested.

In any case, Cowles has focused attention on a major void in the condor recovery effort. No quantitative baseline studies have been made of the character of the vegetation in areas frequented by California condors today, nor do we have any information on vegetation structure in prior decades.

6. Biological concentration of toxic substances is another suspected agent in low reproductive performance of the condors. An immature condor that died accidentally in May 1965 had concentrations of 18 ppm p,p^{1}DDT and 20 ppm p,p^{1}DDE in its visceral fat (Hunt 1969). Another, found dead in November, 1974, had 50 ppm p,p′DDE and much smaller concentrations of other organochlorines in muscle tissue from the leg.[4] An adult female died at the Los Angeles Zoo on October 30, 1976, after being discovered in an emaciated condition 2 weeks earlier. The bird had been shot in the wing. Tissue analyses by California Department of Fish and Game showed 14 ppm p,p′DDE in fatty tissue, and another sample of the same tissue was found by the Patuxent Wildlife Research Center to contain 105 ppm p,p′ DDE (Wilbur, pers. commun.). The basis for this discrepancy is presently unresolved, but even the lower level of DDE in the bird is a matter of concern.

DDT metabolites may affect an organism's steroid hormone balance so as to interfere with normal reproductive behavior (Henkin and others 1971, p. 99-103, provide a succinct summary of this point; see also Stickel 1975). Evidence suggests that Andean condors in Peru concentrate chlorinated hydrocarbons to much higher levels than other local bird species high on their respective food chains (D. W. Anderson, pers. commun. cited by Wilbur[1]). It is entirely possible that high concentrations of pesticide metabolites in California condors have so interfered with hormone balance that birds cannot begin breeding activity.

A better known role of DDT metabolites in avian physiology is in eggshell thinning. Garrett and others[5] recently found that California condor eggshell fragments taken from nests during 1965-69 were 31 percent thinner than shells of eggs collected from 1806 to 1943. Structural abnormalities were also apparent in the shell fragments from the 1960's. Scanty though the data are, they nonetheless indicate that pesticide contamination is a likely factor in low condor reproductive output.

Wilbur (pers. commun.) reported that a number of research projects are now, or soon will be addressed to this problem. Among them are these:

A comparative chemical analysis of condor feathers taken from museum specimens collected be-

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[4] Patuxent Wildlife Research Center, Laurel, Md. (Report on file, cited by Wilbur.[1])

[5] Garrett, R. L., L. F. Kiff, and S. R. Wilbur. *Recent changes in California condor eggshell thickness and structure.* (Manuscript in preparation.)

fore widespread use of pesticides, and from feathers found recently.

Comparative chemical analyses of old fecal samples (obtained from deposits in nest cavities) and fresh ones.

Continued analyses of the possible negative impact of toxic substance accumulation on breeding of turkey vultures.

Continuing efforts to identify all possible sources of toxic substances in the food web exploited by California condors.

7. Investigations are in progress to perfect identification of the sex of condors through chemical analyses of fecal samples and other means (Wilbur, pers. commun.).

8. Evidence that part of the population from the Sespe-Piru area may have relocated in southern Kern County, where there are few suitable nest sites, suggests that artificial nest sites there may stimulate nesting. A proposal for such a project was presented to the California Condor Advisory Committee on May 20, 1976.[6] It has been approved at all levels within the U.S. Fish and Wildlife Service and is now under study by the Office of Endangered Species in Washington, D.C. (Wilbur, pers. commun.).

9. Artificial propagation has been conceded by most of those closest to the condor recovery effort to be a "last resort" operation, but at a meeting (May 20, 1976) with the California Condor Advisory Committee, the California Condor Recovery Team proposed such a program.[6] This proposal also has been approved at all levels within the Fish and Wildlife Service and is now under study by the Office of Endangered Species in Washington (Wilbur, pers. commun.).

10.The U.S. Fish and Wildlife Service (1976) began a captive rearing program with Andean condors at the Patuxent Wildlife Research Center, Laurel, Maryland, in 1966. Immature birds taken from the Andes in 1966 and 1967 were paired off and the pairs placed in separate pens in 1971. Since that time, 3 pairs have laid a total of 10 eggs. Six hatched, and 4 young have survived. A pair of Andean condors at the San Diego Zoo produced 9 young in 11 years, from 1942 to 1952, because either the egg or the young was taken from the pair early enough to free them for reproduction the following year (Lint 1959). The same pair in the wild should have produced only about 5 young in the same period.

Two captive female California condors in the National Zoological Park laid a total of 19 eggs from 1919 to 1939, all infertile because no males were available (Wilbur, pers. commun.).

These experiences with captive condors have provided valuable information applicable to a similar program with California condors. For example, we know that appropriate timing in removing young birds from the care of their parents promises to double a pair's reproductive potential. Personnel are available with considerable experience in handling Andean condors and limited experience in handling California condors. And pen conditions conducive to pair formation and breeding by Andean condors are known, a factor which should reduce the time needed to find suitable pen conditions for California condors.

[6] California Condor Recovery Team. 1976. *Contingency plan.*

Recommendations

These recommendations imply a basic assumption that all efforts made thus far to ensure recovery of the California condor population should continue until there is clear evidence that discontinuing a given effort will not jeopardize the prospects of recovery. Any possible deterrent to condor survival and reproduction must be considered, and every reasonable effort at mitigation must be made. We can hope, then, that only "safe" errors would be made—that is, some insignificant problems would receive attention but no significant ones would be ignored.

1. *Analyze vegetation structure in areas now frequented by the condor.* The analysis may be used for comparison in the event of significant relocations in zones of principal condor activity. Data probably can be obtained satisfactorily by aerial photography, that is, from the condor's view. Information about vegetation structure in the condor's range in past decades should be sought and compared with today's pattern.

2. *Explore effects of two kinds of marking programs, on a pilot basis.* Many questions vital to wise management of the condors cannot be answered without detailed knowledge of such things as age, sex, local and long-distance movement patterns, and frequency of breeding by individual birds. Marking for individual recognition should thus have high priority, but only on a pilot basis initially, to determine whether or not the marking procedures negatively affect the welfare of marked birds.

One marking program should utilize the most up-to-date radio transmitter technology possible. At least one and perhaps two birds (one from each presumed subpopulation) should be fitted with transmitters for the pilot study.

A second program should have the ultimate aim of marking for life as many California condors as possible, so that the mark is unique and identifiable from some distance. Because the traditional means of permanently marking birds would not be suitable, use of tattoos should be explored. A two-letter code in black, tattooed on the back of each condor's head in a size legible for some distance with aid of a spotting scope, would suffice to mark 676 individuals. Marking should include nestlings and subadults, even though their marks would not be visible until their head color changed from black to the yellowish-orange characteristic of adults.

The process might best be tested first on turkey vultures, and perhaps on Topatopa, the captive California condor in the Los Angeles Zoo. It should then be field tested on one or two condors to determine whether or not the markings affect them negatively.

3. *Strive to perfect a method for identification of the sex of captured birds.* Sex determination is a necessary component of the long-term marking program, although many vital data could be obtained through marking without sex identification.

4. *Employ more seasonal help for field observations.* Some assistants could work on regular checking of potential nesting areas to establish whether condor breeding efforts fail because of eggshell thinning or because the adults never begin nesting activities.

In a marking program, other temporary aides could be stationed in blinds near animal carcasses to record markings on condors attracted to the carcasses. These observers could also record other information and test various methods of possible value in condor management. For example, they could note age and sex differences in feeding success at carcasses, and could assess the value of positioning multiple carcasses in increasing feeding success of subordinate birds. They could test other means for individual recognition of condors (perhaps footprints), and evaluate the possibility of obtaining repeated weights of known individuals by placing scale platforms on perches near the carcasses.

5. *Standardize the mid-October census procedures and rigorously maintain them for an indefinite number of years.* If it is combined with a systematic, individual marking program and extensive observation of birds at carcasses, from blinds, a standardized census in mid-October should permit determination of the total condor population, with little error.

6. *Strive to identify the source of any substance toxic to condors.* First, a systematic program of testing air samples from various points in the condor range should be started. Second, a comprehensive trace element assay should be directed at all levels in the condor's food web. Simultaneously, those species whose feeding ecology is most like that of the condors should be similarly tested, especially ravens (*Corvus corax*), coyotes (*Canis latrans*), and black bears (*Ursus americanus*).

7. *Increase the California Condor Recovery Team's goal of four condor offspring per year to at least six.* If six offspring are to be produced each year, management probably should aim toward about eight nesting attempts per year.

8. *Approve and fund as soon as possible the Contingency Plan proposal[6] for erection of artificial nest sites.* Sites should be located in appropriate habitat in southern Kern County, and perhaps in other parts of the condor range. Artificially excavated caves on cliff faces would be preferred, but, where necessary, artificial cliffs could be constructed. They should be

designed so that if condors ever used them for nesting, an observer's station could be added within the "cliff" to permit direct study of parent-offspring relationships at the nest.

9. *Explore the use of condor models in various postures.* Models may be valuable in conjunction with artificial propagation as a stimulant to reproduction by captive pairs, and they might prove useful in directing attention of free-living condors to artificial nest sites.

10. *Approve and fund as soon as possible the Contingency Plan proposal*[6] *to begin rearing condors in captivity, for later release to the wild,* There is, of course, no guarantee that captive rearing would succeed, so any decisions on this vital issue must be adequately based on public understanding and support. I am cautiously optimistic, however, that such a program would be successful. We have the experience of the captive rearing of Andean condors to draw upon. The program has the potential of doubling the reproductive potential of captive pairs. The birds are scavengers; they need not learn to locate, attack, and kill moving prey. Thus they should be more easily naturalized than predatory birds from a captive to a free-living existence.

Recent evidence of the likelihood of pesticide accumulation as a factor in low reproduction makes captive rearing even more appropriate. Captive birds could be placed on a diet known to be free of toxic substances, and the birds' present loads of such substances should be more rapidly purged from their bodies, permitting them to begin breeding successfully sooner than they would in the wild. Finally, if pesticide interference with sex hormone balance is a problem, captive rearing at least offers a chance to restore the natural balance by artificial administration of sex hormones.

If the captive rearing project is approved, the following additional recommendations should be considered:

A. *Rear captive birds in areas where they will be released,* at least from the time they are taken from their parents. It would be advisable to rear them in simulated nest cavities, as studies of other species indicate that breeding locality is markedly influenced by rearing locality.

B. *Use a rearing facility that could be moved from one area to another;* relocation would be determined by the optimum number of birds to be released in each area.

C. *Carefully study the optimum number of birds to be released in any given area.* Population modeling discussed in this report suggests that addition of just a single bird to a small subpopulation may have a major impact on its reproductive potential.

D. *Carefully consider the optimum age for release of birds,* again including population modeling studies. Some compromise may be necessary, since older releases probably would have a higher survival rate, but they also may be more likely to maintain some level of dependence upon or contact with humans.

E. *Evaluate proposed rearing and release sites for air pollution and food chain contamination.*

F. *Permanently mark all captive-reared birds,* as with tattoos, to permit adequate documentation of the success or failure of the project.

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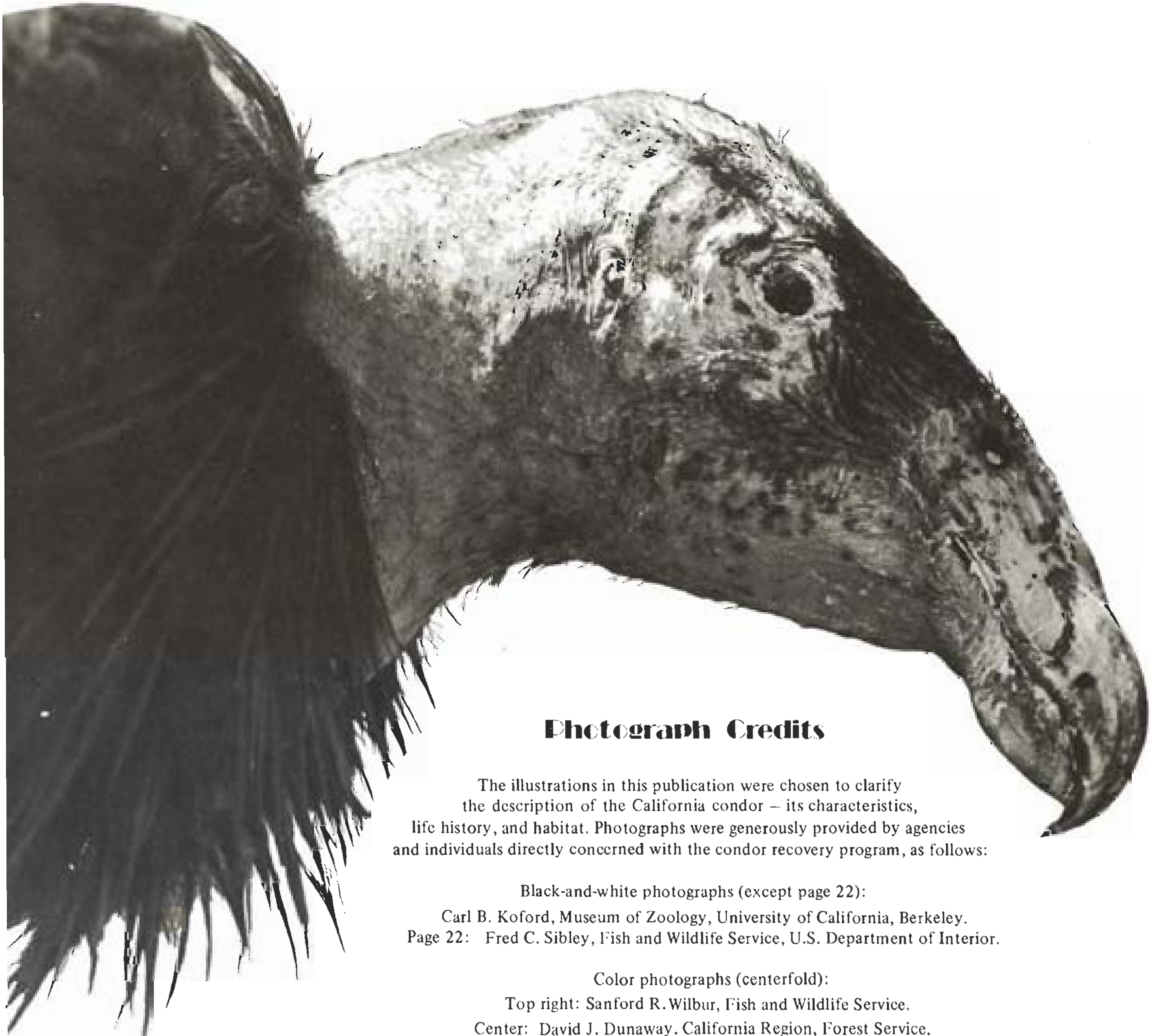

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