



Minnesota State Zoological Board.
Zoo-Related Organizations Files.

Copyright Notice:

This material may be protected by copyright law (U.S. Code, Title 17). Researchers are liable for any infringement. For more information, visit www.mnhs.org/copyright.

THE NOAH'S ARK PROBLEM

Multigeneration Management of Wild Species
in Captivity as a Means of Their Conservation
(3 October, 1977)

U. S. Seal, Ph.D.
Research Service, Veterans Administration Hospital
Minneapolis, MN 55417 USA
&
Departments of Biochemistry, Entomology, and Fisheries & Wildlife
University of Minnesota
St. Paul, MN 55108 USA

Noah was instructed to construct an ark and bring aboard representatives of all the creatures of the earth, the skies, and the waters to provide a nucleus of survival during the floods. At the conclusion of the floods, the instructions received were "Be fruitful, and multiply, and replenish the earth." The ark was stocked with seven pairs of each species. This early wisdom in collecting a significant gene pool reflects, I am sure, the animal husbandry skills of these peoples.

Modern day zoos and aviculturists are faced with the responsibility of developing and maintaining self-sustaining populations of captive wild species and in selected instances of providing the only reservoir for species on the verge of extinction or already extinct in the wild. To accomplish these goals, it is necessary to develop policies for genetic and demographic management of the gene pools over multiple generations, to collect data and share it, to continue work on development of methods for enhancement of reproduction, and finally to develop policies and methods for managing problems of surplus production.

Collection and reporting of appropriate census, vital statistics and pedigree data on zoo animals including mammals, birds and shortly reptiles and amphibians is being partially accomplished by the ISIS program of the

AAZPA, AAZV and USDI. Development of gene pool management concepts for development of a comprehensive breeding policy and breeding management philosophy are sorely needed. Enhancement of reproduction is being accomplished by development of innovative management techniques, behavioral and field studies, and in selected cases through the use of artificial insemination and hormonal manipulation. The problem of managing surplus has become acute for some species, including several on the endangered list with annual production so overwhelming that the carrying capacity of zoos is saturated. However, no coordinated policy has been formulated on a national basis to provide genetic and demographic guidelines for breeding of any species.

Roles of the Modern Zoo

The multiple and expanding roles of the modern zoo have been given thoughtful discussion by people interested in the role of captive animals as a part of man's cultural and biological heritage. The roles of the modern zoo are generally agreed to include recreation, education, conservation and research. It is simple to demonstrate in an analysis of these functions that they can be strongly interrelated and that if they are being performed effectively by a given zoo, it will be reflected within the table of personnel organization and by budgetary expenditures. The primary concerns of this paper are in the area of conservation. The topics include (1) the roles of zoos, (2) components and rationale of breeding programs and (3) a summary of our thinking on problems of long-term genetic and demographic management of captive gene pools.

Conservation

The participation of zoos in current conservation efforts may be considered in terms of four aspects. The first and primary effort is in terms

of education or increasing public awareness through education programs, graphics, design of exhibits, publicity, and gaining participation in local programs. These efforts require personnel and budgetary commitment.

Secondly, design of exhibits and holding facilities are being oriented toward breeding of individual species. This includes a gradual reduction in numbers of species being exhibited by individual zoos and increase in numbers of each of the individual species. The very design of exhibits with emphasis on habitat relationships as well as zoogeographic distribution counteracts the image of zoo animals in sterile environments or caged bathrooms.

Thirdly, as a research tool zoos can provide a major contribution to the needed data base for efforts to increase the likelihood of survival of endangered or threatened species in their native habitat. Thus, it is possible to describe many features of a species' life history from careful studies in captivity. Indeed, it is far more likely that we will develop the information necessary for many species from captive animals than from studies in the wild simply because of the limitations of people, time and money. Utilization of adequate record keeping techniques, allotment of staff time and liasons with researchers at local universities or elsewhere will do much to hasten this process.

Finally, the breeding programs of zoos can also make a direct contribution to the conservation effort. This includes total captive production of animals for exhibit purposes and the actual preservation of a limited number of seriously endangered species or subspecies.

Breeding Programs

The breeding programs of zoos may be considered in terms of two objectives. The first would be that of developing self-sustaining, captive

populations from which animals may be drawn for exhibit purposes and which may be used to provide further information concerning the life history of the respective species. The other objective would be conservation and perhaps actual preservation of species or gene pools whose continued existence in the wild is endangered or which are actually on the verge of extinction. It is in this capacity that the zoos might be a modern days Noah's Ark. They would then be faced with the admonition to "Be fruitful, and multiply, and replenish the earth," (Genesis, Chap. 14).

Since the objective of developing self-sustaining, captive populations can have very different rationale, it is important to consider the genetic strategies by which this might be accomplished. It is possible to selectively breed a zoo-domesticated stock of a given species which is well suited to captive life but completely unsuited to an existence in its original or any wild habitat. In those cases where it is clearly unnecessary to provide a reservoir of a gene pool for preservation of the species, this strategy might be employed. However, this choice should be clearly recognized and documented since such selectively inbred strains from an originally much more heterogeneous genetic heritage in all probability will not provide an accurate representation of the species either for life history studies or development of data suitable for management of the species in the wild. They also run a high risk of loss of vigor, reduced viability, growth rate, fertility and extinction.

The other major strategy is to attempt to maintain as much of the genetic variability present in the wild gene pool as possible. This strategy requires a deliberate maximum avoidance of inbreeding policy,

Figure 1, and demographic management of the gene pool to establish a stable population. It should include consideration of such variables as the number of generations over which the population may have to be sustained; what will be the age and sex composition of the over-all breeding population; age and sex specific fertilities and survivorships; how large a stable population is required on the basis of known features of the life history; carrying capacity of the zoos; surplus requirements and the practicality of developing controlled breeding or mating arrangements. Both of these strategies require accurate record keeping and explicit formulation of the breeding policy to be followed with agreement by all parties concerned.

The components of conservation-oriented long-term breeding programs would include:

(1) Zoos and other institutionalized facilities or formalized collaborative agreements which can provide long-term maintenance and management. Aspects of zoo management involved include exhibit design, development of holding facilities, development of auxiliary breeding facilities, breeding loans, development of breeding techniques, and data collection.

(2) An available gene pool is required. Thus, it is desirable to have animals of known origins and pedigrees traceable back to wild-caught animals. The number of animals should be chosen on the basis of consequences of the breeding strategy, if possible. The age and sex structure should be defined. Explicit definitions of the need for introduction of new wild stock should be made in terms of breeding strategy and breeding management programs with a view to maintaining some defined level of genetic variability in the population.

(3) Data collection, assembly, and sharing are vital elements of a deliberate breeding program. The ISIS program of the AAZPA can provide necessary census and vital statistics data for breeding programs. It can also provide demographic projections, pedigrees, studbooks, and the data for analysis of breeding relationships within the captive population including calculation of inbreeding coefficients. Additional components of the life history analysis are being developed within the ISIS framework to include baseline laboratory data in the Physiological Norms Program in collaboration with the AAZV.

(4) Finally, management of breeding and reproduction are an essential component of this effort. This includes first, successful breeding with sufficient frequency to provide for survival and sustaining the numbers required. Management of reproduction will include both enhancement and limitation of reproduction. Enhancement, where not attainable by management and behavioral manipulation, might include development of techniques on electroejaculation, artificial insemination, estrus synchronization and induction of ovulation. The control of reproduction is intended to imply the actual reduction in number of offspring produced and would have particular emphasis on being selective in that particular individuals are removed from the breeding population by one of several strategies. The costs of such programs need evaluation and consideration given to the possibility of marketing surplus production for exhibit or other acceptable purposes. This would provide assistance for establishment of breeding centers with adequate carrying capacity.

Genetic and Demographic Management

Computer-based demographic programs for analysis of studbook and ISIS data have been developed (Foose, 1977). The use of this tool for captive management programs requires formulation of a model for each species based upon the following kinds of information. (1) An estimate of the carrying capacities of the captive breeding groups should be made. This estimate

might include in addition to sheer physical limitations considerations of logistic, genetic, demographic and conservation criteria. This final refined population size might then be considered an optimum determined by multiple criteria. (2) The need for surplus animals should be evaluated giving consideration to either replacement programs, providing animals for exhibit in nonbreeding center institutions, utilization of animals for research projects contributing to further understanding of life history of the species, or other appropriately defined needs. The size of the existing population relative to the optimum size of the population and the need for surplus animals will determine the desired growth rate of the population.

(3) The fertility and survivorship by age and sex classes must be determined or estimated. It is particularly important for relatively long-lived species to have adequate data on the first year survivorship and the average annual adult survivorship, Figure 2. These two characteristics of the species then determine the required average number of offspring per parent required to maintain a stationary population. This set of relationships makes very clear that it is absolutely mandatory to have adequate death data reporting in order to develop a sound demographic plan. Death data especially around the neonatal period or during the first year of life are also absolutely essential for detection of detrimental inbreeding effects. The failure to

recognize inbreeding effects in most cases can be attributed to the lack of adequate data records, not the overall success of random or inbred breeding management programs. (4) The age and sex structure of the existing population must be known. This information combined with fertility and survivorship data may then be utilized to project into the future the demographic structure of the population. One may then test the effects of various culling or selective removal strategies that might be employed. It also provides a set of data with which to compare actual performance and allow detection of significant deviations which might serve as a signal of unsuspected problems. The use of these projections will also allow development and testing of plans for moving from the existing population to the desired stationary population size. (5) An explicit plan should be devised, tested and agreed upon for moving from the current population to the desired stationary or stable population. This plan then should be examined carefully, utilizing stochastic methods, for fluctuations that might occur in the population. Stated differently, one should formulate the likelihood of significant deviation from the stationary population as the result of random or chance factors and the likelihood that extinction might occur. It is possible to fail despite all best efforts. (6) This same model and the resulting data and projections can be utilized to formulate a strategy for planned reintroductions into the wild of animals from the captive populations. It might also be used to assist in the initial management of these wild populations and guide data collection to assess the success of the reintroduction plan.

Genetic management of captive populations to provide the maximum preservation of heterozygosity can be accomplished more efficiently with a

deliberate breeding plan rather than the current random efforts (Flesness 1977). Our analysis of three currently available studbooks indicates that inbreeding has occurred at about ten times the rate necessary with the available populations. There is evidence of significant detrimental effects occurring with this inbreeding. The guidelines for a maximally efficient genetic management program include three considerations.

(1) The effective population size will determine the rate of loss of genetic diversity per generation, Figure 3. The smaller this number, the more rapid the loss of diversity through the generations. However, it will be noted that a size as small as 64 adults would allow maintenance of about 65% of the original heterozygosity or diversity present in the starting population after 100 generations. It therefore becomes of considerable importance to consider the factors which affect the effective population size in relation to the actual adult animal population in captivity.

(2) Two factors are of primary importance in determining the size of the effective population given the use of a maximum avoidance of inbreeding scheme as shown in Figure 1. These two factors can be adjusted to give an effective population size equal to twice the number of adults in the population so that, for example, an effective size of 64 can be achieved with 32 adults. First there should be an equal contribution by all members of the population to the next generation. That is, family size should be equal between all members or no one animal is bred in preference to another. This is contrary to virtually all current zoo or aviculturist practice. There is a strong and understandable tendency to favor animals that fare well in captivity, breed readily, and this clearly promotes selection for inbred and captive-adapted strains. It also results in a very rapid loss of genetic diversity. Great care in this framework should be taken to randomize the selection of offspring from the pool available

from a given pairing so that selection according to more or less unconscious preferences also does not occur. Breeding to types should be rigorously avoided. If the population is at the stationary size, then each parent would contribute one offspring to the next generation. If it is desired to increase the size of the existing population, then the proportional number of offspring might be increased to a larger number but the same for all of the parents. It is desirable to effect the increase in population size from the current population to the desired population size as rapidly and in as few generations as possible. The second feature of the breeding program is that there should be an equal number of males and females within the breeding population, Figure 4. Deviation from this equal sex ratio in terms of production of young for the next breeding generation will rapidly lead to the loss of genetic diversity. Many species have special social behavioral requirements that do not make such an arrangement possible in terms of the managed social groups. This, of course, is true of herd animals characterized by a dominant male and a number of breeding females. However, it is possible to rotate in a new male each year and not use the same male as the breeding stallion year after year, as has been done for the Przewalski's horse for example. It is this specific practice with the horse that has resulted in a nearly 10-fold greater rate of inbreeding than was necessary. The impact of these two factors upon effective population size may be illustrated by the observation that a population of 16 animals with a 1:1 sex ratio, equal family size and bred according to the maximum avoidance of inbreeding scheme will preserve as much genetic diversity as a population of

128 animals with a 1:5 sex ratio and a standard deviation of 1.4 for family size and using random mating. This is an 8-fold decrease in efficiency.

(3) The maximum avoidance of inbreeding scheme, Figure 1, devised by Sewell Wright many years ago can be used for any size population and is designed to insure that each individual contributes approximately equally to the next generation and that inbreeding is held at an absolute minimum. Another way to maintain or preserve genetic diversity that is the apparent reverse of this strategy is also possible. This would involve establishing perhaps eight inbred lines. Each of these lines would include four to eight adults which would themselves be bred according to the maximum avoidance of inbreeding approach but with the limited number of animals would become inbred quickly. Single groups of two run a very high risk of more rapid extinction. However, even groups of this size run a 95% risk of extinction within 20 generations. Those that survived would preserve indefinitely approximately 90% of the genetic diversity of a single wild animal. Then, at some time in the future individuals from each of the inbred lines could be crossed to recreate a variable population representing the original population. This approach, although theoretically possible, is far more risky and would require far more individual animals to establish. This approach might, however, be used for segments of the population that for any reason are not available to the larger population as a part of the accessible gene pool.

The necessary guidelines and tools are now available to construct rational genetic and demographic programs for management of captive wild species. It remains only to decide that it is worth the effort.

Acknowledgments

The work described in this paper is the result of collaborative efforts with D. Makey, D. Bridgwater, L. Simmons, N. Flesness and T. Foose in the development of the ISIS program. The heroic data and systems management efforts of Linda Murtfeldt, Kim Hastings and Jan Olsen have assured the functioning of this program.

References

- Flesness, N. R. (1977) Gene pool conservation and computer analysis.
Int'l. Zoo Yrbk. 17: 77-81.
- Foose, T. J. (1977) Demographic models for management of captive populations.
Int'l. Zoo Yrbk. 17: 70-76.
- Seal, U. S., Makey, D. G., Bridgwater, D., Simmons, L. and Murtfeldt, L.
(1977) ISIS: A computerised record system for the management of
wild animals in captivity. Int'l. Zoo Yrbk. 17: 68-70.
- Wright, S. (1921) Systems of mating. II. The effects of inbreeding on the
genetic composition of a population. Genetics 6: 124-143.

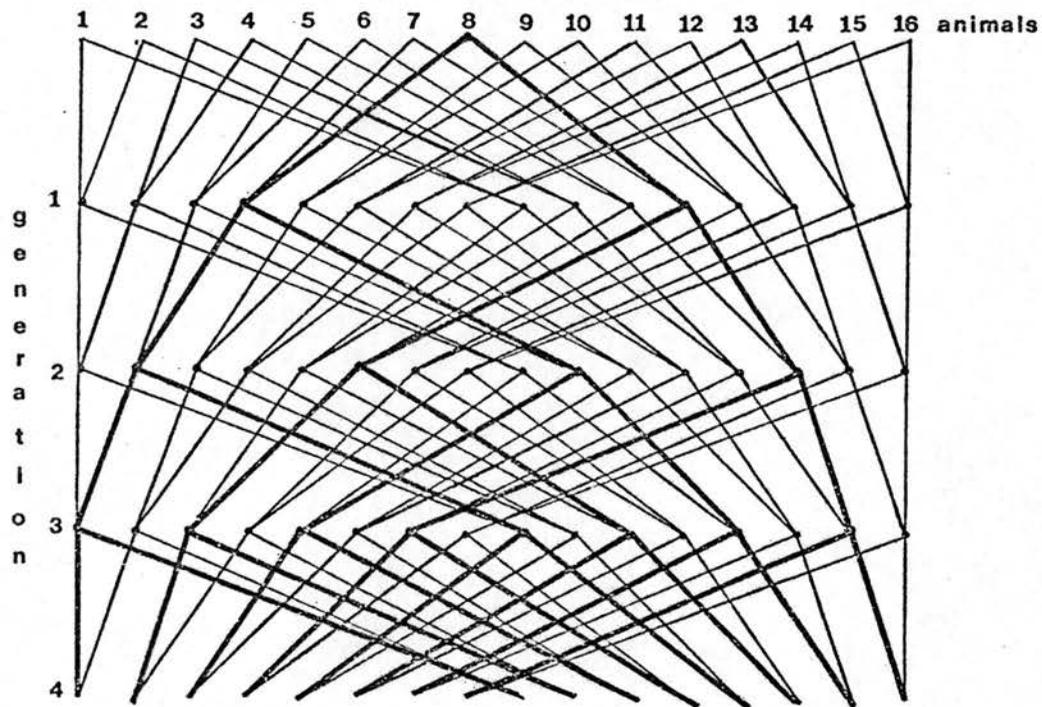


Figure 1. Scheme for maximum avoidance of inbreeding in a stationary population of 16 individuals composed of 8 males and 8 females each of whom contribute 1 individual to the next generation. From Flesness (1977).

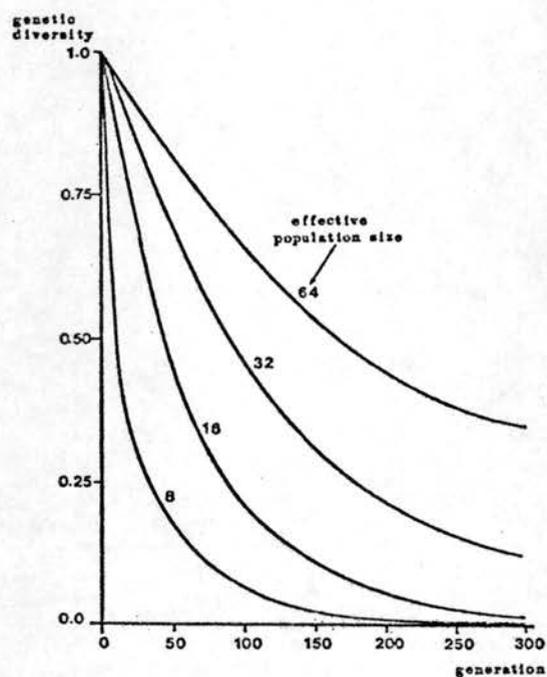


Figure 3. The rate of loss of genetic diversity per generation as a function of effective population size. From Flesness (1977).

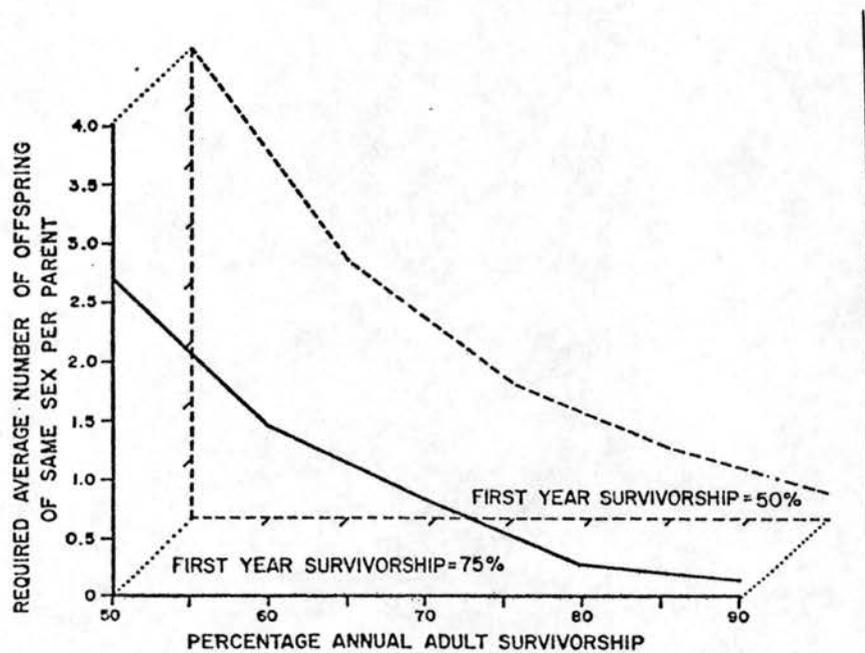


Figure 2. Interaction of first year and adult survivorship to determine the required number of offspring of the same sex per parent to maintain a stationary population. From Foose (1977).

CAPTIVE BIRTHS BY YEAR

PANTHERA TIGRIS ALTAICA

1938	3*
1939	0
1940	3*
1941	2*
1942	0
1943	0
1944	0
1945	0
1946	0
1947	0
1948	2*
1949	2*
1950	0
1951	0
1952	0
1953	0
1954	2*
1955	0
1956	1
1957	10***
1958	20*****
1959	13***
1960	14****
1961	11***
1962	17****
1963	18*****
1964	10***
1965	17****
1966	23*****
1967	35*****
1968	51*****
1969	72*****
1970	74*****
1971	82*****
1972	133*****
1973	153*****
1974	180*****
1975	118*****
1976	33*****
1977	22*****

EACH * REPRESENTS 4

NOTE: DATA FROM ISIS RECORDS IS NEARLY COMPLETE THROUGH 1977.

DATA FROM DR. SEIFERT'S STUDBOOK IS ALSO INCLUDED, BUT ONLY THROUGH 1975.

CAPTIVE DEATHS BY YEAR

PANTHERA TIGRIS ALTAICA

1935	1*
1936	0
1937	1*
1938	0
1939	0
1940	0
1941	1*
1942	1*
1943	1*
1944	0
1945	0
1946	0
1947	0
1948	0
1949	2*
1950	0
1951	0
1952	0
1953	2*
1954	0
1955	1*
1956	0
1957	8*****
1958	12*****
1959	4**
1960	2*
1961	6***
1962	6***
1963	13*****
1964	5***
1965	5***
1966	7*****
1967	13*****
1968	27*****
1969	29*****
1970	35*****
1971	38*****
1972	76*****
1973	66*****
1974	49*****
1975	82*****
1976	23*****
1977	5***

EACH * REPRESENTS 2

NOTE: DATA FROM ISIS RECORDS IS NEARLY COMPLETE THROUGH 1977.
 DATA FROM DR. SEIFERT'S STUDBOOK IS ALSO INCLUDED, BUT ONLY
 THROUGH 1975.

UNIVERSITY OF MINNESOTA 313525 COMPUTER CENTER

CAPTIVE DEATHS BY YEAR
PANTHERA TIGRIS ALTAICA

1935	1*
1936	0
1937	1*
1938	0
1939	0
1940	0
1941	1*
1942	1*
1943	1*
1944	0
1945	0
1946	0
1947	0
1948	0
1949	2**
1950	0
1951	0
1952	0
1953	2**
1954	0
1955	1*
1956	0
1957	5*****
1958	9*****
1959	2**
1960	0
1961	5*****
1962	0
1963	3***
1964	3***
1965	0
1966	4****
1967	3***
1968	10*****
1969	8*****
1970	5*****
1971	4****
1972	21*****
1973	16*****
1974	15*****
1975	21*****
1976	18*****
1977	5*****

EACH * REPRESENTS 1

NOTE: ISIS DATA FOR 1977 IS NEARLY, BUT NOT ENTIRELY, COMPLETE.

329687

UNIVERSITY OF MINNESOTA
COMPUTER CENTER

DEATH SEASONALITY

PANTHERA TIGRIS ALTAICA

JAN	20*****
FEB	33*****
MAR	33*****
APR	54*****
MAY	63*****
JUN	36*****
JUL	73*****
AUG	47*****
SEP	60*****
OCT	29*****
NOV	29*****
DEC	29*****

EACH * REPRESENTS 2

BIRTH SEASONALITY

PANTHERA TIGRIS ALTAICA

M	F		
5	10	JAN	15***
22	15	FEB	37*****
35	47	MAR	82*****
81	92	APR	173*****
105	96	MAY	201*****
65	82	JUN	147*****
76	42	JUL	118*****
43	54	AUG	97*****
42	47	SEP	89*****
28	17	OCT	45*****
14	19	NOV	33*****
10	17	DEC	27*****

EACH * REPRESENTS 5

MALE BIRTHS / FEMALE BIRTHS = 526 / 538

313523 THE UNIVERSITY OF MINNESOTA UNIVERSITY COMPUTER CENTER

DEATH SEASONALITY

PANTHERA TIGRIS ALTAICA

JAN	9*****
FEB	13*****
MAR	10*****
APR	20*****
MAY	12*****
JUN	6*****
JUL	29*****
AUG	15*****
SEP	21*****
OCT	5*****
NOV	9*****
DEC	15*****

EACH * REPRESENTS 1

BIRTH SEASONALITY

PANTHERA TIGRIS ALTAICA

M	F		
3	1	JAN	4**
13	7	FEB	20*****
10	20	MAR	30*****
24	29	APR	53*****
23	16	MAY	39*****
17	18	JUN	35*****
29	18	JUL	47*****
22	23	AUG	45*****
14	20	SEP	34*****
13	8	OCT	21*****
4	4	NOV	8****
4	12	DEC	16*****

EACH * REPRESENTS 2

MALE BIRTHS / FEMALE BIRTHS = 176/ 176

329685

THE UNIVERSITY OF MINNESOTA

UNIVERSITY COMPUTER CENTER

WILD CAPTURES BY YEAR

PANTHERA TIGRIS ALTAICA

1953	1*
1954	2**
1955	8*****
1956	7*****
1957	0
1958	4****
1959	0
1960	0
1961	1*
1962	0
1963	0
1964	0
1965	1*
1966	0
1967	1*
1968	5*****
1969	1*
1970	3***
1971	0
1972	2**
1973	3***

EACH * REPRESENTS 1

313526

THE UNIVERSITY OF MINNESOTA

UNIVERSITY COMPUTER CENTER

WILD CAPTURES BY YEAR
PANTHERA TIGRIS ALTAICA

1955	2**	<i>P</i>
1956	2**	<i>SH</i>
1957	0	
1958	2**	<i>1/2</i>
1959	0	
1960	0	
1961	1*	<i>Continued</i>
1962	0	
1963	0	
1964	0	
1965	0	<i>0</i>

EACH * REPRESENTS 1

329688
THE UNIVERSITY OF MINNESOTA
UNIVERSITY COMPUTER CENTER