Artificial Incubation of Exotic or "Non-domestic" Bird Eggs

by Cyndi Kuehler
Curator of Zoology
Zoological Society of San Diego
San Diego, California

Photo by Alan Lieberman

Kiwis lay the largest egg in proportion to the size of the bird than any other species. This egg has reptilian-like qualities and is artificially incubated under still-air conditions, without turning.

Artificial incubation of bird eggs is not a new avicultural practice, although the actual origins have been lost in the passage of time. One of the first records of human beings artificially incubating and hatching eggs was written in the fourth century B.C. by Aristotle. In his writings about animals, he described some of the earliest known techniques: "in some cases, as in Egypt, they are hatched spontaneously in the ground,by being buried in dung heaps. Instances have occurred of eggs being deposited in warm vessels and getting hatched

Photo by Ron Garrison

Over 200 different species of bird eggs have been successfully artificially incubated at the Avian Propagation Center (APC) at the San Diego Zoo.

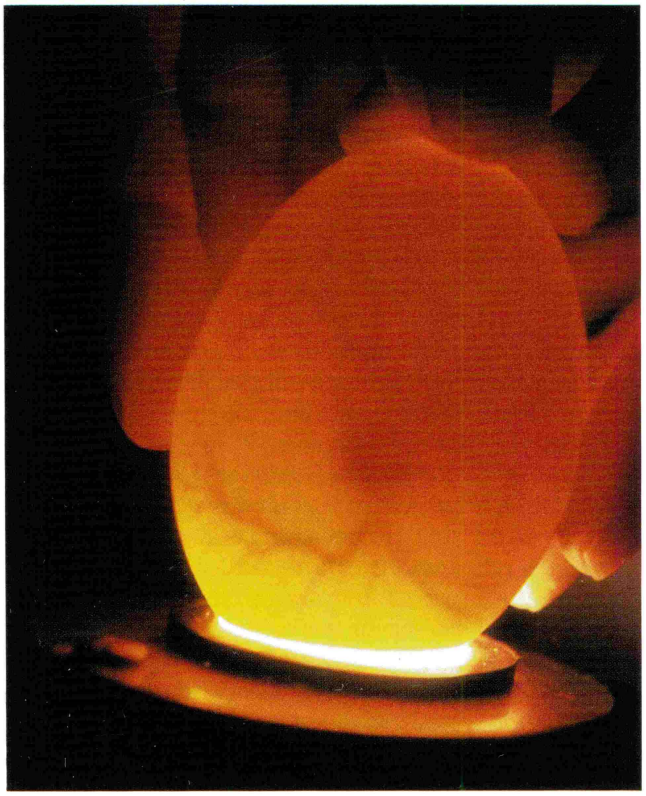


Photo by Ron Garrison, Zoological Society of San Diego

Candling is a valuable diagnostic technique which allows the hatchery technician to monitor the health and development of the embryo.

Photo by Ron Garrison, Zoological Society of San Diego

Weighing eggs throughout incubation and calculating the egg weight loss (water loss) from set to pip is a valuable method to evaluate the humidity conditions within the incubator.

spontaneously" (Aristotle, 1910). De Reaumur (1750) also wrote about the success of the sun-dried mud brick (adobe) incubating ovens of ancient Egypt, and is quoted as saying "Egypt ought to be prouder of them than her pyramids." Techniques involving chicken and duck eggs also originated during the same time period in ancient China and spread to what are now the Philippine Islands, Vietnam, Laos, Cambodia and Taiwan.

During the 20th century, the poultry industry elevated the art of artificially producing chickens into the realm of modern science, and today it is an international food industry. Techniques for producing, storing, incubating and hatching eggs are well researched and continually improving. Unfortunately, the correct husbandry techniques for artificially hatching most exotic or "non-domestic" bird eggs are still in the experimental phase. However, the basic principles which govern the development of the chicken in an artificial environment also applies to other bird species. Poultry literature is an excellent source for learning techniques and determining causes of mortality in exotic birds.

Today the role of the aviculturist is expanding, and effective captive propagation programs incorporate knowledge from disciplines such as avian science, field biology, genetics, nutrition, veterinary science and behavior. The exotic bird industry which involves zoos, conservationists and private aviculturists is evolving very rapidly. Age-old avicultural wisdom combined with poultry techniques, such as artificial incubation and information about birds in the wild, improves husbandry and maximizes reproduction in a captive environment.

The benefits of artificially incubating bird eggs are well known. Captive birds do not always incubate or hatch their eggs successfully and inadequate parental care often results in egg abandonment, breakage and chick mortality. Manipulating egg production by removing eggs from the nest for artificial incubation and hatching also induces hens to "double clutch" and lay additional eggs during the breeding season. This is a management tool which has been used successfully when the production of additional chicks is critical, as in the case of endangered species such as the Whooping Crane *(Grus americana),* San Clemente Loggerhead Shrike *(Lanius ludovicianus mearnsi)* (Kuehler et al., 1992) and the California Condor *(Gymnogyps californianus)* (Erickson and Derrickson, 1981; Kuehler and Witman, 1988).

The successful hatching of eggs in an incubator requires two things: a "potentially hatchable" egg and an adequate incubation environment. First, in order for an egg to be potentially hatchable it should be clean and free of viral, bacterial and fungal infection, and it must have been produced by genetically and nutritionally sound parental stock. Contamination, inbreeding and inadequate maternal diet can result in eggs which are not hatchable under conditions of either natural or artificial incubation. The second requirement is the correct incubation environment. This means that the dry bulb temperature, humidity level and turning process is appropriate for optimal embryonic development.

Egg Storage

To improve the chances for a successful hatch, eggs should be set as soon as possible. Egg storage is a husbandry technique which enables breeders to hatch clutches together and simplify the chick rearing process by producing birds which can be brooded in like-age groups. However, proper techniques for egg storage are often overlooked which results in an increase in early embryonic mortality, poor hatchability, prolonged incubation periods and weaker chicks (Proudfoot, 1968; Chahil and Johnson, 1974).

Loss of hatching viability appears to be species dependent and very little is known about the storage tolerance of non-domestic bird eggs. For example, Chukar *(Alectorus graeca chukar)* eggs can be stored for as long as 28 days without any effect on hatchability, while Cockatiel *(Nymphicus hollandicus)* clutches stored for only six or seven days show a reduced hatch rate; eggs stored for longer than eight days do not hatch at all (Woodard and Morzenti, 1975; Roudybush, 1984).

If storage is necessary, non-domestic eggs should be maintained at 12.8 to 18.3°C (55 to 65°F), at a relative humidity of 80 to 90 percent, for no more than seven days (Schwartz, 1977; Roudybush, 1984; Kuehler, pers. obs.). Holding temperatures above 26.7°C (80°F) will allow cell division to continue at an abnormal rate resulting in decreased hatchability and abnormalities in the brain and eye regions of developing embryos. There is also some evidence suggesting that placing eggs in fine-pored plastic bags that allows some air circulation, increases the hatchability of stored eggs. The incubation period is still longer than normal because some embryos, from stored eggs, require a longer developmental period (Bowman, 1966; Schwartz, 1977).

Sanitation/Egg Contamination

Parent birds and the hatchery itself are both recognized as potential sources of infection in newly-hatched chicks and incubating eggs. Because the hen uses a common passage for both eggs and fecal matter, and the incubator environment is warm and moist, embryonic diseases are caused both by the intestinal contents of parent birds and contamination from incubators and hatchers. Microbial contamination resulting in infection is of two types: exterior eggshell-borne diseases and interior egg-borne diseases. Contaminants are more easily eradicated from the surface of the shell than from within the egg.

Hatchery sanitation should include maintenance of disease-free birds and a well ventilated, easily cleaned incubation and hatching area. Protocols which emphasize egg handling with clean, dry hands and a flow pattern which minimizes traffic from areas that are possible sources of contamination (such as adult breeding stock) are optimum.

One of the most common contaminants is *Pseudomonas,* but *E. coli* infection, infectious bronchitis, Newcastle's disease, staphylococcal and *Salmonella* infections have all been implicated in embryonic and early

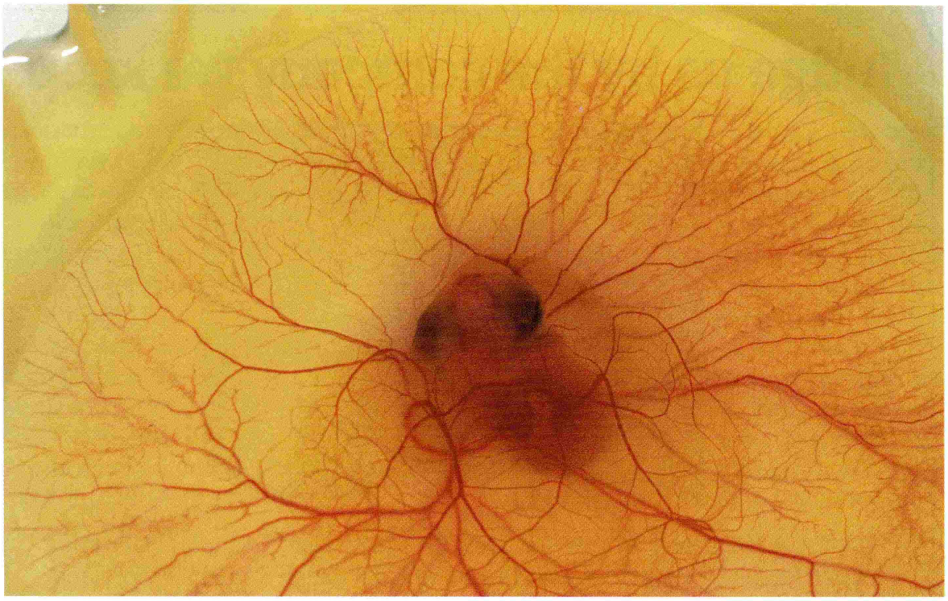
chick mortality. In general, avian eggs are more susceptible to gram negative bacterial infection. There is a direct relationship between bacterial contamination of eggs, the incidence of embryonic malformations and mortality, and the degree of yolk sac infections in resulting chicks (Biswal and Morrill, 1954; Harry, 1957; Board, 1974; Brandt, 1987). Many aviculturists are unaware that weak chicks, "poor doers," that do not eat or thrive may have hatched with yolk sac infections due to contamination of the egg prior to laying or during the incubation process. Not all yolk sac infections are caused by poor seals or contamination at hatch (Harry, 1957; Calle et al., 1989).

Prior to being laid, eggs can be infected transovarially and in the oviduct prior to egg cuticle formation. Transovarial infections with *Salmonella* are well documented. *Salmonella* can infect the ovary via the hematogenous route from gastrointestinal infections or sepsis. Infections in the oviduct can result from an ascending oviduct infection.

One routine sanitizing technique is the fumigation of eggs with formaldehyde gas.* This procedure is most effective if clean eggs are fumigated as soon as possible after laying, prior to egg storage, before bacterial penetration can occur. The accepted procedure is: 2-1/2 fluid ounces of formalin (40%) and 1/3 ounce of potassium permanganate (KMN04) per 100 cubic feet, in an earthenware container or approximately 1.5 ml of formalin (40%) and 1 g of potassium permanganate (KMN04) per .1 cubic meters (Burr, 1987). Disinfection is most effective at a temperature of at least 32.2°C (90°F); wet bulb reading 31.1 to 32.2°C (88 to 90°F), for at least 20 minutes. The enclosed environment of an old, forced-air incubator with a circulating fan system is a desirable fumigant cabinet.

Poultry eggs are not fumigated during the first five days of development because formaldehyde is teratogenic and increases the incidence of embryonic malformations (Lancaster et al., 1954). Additionally, chicks that have been over-fumigated during late incubation may develop a high-

Photos by Ron Garrison, Zoological Society of San Diego



The best method to learn artificial incubation is to practice with chickens. This is an embryo grown in a petri dish to demonstrate avian embryonic development.

pitched, whistling-type chirp or respiratory problems (Hofstad et. al., 1984). It is advisable not to routinely fumigate non-domestic bird eggs during the initial stages of incubation until research has been conducted on the effects of fumigation on exotic birds. Many species of birds lay eggs with shells that are considerably thinner and more porous than poultry eggs and the teratological effects of fumigation may be more extreme.

A second method for disinfecting eggs is egg washing. Extreme care should be taken when utilizing this method because improper egg washing can spread disease and contaminate previously clean eggs. Disinfecting solutions containing quaternary ammonia or chlorine compounds are usually used. The wash-water should be warmer than the eggs 43.3 to 48.9°C (110 to 120°F), to prevent the wash compound from being

Altricial birds, such as Gold-crested Mynahs, are particularly challenging to incubate and raise.

Elegant Crested Tinamou with an abnormal beak due to incorrect fumigation techniques.

Black-backed Fruit Doves are one of many pigeons and doves hatched and reared at the APC in recent years.

absorbed through the pores of the shell and contaminating the egg.

A sample stock solution of egg disinfecting compound consists of 10% quaternary ammonium disinfectant (alkyldimethyl benzyl ammonium chloride), .4% ethylenediaminetetraacetic acid (EDTA; disodium salt) (15 grams/4 liters), and 4.2% sodium carbonate (160 grams/4 liters). For egg washing, use 30 ml of the stock solution in 12 liters of water (Hofstad, 1984 and Ernst, 1987).

Interior eggborne diseases are much more difficult to identify and treat. Measures to control bacterial infections in fertilized eggs include differential pressure and temperature dips and injections into the air cell, albumen, or yolk (Calle et al., 1989).

Hatchery and hatchery equipment cleanliness cannot be over emphasized. Wet bulbs, water pans, egg trays and hatching trays are all potential sources of infection. The warm, humid environment of an incubator or hatcher is the ideal climate for growth of bacteria, viruses and fungus. Additionally, improper artificial incubation techniques may result in chicks with poor seals which are more susceptible to infection.

Artificial Incubation

Birds are the best incubators for developing avian embryos. Nature has designed parent birds, the nests they build, and the eggs they produce, to be an evolutionary matched fit, in order to maximize reproductive success (White and Kinney, 1974). The body temperature of the brooding parent provides the correct amount of heat to maintain development. Generally heat is transferred to the embryo as a still-air gradient from the body of the bird to the top of the egg, down through to the bottom of the nest. The eggshell and humid conditions of the nest microclimate keep the egg from desiccating, while the cuticle and pore structure of the shell acts to facilitate gas exchange between the embryo and the environment and provides a barrier to contaminants. Behaviorally, the parent bird contributes to the incubation process by turning the egg and giving the chick auditory and tactile stimulation in order to promote hatching (Ar et al., 1974; Kuo, 1932; Gottlieb, 1965; Impekovan and Gold, 1973; Bruning, 1973).

Artificial incubation, using a machine, provides a very different physical environment for the developing embryo and is generally not as efficient as an incubating parent (Burnham, 1983). Most bird eggs will benefit from some natural incubation prior to being removed from the nest and placed in an incubator. Simkiss (1980) suggests that parentally-incubated eggs are subjected to oscillating temperatures during development which facilitates calcium metabolism from the shell to the embryo. Burnham (1983) has hypothesized that the consistent heating environment of an incubator decreases calcium metabolism and subsequent eggshell conductance. This may be why artificial incubation of fresh eggs is less successful, compared with eggs receiving natural incubation prior to being removed from the nest and set in an incubator.

It is very difficult to reliably mimic the variable temperature gradient of a parent bird transferring heat to its egg, with a machine. Still-air incubators attempt to do this by providing a heat source at the top of the incubator so the eggs experience a temperature gradient. This is a very successful hatching system. However, the drawback of this method is that a limited number of eggs can be set in the incubator before carbon dioxide build-up occurs and suffocates the developing embryos. Most hatcheries use the circulating fan system of forced-air incubation developed by the poultry industry. This type of system increases the ventilation within the machine, cir-

culates the heat and maintains a more consistent temperature throughout the incubator than would be found at the top of an egg under an incubating bird. Consequently, more eggs can be incubated at one time. Generally, eggs which are incubated in a still-air system are set at a temperature which is two to three degrees higher (similar to the top of the egg under an incubating bird) than in a forced-air system which provides a lower, more consistent temperature throughout the egg and incubator. This promotes similar developmental rates in both types of incubating systems.

Dry Bulb Temperature

The dry bulb incubation temperature is the most critical incubation parameter. Eggs incubated at temperatures too high or too low show increased embryonic malformations and mortality (Romanoff and Romanoff, 1972). The correct dry bulb parameters for artificial incubation of most bird eggs have not been established beyond the requirements for chickens, turkeys, domesticated pheasants, chukar, quail, and domesticated waterfowl (Woodard et. al, 1978; Ernst and Coates, 1981). Aviculturists must rely on the limited published information on specific groups of birds and shared experiences (Bruning, 1973; Archibald, 1974; Burnham, 1983; Kuehler and Good, 1990).

In establishing dry bulb temperature parameters for non-domestic birds, the incubation requirements of the chicken should be viewed as a baseline guide. The optimum temperature for the 21-day incubation period of the domestic chicken has been established to be 37.5°C (99.5°F) in a forced-air incubator, 38.6 to 39.2°C (101.5 to 102.5°F) under still-air conditions. Generally, eggs larger than a chicken's have a longer incubation period and may require a lower artificial incubation temperature. Eggs smaller than a chicken usually have a shorter incubation period, develop at a faster rate and may require an incubation temperature of 37.5°C (99.5°F) or higher. However, the best method to determine a correct dry bulb temperature is to compare the artificial incubation period with the natural incubation period of the species in question. In the absence of other problems such as inbreeding, chicks that hatch earlier than the known natural incubation period were probably incubated at a temperature that was too high. Chicks delayed in hatching were probably incubated at conditions that were too low.

Wet Bulb Temperature

Although important, the wet bulb temperature or relative humidity environment is not as critical as the dry bulb temperature. Recently, much research has been devoted to the factors affecting the gas/water exchange between the avian embryo and its environment. The rate of water loss (weight loss) is dependant upon the shell thickness, porosity and the water vapor concentration in the atmosphere around the egg (Ar, et. al, 1974; Rahn et. al., 1977). Weighing the egg throughout incubation to record the weight loss will provide an indication of water loss. Excessive humidity may increase the mortality of embryos. Humidity that is too low may result in dwarfing or decreased calcium metabolism (Romanoff, 1929 & 1930). The establishment of humidity parameters is dependant upon information on the microclimate of the nest under natural conditions. Birds that lay their eggs in wet, soggy conditions generally require a high incubation humidity. Desert species usually have evolved eggs with thick shells or specialized pores which resist desiccation and usually require drier, artificial incubation conditions (Swart et. al, 1987). Evaluation of the condition of the hatchlings also provides critical information on proper humidity. Chicks that are edematous or "sticky" at hatching, may have been incubated under conditions which were either too wet or too dry.

Egg Turning

The third parameter of artificial incubation in addition to dry bulb and wet bulb temperature, is egg turning. Turning during avian development is essential to minimize adhesions and disruption of embryonic membranes, and to decrease the possibility of chick malpositions within the egg (New, 1957; Robertson, 1961a,b). Rotation should alternate between clockwise and counterclockwise directions; continued turning in one direction can cause twisting of the chalazae or rupturing of the yolk sac or blood vessels in a developing embryo (Olson and Byerly, 1936).

Candling

Candling is a technique which allows the hatchery technician to observe the development of the avian embryo throughout incubation. It is a valuable diagnostic technique which requires time and experience to learn accurately. By shining a high intensity light through the shell, embryonic structures, yolk sac circulation integrity, air cell size and embryonic health can be monitored. Because the embryo lives in a fluid-filled environment suspended by delicate membranes, care should be taken when placing an egg against the hot light source to avoid overheating or rapid jerky movements which could cause damage. Clean, dry hands are imperative to reduce the risk of contamination. Rotten or dead embryos should not be handled prior to candling.

The best method to learn candling techniques is to acquire chicken eggs and incubate them. Candle the eggs daily observing all the developmental changes with the aid of pictures from a good embryology text. Not all species of birds have the same shell porosity, air cell size and developmental rate. Stages of development have been categorized and published for precocial chicken embryos (Hamburger and Hamilton, 1951) and more recently for altricial cockatiel embryos (Abbott et al., 1992). Both series serve as good guidelines for aviculturists. Remember, never presume an embryo is dead unless you are sure —"if in doubt, don't break it out."

"Breakouts" — Helping Weak Chicks at Hatch

Occasionally it may become necessary to "breakout" or help a chick hatch if it is having difficulty completing the hatching process. Usually, if it becomes necessary to breakout chicks, the artificial incubation or hatching parameters are incorrect (incorrect temperature or humidity) or the chick is weak due to problems such as infection, nutritional deficiencies, or malpositioning. This technique should only be used as a last resort and the cause of the problem should be corrected prior to future eggs being laid.

The correct pip-to-hatch intervals for many non-domestic bird eggs are unknown and care must be taken when assisting a chick during hatch-

ing. In all cases, membranes should be moistened with sterile water prior to slow removal of pieces of shell over a several hour period. Placing the egg in a small plastic bag (partially open) helps to retain moisture and decrease membrane drying during the process. Ruptured blood vessels and unretracted yolk sacs, resulting from over anxious intervention, can cause the death of the chick. Additionally, waiting too long to help can cause an increase in the incidence of crooked necks, "poor doers" and "pip and dies."

Data Collection

Optimum artificial incubation parameters for most non-domestic species of birds are unknown. In order to determine correct artificial incubation conditions and evaluate causes of embryonic mortality and weak chicks, consistent, accurate record keeping is necessary. Incubation record keeping in a captive situation falls into three categories: 1) pre-incubation factors, 2) incubation data and 3) evaluation of the embryo/chick at death or at hatch. Following is a list of the important information required:

Pre-incubation factors
parental pedigree
parental nutrition
parental incubation behavior
pre-incubation handling of eggs
egg size and shape
degree of eggshell thinning
air cell membrane integrity

Incubation data
incubator/hatcher type
turning mechanism
incubation/hatching temperature
incubation/hatching humidity
egg weight/water loss
air cell size
candling
pip to hatch interval

Evaluation of the embryo/chick at death or hatch
bacterial culture of yolk and albumin
bacterial analysis of incubators/hatchers
determination of embryonic stage at time of death
embryonic position
embryo/chick measurements (toe,

nare, yolk sac, body weight)
characteristic embryonic abnormalities (e.g., clubbed down)
degree of yolk sac retraction
amount of residual albumen
"stickiness" or edema in chick
hatch weight
growth rate (hatch to death)
neurological status (e.g., stargazer)
begging response
degree of yolk sac depletion
pip muscle fluid depletion
toe problems
"noisiness" of chick
pasted vent
additional necropsy and culture results
(Osborn and Kuehler, 1989)

Causes of Embryonic Mortality and Weak Chicks

The normal mortality curve for avian embryos has been determined to be approximately one-third of the deaths occurring in the first third of incubation during organ system development, so that the rate of mortality during this critical period can be a guide to the fate of the entire hatch. The majority of other deaths occur during the last third of incubation as the chick prepares to hatch (Romanoff, 1949; Riddle, 1965). A summary of some of the known causes of incubation failure, some of which are applicable both to artificial and natural incubation as well as to breeding in the wild, is given below. In some cases, the condition listed may affect the egg or embryo at more than one stage of development and the point at which it becomes apparent may depend on its severity.

Egg characteristics:

1) Abnormal egg shape: viral infections (e.g., Newcastle's disease); parental reproductive tract abnormalities; age of hen (immature or beyond optimum breeding age); inbreeding, pesticide contamination.

2) Abnormal or poor quality eggshells: nutrient deficiencies (calcium, phosphorus, manganese, vitamin D); age of hen; exhaustion of parents from over-extended production; pesticide contamination.

3) Poor air-cell quality: viral infections; excessive jarring of eggs through mishandling or transportation (e.g., helicopter vibrations or DDT can cause membranes to slip); air pressure changes in airplanes. (Tur, 1907; Hays and Sanborn, 1924; Buckner et al., 1924-1925; Knox and Olson, 1936; Hays and Talmadge, 1949; Swanson and Bell, 1975; B. Walton, pers. comm.).

Infertility:

1) Age: one or both parents immature or beyond optimum breeding age.

2) Inbreeding: reduced fertility.

3) Incompatibility or behavioral problems of parents: asynchronous breeding condition; preferential mating; lack of pair-bonding; abnormal imprinting; infrequency of mating, an increase in the age of the sperm decreasing egg fertility.

4) Disease: unfit parent birds fail to mate; side effects of antibiotics leading to secondary vitamin deficiencies which affect fertility; chronic disease affecting fertility through decreased food intake or utilization.

5) Parental reproductive tract abnormalities caused by poor incubation practices during embryonic development.

6) Weather: decreased fertility in cold or hot weather; incorrect photoperiod.

7) Parental diet: insufficient food intake through disease or stress; nutrient deficiencies arising from incorrect diet or abnormal food imprinting.

8) Incorrect artificial insemination procedures (e.g., wrong diluent, insufficient or incorrect penetration, contaminated semen samples). (Parker, 1949; Lorenz, 1959; Romanoff, 1960; Ernst Abbott, 1973; Abbott, 1979, unpubl. a; Brown, 1979; Ernst, 1987.)

Death or abnormalities of embryos arising during each of the three stages of the incubation period.

Stage 1

1) Egg handling; storage at incorrect temperature or for too long; excessive jarring of eggs; washing at too high a temperature.

2) High inbreeding coefficient resulting in fertile eggs with no development; parthenogenesis; prelaying mortality; chromosome abnormalities.

3) Incubation faults: inadequate or incorrect egg turning; incorrect temperature through incubator failure or abandonment by parents can cause death or malformation of embryo; suffocation through inadequate incu-

bator ventilation; fumigation at wrong developmental stage.

4) Disease: viral infections, parent to egg transmission; bacterial infections, parent to egg and egg to egg transmission.

5) Parental nutrient deficiencies leading to egg nutrient deficiencies: vitamin E deficiency causing formation of a "lethal ring" (the embryo is surrounded by tissue).

6) Aged or abnormal sperm.

7) Developmental; abnormalities of unknown causes: failure of development of amnion; heterotaxia (embryos turn to right instead of left interfering with heart development). (Jull, 1928-1929; Adamstone, 1931; Lancaster et al., 1954; Harry, 1957; Board, 1966, 1974; Bloom, 1969; Lodge et al., 1971; Romanoff and Romanoff, 1972; Cahil and Johnson, 1974; Brown, 1979; Abbott, unpubl. b, c).

Stage 2

1) Parental nutrient deficiencies: riboflavin deficiency causing abnormal cartilage development (chondrodystrophy), dwarfism, curled toes, clubbed down, kidney degeneration, edema, underdeveloped limbs (micromelia); B12 deficiency causing hemorrhaging, enlarged thyroid, edema, short beaks, dead embryos without visible malformation; biotin deficiency causing skeletal deformities (shortened, twisted bones, edema, webbing between toes); folic acid deficiency causing micromelia, curved tibiotarsus, syndactylism, beak defects (parrot beak); manganese deficiency causing micromelia, edema, shortened leg bones and softening of bones; zinc deficiency causing abnormal limb development, parts of limb missing; vitamin K deficiency causing hemorrhaging, causing skeletal deformities.

2) Secondary vitamin deficiencies: drugs, prolonged antibiotic therapy destroying vitamin-producing flora; insufficient food intake or diet imbalances.

3) Disease; viral infections (Newcastle disease, infectious bronchitis); Gram-negative bacterial infections (salmonella, staphylococcus, streptococcus and E. coli); fungal infections, spores transmitted into egg; parental protozoal infections or parasite infestations leading to insufficient food intake and production of poor quality eggs with reduced hatchability.

4) Poor handling of eggs before or during first days of incubation; jarring or shaking of eggs causing twinning and duplications; inadequate egg turning causing malformed or cystic embryos.

5)Incubator conditions; inadequate ventilation or high level of carbon dioxide causing suffocation; incorrect temperature causing circulation problems in embryos and disproportionate growth of organ systems owing to temperature sensitivity of enzymes.

6)Lethal genes: often result of excessive inbreeding. (Landauer, 1967; Beer, 1969; Scott & Krook, 1972; Ernst & Abbott, 1973; Board, 1974; Anon., 1977; Abbott, 1979, unpubl. b, c; Brown 1979).

Stage 3

1) Lethal malpositioning; caused by incorrect or insufficient turning; parental inbreeding; abnormal egg size or shape; incorrect incubation temperature.

2) Poor incubator ventilation: chick suffocates on pipping into air-cell.

3) Lethal genes.

4) Old eggs: time lag between laying and setting.

5) Disease.

6) Nutritional deficiencies: vitamin E deficiency affecting mortality of late embryos without characteristic malformations; pantothenic acid deficiency: late mortality and subcutaneous hemorrhage; folic acid deficiency: apparently normal chicks dead in shell.

7) Egg cooling early in incubation.

8) Improper egg handling prior to incubation, particularly eggs wet before setting.

9) Inadequate or incorrect turning during incubation leading to malposition or malformed embryos.

10) Incubation temperature too low: chicks dead in shell or retarded development; chick exhaustion at hatching; residual albumen.

11) Temperature too high: malformation of embryo (hernia and "rumplessness") ; chick dead in shell or accelerated development; unretracted yolks-sacs.

12) Humidity too low or transfer into hatcher too late: membranes dry after chick pips: chick exhausted at hatch; skeletal abnormalities owing to insufficient calcium transport at end of incubation because of retracted inner shell membrane.

13) Incubation humidity too high or

transfer to hatcher too early: "chick drowns" (dead in shell); unretracted yolk-sac and poor seal: residual albumen. (Romanoff, 1929, 1930; Dove, 1935; Olson & Byerly, 1936; Lancaster et al., 1954; Robertson, 1961; Board, 1966; Romanoff & Romanoff, 1972; Ernst & Abbott, 1973; Abbott, 1979, unpubl. a, b, c; Brown, 1979).

Poor and abnormal chicks

1) Incorrect incubation temperature, general symptoms: poor seals, yolk sac infections; curled or crooked toes, splayed legs; reproductive tract abnormalities affecting later fertility and egg production.

2) Temperature too low (effect proportional to degree of error): delayed hatch; unretracted or partially retracted yolk sacs; bent necks; residual albumen producing "sticky chicks"; abnormal "soft" down; small, weak chicks with stunted growth; nervous disorders (usually due to incorrect temperatures during early development).

3) Temperature too high (effect proportional to degree of error): early hatch; abnormal "scruffy" down; dry membranes at pipping; small noisy chicks; neurological problems, including ataxia and "star gazing"; head abnormalities (hernias); unretracted yolk sacs.

4) Humidity too low: poor, weak chicks; skeletal abnormalities because of inability to transport minerals from shell during Stage 3 of incubation; "scruffy" down; bent necks; abnormally large air cells at pipping.

5) Humidity too high: large, soft "blobby" chicks, weak chicks; poor seals, unretracted yolk-sacs and infections.

6) Unsuitable hatching substrate: splayed legs; slipped tendons.

7) Parental nutrient deficiencies: small, weak chicks; depressed growth rates.

8) Parental inbreeding: general weakness and depressed growth rates: specific developmental abnormalities (e.g., splitfoot).

Determination of crooked or curled toe condition can be made by histological examination of the sciatic nerve. Curled toes can be caused by riboflavin deficiency or incorrect incubation temperature. Crooked toes are a genetic tendency aggravated by substrate, inbreeding and infra-red brooding. (Harry, 1957; Peckman, 1972; Ernst & Abbott, 1973; Abbott, 1979, unpubl. b, c; Greenwell et al., 1982; Woodard & Ernst, 1983).

Incubation Equipment

There are fewer bad incubators than there are bad incubator users. It is necessary to take the time to understand the machine. If you understand it —you can work with it effectively. What is the air flow system (forced-air or still-air)? Where are the hot spots? What kind of thermostat does it have? Is there a backup thermostat?

Some important considerations before purchasing an incubator or hatcher are:

1) Size and species of bird eggs to be incubated. Large ratite eggs require different conditions than small, altricial, softbill eggs and possibly different sized machines.

2) Cost. Do you want one high tech machine for a few valuable eggs or several medium priced machines to incubate several different species which require different artificial incubation parameters? What is the cost of a new thermostat, turner or water pan?

3) Reliability. How easy is it to acquire replacement parts? Can you install them yourself? Is there someone to answer your questions after you buy? Is a wiring diagram available?

4) Space. Incubators and hatchers work most effectively in a temperature controlled environment. Do you have the space, or is this going into the garage?

5) Turning mechanism. How does it work? Will it effectively turn the eggs you are considering incubating, or will it over-turn small eggs and under-turn large eggs?

6) Thermostat. Is it a wafer system which will require constant adjustment or solid-state, light bulb, or mercury control?

7) Sanitation. How easy is it to clean the incubator; can you take it apart? Are water pans easily removable?

There are many different types of forced-air and still-air incubators available for purchase by zoos and aviculturists (see appendix). Most important is the purchase of high quality thermometers and wet bulbs.

Following is a table listing the species successfully artificially incubated and hatched at the San Diego Zoo and San Diego Wild Animal Park from 1980 - 1992 and the parameters used. This table is only a guideline. Artificial incubation parameters vary based on many factors such as type of incubator, altitude, and relative humidity. The key ingredients for successful artificial incubation are the desire to keep learning and experimenting, a holistic outlook and an open mind...

* Formaldehyde is carcinogenic and teratogenic. Fumigation of eggs using this disinfectant should be carried out with extreme care under well-ventilated conditions. Under no circumstances should this procedure be undertaken by a pregnant woman.

Acknowledgements

Artificial incubation and hand-rearing of birds would not be possible without the hard work and efforts of all the Bird Department staff at the San Diego Zoo and San Diego Wild Animal Park.

Appendix

Agriculture Publications
University of California
Agriculture and Natural Resources
6701 San Pablo Ave.
Oakland, CA 94608-1239

Grumbach Incubators
12240 Spencer Road
Saginaw, MI 48609

Humidaire Incubator Co.
217 West Wayne Street
New Madison, OH 45346

International Hatchery Practice
P.O. Box , Driffield
North Humberside Y025 8BJ
England

Kuhl Corporation
Kuhl Rd.
P.O. Box 26
Flemington, N.J. 08822-0026

Lyon Electric Co.
Manufacturers of Marsh Farms Products
2765 Main Street
Chula Vista, CA 92011

Petersime Incubator Co.
300 North Bridge Street
Gettysburg, OH 45328

Editor's Note: *Because Keubler's literary references were 96 in number and her incubation parameter charts occupied 11 pages, it is not practical to publish them here. They are available by requesting them from the AFA Home Office.*●