USING SOUTH DAKOTA DUCK EGGS AS A MEANS OF TIME-TRAVEL RESEARCH INTO THE PAST 150 YEARS OF CLIMATE HISTORY

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ABSTRACT

We collected maximum length and width (± 0.1 mm) of 4,257 duck eggs, which represent 12 different duck species nesting in South Dakota. These results were part of a larger on-going project which is analyzing the possible effects of climate changes on the size of North American duck eggs (DeJong and Higgins 2011). Hundreds of waterfowl specimens and waterfowl eggs that were collected from South Dakota during the last 150 years are currently archived in museums throughout North America. The early collection efforts of various oologists plus the foresight of others to preserve the eggs in some of North America's private and public museums have enabled us to conduct a type of time travel research on duck eggs that were collected and preserved as early as 1859. Egg size metrics were taken from museum egg collections of duck eggs which were collected from 1877-1922 (N = 371) and from 3,886 eggs measured during recent (2009-2010) duck nesting studies in eastern South Dakota. All of the eggs collected or measured for this research originated in 14 eastern South Dakota counties, emphasizing the scarcity of duck egg collection and duck nesting research in western South Dakota. Egg volumes from five species of ducks in South Dakota indicated a statistically significant ($P < 0.05$) relationship to climate conditions (Palmer Drought Severity Indices). Duck egg volume of nine species varied between years when collected and/or measured.

Keywords

ducks, eggs, climate, South Dakota, museum

INTRODUCTION

Climate is not a stable condition. It changes due to large scale factors such as the periodic changes of the earth's orbit and also due to finer scale factors such as the amount of cloud cover blocking incoming sunlight. North America has experienced many changes in climate throughout history. During the last 150 years, several droughts have occurred across the United States. One of North America's most memorable droughts, often referred to as The Dust Bowl, occurred throughout the Great Plains during the 1930s. However, climate data also show time periods with above normal precipitation events. During the last 50 years, high annual precipitation conditions were occurring in some North American regions (Gutowski et al. 2008), while other regions were experiencing drought conditions. North American duck species often migrate long distances during the spring on their way to northern breeding locations, and may pass through both wet and dry climate extremes. Climates across North America are predicted to become more extreme (Gutowski et al. 2008). How have ducks responded to extensive periods of drought or flooding encountered during migration and nesting, and what may be their response to future climate change?

Numerous types of data have been or are being used to track climate change, including studies of tree-ring growth patterns (Fritts 1991), core samples from glacial ice (Alley 2000), and temperature and precipitation measurements across years and geographic locations (Jones and Mann 2004). Collateral studies of climate change effects have also been conducted on several kinds of animals, including polar bears (Derocher et al. 2004; Schliebe 2010), butterflies (Parmesan et al. 1999), and penguins (Barbraud and Weimerskirch 2001; Cunningham and Moors 1994). Researchers have found that the timing of seasonal activities of plants and animals have changed with climate changes (Brown et al. 1999; Menzel and Estrella 2001; Walther et al. 2002). Some birds are nesting earlier than in documented history (Brown et al. 1999; Crick and Sparks 1999), while others are laying eggs which are larger than in the past (Jarvinen 1994) due to warmer spring temperatures. Scientists predict future variation in the distribution of vegetation due to climate changes (US Environmental Protection Agency 2011, U.S. Forest Service 2010). Additionally, climate change will have an effect on abiotic factors such as the presence and depth of lakes and ponds, and the intensity and frequency of weather events. These factors are extremely important when considering smaller, temporary wetlands like those found in the Prairie Pothole Region of South Dakota. However, except for some recent habitat effects modeling (Burkett and Kusler 2007; Johnson et al. 2005), a comparison of duck abundance variability due to agriculture and precipitation (Bethke and Nudds 1995), and reproductive performance and body condition studies of marine birds (Sydeman et al. 2001), very little other information exists relative to direct or indirect effects of climate change on ducks or their eggs relative to the past 150 years.

Drought conditions cause prairie pothole wetlands to diminish in size or to dry out completely. This in turn reduces the habitat and food resources available for hens during the nesting season. Hens rely heavily on food resources to provide them with the extra energy needed to produce eggs. If there is less food available, hens may lay fewer and possibly smaller eggs. Eldridge and Krapu (1988) found that mallard hens with enhanced nutrition produced larger eggs than hens that were fed a natural diet. Our research utilized duck egg measurements from museum collections eggs and recent field studies to determine if past climate changes, such as drought, have had any effect on the size of duck eggs during the last 150 years.

Hundreds of waterfowl specimens and waterfowl eggs from South Dakota are currently archived in museum collections throughout North America (Table 1;

ORNIS 2011). These specimens are stored in climate-controlled, insect-free storage facilities (Figure 1). Egg shells do not change in size or shape through time unless they become physically damaged. Egg collectors have adopted a standardized system of preserving and marking the eggs that they collect. The contents of an egg are removed through a small hole drilled in the side of the egg. Each egg is then labeled with the bird species name and/or American Ornithologists Union (AOU) code, the date of collection from the nest, and the number of eggs that were in that clutch (Figure 2). Additionally, each egg/clutch is accompanied by a nest card. The nest card contains the same information listed above, but may also contain more details about the eggs, the collector, and descriptions and locations of the nest (Figure 3). Occasionally the hen and nest would also be collected. Through time, the eggs from most private collections have been transferred to repositories in museums across North America. A few museums, such as the Western Foundation of Vertebrate Zoology in California, contain over a million bird and egg specimens.

Even though the practices of some commercial collectors severely affected some bird populations, egg collecting did serve a very important long-term purpose. Generally, an average egg collector was also a naturalist, recording information about the time of nesting and the type of nest or habitat used during nesting. This information has enabled scientists to understand more about each bird species. Early harvests by naturalists such as John James Audubon led to the first published bird identification guides. William Over and Craig Thoms

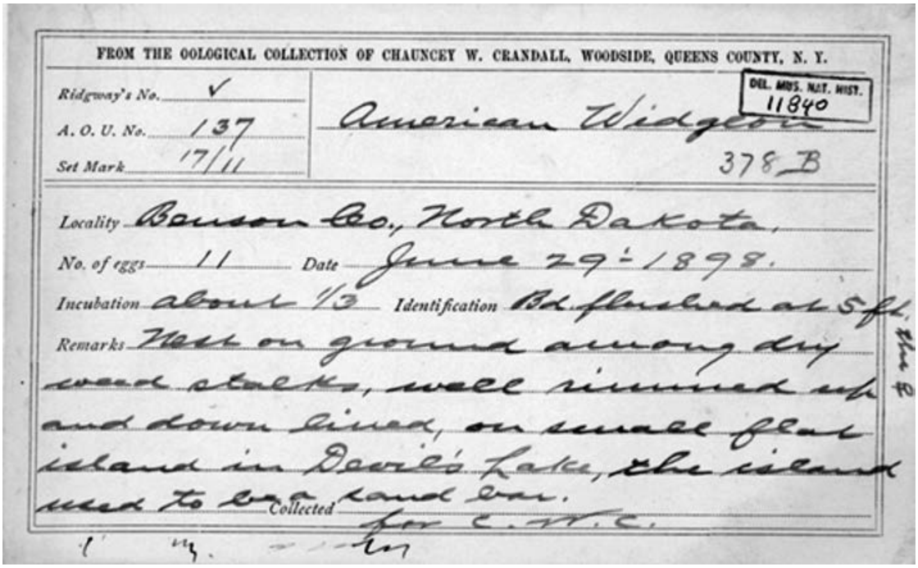
Figure 1. Duck eggs in storage at the Smithsonian National Museum of Natural History. Eggs are stored in dark, dry, and cool conditions to inhibit fading, dust collection, and fungus growth.

Figure 2. Egg collectors used a standardized labeling system. Each egg would have the American Ornithologist's Union unique identification code for each species above the drill hole. In this case the number 135 signifies that this egg was from a Gadwall. The number of sets of eggs of that species which were collected that day is denoted by the top number over the dividing line. The number of eggs in the clutch was written under the dividing line. The date the egg was collected was also written on the egg.

published the first comprehensive bird guide for South Dakota (The Birds of South Dakota) in 1920. Museum collections have also been used for determining the past geographic distribution of certain species (McNair and Dean 2003), the timing of nesting (Tryjanowski 2002) and other natural history information. One of the most important and well-known uses for museum egg collections was the detection of the pesticide DDT (dichlorodiphenyltrichloroethane) in egg shell fragments. DDT caused egg shells to become brittle and weak, resulting in the parents crushing or breaking the eggs when they settled their weight upon them during incubation. Museum egg collections represent thousands of bird species and provide specimens from a wide range of geographic locations and time periods which are impossible to reproduce with current field studies.

METHODS

We used digital calipers to obtained maximum width (W) and length (L) measurements (± 0.1mm) of 69,960 duck eggs (DeJong and Higgins 2011) from museums and field research. Eggs in museum collections were originally collected from across North America from 1859-1979. Some eggs were missing location data (2,109 eggs), and other eggs were originally collected from Iceland or Greenland (314 eggs), so were removed from analysis as were eggs that were cracked or broken. Additionally, duck eggs were measured during past and pres-



FROM THE OOLOGICAL COLLECTION OF CHAUNCEY W. CRANDALL, WOODSIDE, QUEENS COUNTY, N. Y.

Ridgway's No. ✓

A. O. U. No. 137

Set Mark 17/11

American Widgeon

DEL. MUS. NAT. HIST. 11840

378 B

Locality Benson Co., North Dakota.

No. of eggs 11 Date June 29th 1898.

Incubation about 1/3 Identification Bd. flushed at 5 ft.

Remarks Nest on ground among dry weed stalks, well rimmed up and down lined, on small flat island in Devil's Lake, the island used to be a sand bar.

Collected for C. W. C.

Figure 3. Each clutch of eggs in a museum collection is accompanied by a nest card or catalog card. The nest card contains information about when and where the clutch was found, the certainty of identification, the collector, the number of eggs in the clutch, the stage of incubation, and other details about the nest site.

ent field research (1980-2010). Approximately 6% of all eggs in this database were collected or measured in South Dakota; 371 eggs were collected during the time period 1877-1922 (Table 2), and the other 3,886 eggs were measured at the nest and immediately replaced in the nest during duck nesting field studies conducted in 2009 and 2010. Overall, the eggs of 12 species of ducks were measured from 14 counties in eastern South Dakota. Volume (cm^3) for each egg was calculated using the equation $0.51*LW^2$ (Hoyt 1979). In order to examine past climate over a large geographical area and longer time scale, we used Palmer Drought Severity Indices (PDSI) which are reconstructed from tree-ring data (Cook et al. 1999, 2004). PDSI values are calculated using the past and current precipitation and temperature of a particular area, and are an indicator of long-term drought or extremely wet conditions. The index values are as follows: 1) Extreme drought (-4.0 and below), 2) Severe drought (-3.00 to -3.99), 3) Moderate drought (-2.00 to -2.99), 4) Mid-range (-1.99 to +1.99), 5) Moderately moist (+2.00 to +2.99), 6) Very moist (+3.00 to +3.99), and Extremely moist (+4.00 and above). PDSI values were acquired for the year and nearest location for the original nest location. We then conducted linear regression modeling to examine the relationships between egg volume (cm3) and PDSI value for the eggs of 12 duck species found in South Dakota using R Statistical Software Version 2.13.2 (R Development Core Team 2008).

RESULTS

Blue-winged teal (*Anas discors*), mallard (*Anas platyrhynchos*) and gadwall (*Anas strepera*) were the most commonly found duck eggs during field research in 2009 and 2010 in South Dakota. Eggs from certain species, such as ruddy duck (*Oxyura jamaicensis*), canvasback (*Aythya valisineria*) and green-winged teal (*Anas crecca*) were measured only from early museum collections (Table 2), while certain others, such as the wood duck (*Aix sponsa*) and lesser scaup (*Aythya affinis*), were found only during field research in 2009 and 2010.

Eggs collected in South Dakota from blue-winged teal, mallard, gadwall, and canvasback (Table 3) were smaller than the previously published average size (Bellrose 1980; Baicich and Harrison1997). American wigeon (*Anas americana*) eggs were larger than previously published. Egg volumes from five species of ducks in South Dakota indicated a statistically significant ($P < 0.05$) relationship to climate conditions (Table 4). PDSI values were not significantly different between 2009 and 2010, but varied substantially in the years 1877-2010. Blue-winged teal and green-winged teal egg volumes were larger during periods of moderately moist conditions (+ 1.0 to + 3.49 PDSI), and were smaller during years that were either extremely drier or wetter (Table 5). Northern shoveler (*Anas clypeata*) eggs (N = 380) were larger during years with severe or extreme drought conditions than they were in years with moist conditions. Northern pintail (*Anas acuta*) egg volume was greater during mid-range conditions (- 1.24 to + 0.99 PDSI) than during extremely moist conditions (> +3.5 PDSI). Eggs of the American wigeon had the strongest response to PDSI variability ($P < 0.05$, $R^2 = 0.82$), but unfortunately the number of specimens from this species was low ($N = 20$), and constituted only three clutches. The egg volume of nine species of ducks also varied significantly between years of collection or measurement (Table 4). Additional statistical analysis of the entire duck egg dataset is currently underway, and will provide more information concerning the effects of past climates on duck egg sizes across North America.

DISCUSSION

Climate during the duck breeding season in South Dakota periodically alternates between drought and flooding and affects the occurrence and availability of wetlands. Eastern South Dakota experienced above normal precipitation during the summers of both 2009 and 2010, but is experiencing mid-range to moderate drought conditions in 2012. Our results indicate that ducks may be compensating physiologically for the fluctuation in nutritional and habitat resources during dynamic hydrological periods by modifying the size of their eggs. Larger eggs produce ducklings which are more capable of fending off starvation (Rhymer 1988), surviving cold temperatures, and feeding at a greater rate than ducklings from smaller eggs (Anderson and Alisauskas 2001). The lack of suitable breeding and feeding habitats, as are predicted under future warmer climate change scenarios, could lead to a large-scale decline in overall duck recruitment and production, and hence a decline in duck populations (Johnson et al. 2005).

Surprisingly, the response of "dabbling" feeders, those which rely on shallow wetlands during the breeding season, varied among species. There is likely an ideal climate under which each species is able to be the most productive. Small, temporary wetlands are the first to disappear during drought conditions, forcing ducks into larger wetlands for feeding. Certain species, such as the blue-winged teal, specifically target seasonal and temporary wetlands during the breeding season. Other species, such as mallards, are more adaptable in their wetland selection. Therefore, the loss of seasonal and temporary wetlands due to drainage and long-term drought conditions would likely have a larger effect on habitat-constrained species such as the blue-winged teal than on more adaptable species.

Other factors which may play a role in the annual variation in the size of eggs are the age of the hen, nutrition limitations or additional stressors during spring migration, and difficult wintering conditions, to name just a few. Variation in interspecific and intraspecific egg sizes has been documented in previous studies (Krapu 1979; Ankney 1980; Birkhead 1985; Rohwer 1986; Hepp et al. 1987); however, the factors which play a role in those variations are not known. Regional variation in egg size of individual species may also exist, due to changes in food resources and genetics. The eggs measured for certain species were often smaller in South Dakota than the average size previously published (Bellrose 1980; Baicich and Harrison 1997).

The greatest hurdles for this research project were the gaps in data both temporally and spatially. Long-term data (eggs and climate) in specific locations were not available. For example, our sample size of eggs from South Dakota was low - only 6% of the total eggs measured for this project. It is unfortunate that so few duck eggs were historically collected for preservation from South Dakota. As part of the Prairie Pothole Region, South Dakota contains some of the most productive habitats for duck populations in the United States. The remoteness and low human population of South Dakota are likely the prevailing factors limiting the number of eggs collected in this state. European settlement of South Dakota officially began in 1851, and was later augmented by the installation of the first railroad tracks in 1877 (Hufstetler and Bedeau 1998). In 1870, only 11,776 people resided in southern Dakota Territory (Hufstetler and Bedeau 1998), the majority of which lived in what is now eastern South Dakota. The railroad line was completed as far as Sioux City, Iowa in 1868, which could help account for the earliest eggs (blue-winged teal, mallard, redhead (*Aythya americana*), and northern shoveler) which were collected nearby in Clay and Lincoln Counties in 1877.

The earliest information about duck eggs acquired in South Dakota was likely not gathered by university-trained scientists, but instead by farmers, ranchers, hunters, doctors, and clergymen. These citizens had a genuine interest in the environment, and spent many hours trudging through prairies and wetlands or climbing trees to acquire eggs and bird specimens. Egg hunting was a very popular hobby for the nation's young men during the late 1800s through the early 1900s. Eggs, nests and birds that were collected either were kept in home display cabinets or were sold commercially. A large percentage of bird and egg collections occurred before binoculars were commonly available, so to get a good look at a bird and identify it, meant you had to shoot it first. Birds were often collected with a "naturalist shotgun" as they flew from the nest (Henderson 2007). As a hobby, egg collecting could be an arduous affair. The collector's mode of travel was often limited to walking, riding horseback or the use of a horse drawn buggy. If they were lucky and could afford the luxury, collectors could take a train or riverboat on long journeys, and then hire a horse drawn buggy for the remainder of the expedition (Raine 1892). Some collectors hired native peoples to collect eggs for them (Raine 1892). Collection activity dropped off in the 1930s, presumably due to the economic depression and the Dust Bowl droughts.

Few eggs have been collected since the implementation of the Migratory Bird Treaty Act, enacted in 1918 with the goal of protecting migratory birds such as ducks and geese from the extreme overharvests which were occurring throughout North America. Collectors are now required to go through a permitting process with state and federal wildlife agencies before they can collect eggs. Technological advances such as automobiles, digital cameras, global positioning systems (GPS), binoculars, spotting scopes, and detailed guide books not only enable more people to enjoy birding, but they also enable identification of the bird without having to collect the birds or their eggs. Currently, few bird or egg specimens are purposely taken for collections. Most are acquired through accidental deaths due to collisions with vehicles or windows, natural deaths due to disease, or predation by domestic pets. Researchers from The Western Foundation of Vertebrate Zoology are still collecting eggs, but at a much reduced number than in the past. Many museums are struggling to maintain funding for preserving and housing the eggs that they already have (Suarez and Tsutsui 2004). Additional egg collections would require more storage space, labor and increased funding. On the other hand, the lack of further collecting of eggs will result in data gaps for future research. We believe that eggs should continue to be collected to provide future generations with a continuous data and reference source. Federal and State guidelines and permits are in place to limit the excessive or illegal overharvest of birds and eggs, not to totally limit the scientific collection and storage of future specimens. None of our research on climate change effects on duck egg size metrics or the earlier efforts on the effects of DDT on egg shell thinning could have been possible without eggs because the samples and metrics needed for these projects could not have been obtained from photo images alone. Considerable effort is still being focused on waterfowl nesting studies in South Dakota as well as in other states and Canadian Provinces. With the advent of new technology, a well-planned coordinated effort by various public and private agencies and educational institutions could assure and sustain a continuous waterfowl egg database that would be available for many types of future research efforts.

We hope our duck egg research stimulates thought about other possible uses of egg collections and of other kinds of specimen collections in museums around the world. By making use of these collections, we pay tribute to those early naturalists for their hard work, perseverance and love of nature. The early collection efforts of various oologists plus the foresight of others to preserve the eggs in some of North America's private and public museums enabled us to conduct a type of time travel research on duck eggs that were collected and preserved as early as 1859.

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LITERATURE CITED

Alley, R.B. 2000. Ice-core evidence of abrupt climate changes. Proceedings of the National Academy of Sciences of the United States of America 97(4): 1331-1334.

Anderson, V.R., and R.T. Alisauskas. 2001. Egg size, body size, locomotion, and feeding performance in captive King eider ducklings. The Condor 103:195-199.

Ankney, C.D. 1980. Egg weight, survival, and growth of Lesser Snow Goose goslings. Journal of Wildlife Management 44:174-182.

Baicich, P.J., and C.J.O. Harrison. 1997. Nests, eggs, and nestlings of North American Birds: Second Edition. Princeton University Press, Princeton, NJ. 347 pp.

Barbraud, C., and H. Weimerskirch. 2001. Emperor penguins and climate change. Nature 411:183-186.

Bellrose, F. C. 1980. Ducks, geese & swans of North America. Stackpole Books, Harrisburg PA. 540pp.

Bethke, R.W., and T.D. Nudds. 1995. Effects of Climate Change and Land Use on Duck Abundance in Canadian Prairie-Parklands. Ecological Applications 5(3):588-600.

Birkhead, M. 1985. Variation in egg quality and composition in the Mallard Anas platyrhynchos. Ibis 127:467-475.

Brown, J.L., S. –H Li, and N. Bhagabati. 1999. Long-term trend toward earlier breeding in an American bird: A response to global warming? Proc. Natl. Acad. Sci. 96:5565-5569.

Burkett, V., and J. Kusler. 2007. Climate change: potential impacts and interactions in wetlands of the United States. Journal of American Water Resources Association 36(2):313-320.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 1999. Drought reconstructions for the continental United States. Journal of Climate 12:1145-1162.

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M., and Stahle, D.W. 2004. “Long-Term Aridity Changes in the Western United States”. Science 306(5698):1015-1018.

Crick, H.Q., and T.H. Sparks. 1999. Climate change related to egg-laying trends. Nature 399:423-424.

Cunningham, D.M., and P.J. Moors. 1994. The decline of rockhopper penguins Eudyptes chrysocome at Campbell Island, Southern Ocean and the influence of rising sea temperatures. Emu 94:27-36.

DeJong, J.R., and K.F. Higgins. 2011. An Evaluation Of Climate Change Effects During The Last 150 Years On The Size Of North American Duck Eggs. Proceedings of the South Dakota Academy of Science 90:33.

Derocher, A.E., N.J. Lunn, and E. Stirling. 2004. Polar Bears in a Warming Climate. Integrative and Comparative Biology 44(2):163-176.

Eldridge, J.L., and G.L. Krapu. 1988. The Influence of Diet Quality on Clutch Size and Laying Pattern in Mallards. The Auk 105:102-110.

Fritts, H.C. 1991. Reconstructing large-scale climatic patterns from tree-ring data. The University of Arizona Press, Tucson, AZ. 340pp.

Gutowski, W.J., G.C. Hegerl, G.J. Holland, R.J. Stouffer, P.J. Webster, M.F. Wehner, F.W. Zwiers, H.E. Brooks, K.A. Emanuel, P.D. Komar, J.P. Kossin, K.E. Kunkel, R. McDonald, G.A. Meehl, and R.J. Trapp. 2008. Causes of Observed Changes in Extremes and Projections of Future Changes. Chapter 3 in Weather and Climate Extremes in a Changing Climate. Regions of Focus North America: Hawaii, Caribbean. Synthesis and Assessment Product 3.3. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Karl, T. R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W. L. Murray eds. Washington, DC. 180pp.

Henderson, C.L. 2007. Oology & Ralph’s Talking Eggs: Bird Conservation Comes Out of Its Shell. University of Texas Press, Austin, TX. 177pp.

Hepp, G.R., D.J. Stangohr, L.A. Baker, and R.A. Kennamer. 1987. Factors affecting variation in the egg and duckling components of Wood Ducks. Auk 104:435-443.

Hoyt, D.F. 1979. Practical Methods of Estimating Volume and Fresh Weight of Bird Eggs. The Auk 96:73-77.

Hufstetler, M., and M. Bedeau. 1998. South Dakota’s Railroads: An Historic Context. South Dakota State Historic Preservation Office. Pierre, SD. 134pp.

Jarvinen, A. 1994. Global warming and egg size of birds. Ecography 17:108-110.

Johnson, W. C., B.V. Millett, T. Gilmanov, R.A. Voldseth, G.R. Guntenspergen, and D.E. Naugle. 2005. Vulnerability of Northern Prairie Wetlands to Climate Change. BioScience 55(10): 863-872.

Jones, P., and M.E. Mann. 2004. Climate over past millennia. Reviews of Geophysics 42 (RG2002):1-42.

Krapu, G.L. 1979. Nutrition of female dabbling ducks during reproduction. Pp. 59-70 in Waterfowl and Wetlands – An Integrated Review. T. A. Bookhout, Ed. Proc. Symp, North Central Section, The Wildl. Soc., Madison, WI.

McNair, D.B., and J.P. Dean. 2003. Distributional information on birds from egg sets collected by Henry Rogers Durkee in 1870 in southwestern Wyoming. Western North American Naturalist 63(3):320-332.

Menzel, A., and N. Estrella. 2001. Pp. 123-137 in "Fingerprints" of Climate Change-Adapted Behaviour and Shifting Species Ranges. Kluwer Academic, New York. Eds Walther, G. -R., Burga, C. A. and P. J. Edwards).

Ornithological Networked Information System (ORNIS). 2011. ORNIS Data Portal. Available at http://www.ornisnet.org [Cited July 2012].

Over, W.H., and C.S. Thoms. 1920. The Birds of South Dakota. The University of South Dakota, Vermillion. South Dakota Geological and Natural History Survey: Series XXI:Bulletin 9. 184pp.

Parmesan, C., N. Ryrholm, C. Stefanescu, J.K. Hill, C.D. Thomas, H. Descimon, B. Huntley, L. Kaila, J. Kullberg, T. Tammaru, W.J. Tennent, J.A. Thomas, and M. Warren. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399: 579-583.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, Available at http://www.R-project.org [Cited July 2012].

Raine, W. 1892. Bird-nesting in North-west Canada. Toronto: Hunter, Rose.

Rhymer, J.M. 1988. The effect of egg size variability on thermo-regulation of Mallard (*Anas platyrhynchos*) offspring and its implications for survival. Oecologia 75:20-24.

Rohwer, F.C. 1986. Composition of Blue-winged Teal eggs in relation to egg size, clutch size, and timing of laying. Condor 88:513-519.

Schliebe, S. 2010. What has been happening to polar bears in recent decades? National Oceanic and Atmospheric Administration. Available at http://www.arctic.noaa.gov/essay_schliebe.html [Cited July 2012].

Suarez, A.V., and N.D. Tsutsui. 2004. The Value of Museum Collections for Research and Society. Bioscience 54:66-74.

Sydeman, W.J., M.M. Hester, J.A. Thayer, F. Gress, P. Martin, and J. Buffa. 2001. Climate change, reproductive performance and diet composition of marine birds in the southern California Current system, 1969-1997. Progress in Oceanography 49:309-329.

Tryjanowski, P. 2002. A long-term comparison of laying date and clutch size in the Red-backed Shrike (Lanius collurio) in Silesia, Southern Poland. Acta Zoologica Academiae Scientiarum Hungaricae 48(2): 101-106.

U. S. Forest Service. 2010. Climate change may impact maple syrup production. USDA Forest Service News Release No. 1022. Washington, D. C.

U.S. Environmental Protection Agency. 2011. Climate change - Health and Environmental Effects. U.S. Environmental Protection Agency. Available at http://www.epa.gov/climatechange/effects/forests.html. [Cited February 2012].

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, , O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389-395.

Table 1. Waterfowl specimens (Family Anatidae) from South Dakota can be located in museums across the United States. The storage locations and information below are from the Ornithological Networked Information System (ORNIS 2011) and may not include all possible storage locations. Some records do not specify the number of eggs in the clutch, and are then signified in the table by the term: Eggs/clutch. If the exact number of specimens could be acquired from ORNIS, that number is listed behind the specimen type in parentheses.

NAME OF MUSEUM	LOCATION OF MUSEUM	SPECIMEN TYPE (NUMBER)
Smithsonian National Museum of Natural History	Washington, D.C.	Eggs (91), Skins (52), Skeletons (11)
Michigan State University	East Lansing, Michigan	Eggs (9), Skeletons(2)
Bell Museum	University of Minnesota	Eggs (11), Skins and /or Skeletons
Field Museum	Chicago, Illinois	Eggs (64), Skins and/or Skeletons
Western Foundation of Vertebrate Zoology	Camarillo, California	Eggs (110), Skins and/or Skeletons
American Museum of Natural History	New York, New York	Eggs (86), Skins (2)
UCLA Dickey Collection	University of California Los Angeles, California	Skin (1)
Humboldt State University	Arcata, California	Skins (7)
Burke Museum of Natural History and Culture	University of Washington Seattle, Washington	Skeletons (3)
Sam Noble Oklahoma Museum of Natural History	University of Oklahoma Norman, Oklahoma	Egg/clutch (1), Skin (1)
Santa Barbara Museum of Natural History	Santa Barbara, California	Skins (2)
Museum of Comparative Zoology at Harvard University	Harvard University Cambridge, Massachusetts	Egg/clutch (1), Skins (34)
University of Kansas Natural History Museum	University of Kansas Lawrence, Kansas	Skins (23), Skeletons (4)
University of Michigan Museum of Zoology	University of Michigan Ann Arbor, Michigan	Skins (45), Skeletons (2)
Delaware Museum of Natural History	Wilmington, Delaware	Skins (7)
Florida Museum of Natural History	Gainesville, Florida	Egg/clutch (3)

Table 2. Duck species and locations of eggs collected from 1877-1922 in South Dakota. Museums are identified by the following acronyms: Western Foundation of Vertebrate Zoology (WFVZ), American Museum of Natural History (AMNH), Field Museum of Natural History (Field), Bell Museum of Natural History (Bell), Smithsonian National Museum of Natural History (NMNH) and Michigan State University (MSU).

COMMON NAME	COUNTY	MUSEUM (NUMBER OF EGGS): YEAR COLLECTED
Blue-winged Teal	Charles Mix	WFVZ (5):1910
	Clay	AMNH (14):1877; Field (1):1879; WFVZ (12):1884 Field (12):Unknown date
	Douglas	Field (2):1893
	Miner	Bell (6):1891; AMNH (11):1891; NMNH (12):1892; WFVZ(11):1913
	Moody	AMNH (2):1882
	Sanborn	WFVZ(12):1922
Mallard	Clay	AMNH (12):1877
	Douglas	Field (2):1893
	Miner	Field (1):1893
Green-winged Teal	Clay	AMNH (9):1880
	Kingsbury	WFVZ (4): 1922
Northern Pintail	Bon Homme	NMNH (7):1893
	Miner	NMNH (9): 1891
Gadwall	Clay	AMNH (7):1888
	Kingsbury	NMNH (11):1894
	Miner	WFVZ (9):1922
Northern Shoveler	Charles Mix	WFVZ (6):1911
	Lincoln	WFVZ (6):1877; AMNH (8):1877
	Miner	NMNH (10):1891: NMNH (9):1892; MSU (9):1893; AMNH (9):1893
	Minnehaha	Field (11):1896
American Wigeon	Kingsbury	WFVZ (5):1922
	Miner	NMNH (9): unknown date
Canvasback	Douglas	WFVZ (2):1893
	Hamlin	NMNH (5):1901
	Miner	WFVZ (8):1888; Bell (5):1890
Ruddy Duck	Kingsbury	Field (12):1922
	Moody	AMNH (13):1882
	Union	Field (3):1891
	Miner	NMNH (10):1892
Redhead	Beadle	WFVZ (7):1885
	Brown	WFVZ (12):1914
	Kingsbury	WFVZ (11):1922; Field (16):1922
	Lincoln	AMNH (9):1877
	Sanborn	Field (4):1892

Table 3. Measurements of eggs from museum collections and field surveys in South Dakota. Published egg sizes (Bellrose 1980; Baicich and Harrison 1997) for comparison are in the last two columns.

COMMON NAME	NUMBER OF EGGS	VOLUME (cm^3) Mean (Min.-Max.)	LENGTH (mm) Mean (Min.-Max.)	WIDTH (mm) Mean (Min.-Max.)	BAICICH AND HARRISON Length x Width (mm)	BELLROSE Length x Width (mm)
Wood duck	121	36.34 (33.50-53.71)	51.15 (47.5-57.9)	38.80 (36.8-43.8)	52 x 40	51.1 x 38.8
Blue-winged Teal	1536	26.22 (19.63-46.5)	46.27 (36.1-56.4)	33.31 (30.4-44.0)	47 x 33	47.1 x 33.9
Mallard	1076	46.87 (29.76-66.91)	55.87 (46.8-65.5)	40.51 (32.5-45.1)	58 x 41	57.8 x 41.6
Northern Pintail	186	38.83 (26.67-45.22)	53.37 (35.1-58.3)	37.74 (34.6-40.9)	54 x 37	53.6 x 38.2
Gadwall	602	41.11 (30.21-51.16)	53.26 (47.9-59.0)	38.88 (34.4-42.3)	54 x 39	55.3 x 39.7
Northern Shoveler	380	37.04 (28.69-67.43)	52.44 (47-60.28)	37.15 (34-47.1)	52 x 37	52.2 x 37
American Wigeon	20	44.78 (37.23-59.55)	55.14 (51.22-62.4)	39.74 (37.75-43.5)	54 x 38	53.9 x 38.3
Redhead	113	58.4 (47.95-68.78)	60.27 (55.85-69.9)	43.55 (40.4-45.39)	61 x 43	60.2 x 43.4
Lesser Scaup	152	45.41 (39.74-53.47)	57.11 (51.3-61)	39.46 (37.3-42.5)	58 x 40	57.1 x 39.7
Canvasback	20	56.67 (50.44-67.35)	59.68 (54.78-62.9)	43.12 (41.39-45.82)	63 x 45	63.7 x 44.6
Ruddy Duck	38	67.26 (54.52-77.65)	62.5 (59.21-66.19)	45.91 (42.49-48.28)	64 x 42	62.3 x 45.6
Green-winged Teal	13	26.65 (23.55-29.84)	46.33 (42.93-49.19)	33.56 (32.39-35.1)	46 x 32	45.8 x 34.2

Table 4. Results from linear regressions of duck egg volume against PDSI values and year of egg collection or measurement. A dash (-) indicates a species with non-significant relationship between egg volume and the independent variable (PDSI Index or Year).

	EGG VOLUME~PDSI INDEX			EGG VOLUME~YEAR		
	Estimate	***P*-value**	R^2	**Estimate**	***P-value***	R^2
Northern Pintail	-0.37	0.003	0.05	-0.02	0.024	0.027
Northern Shoveler	-0.34	3.08e-05	0.05	-0.01	0.027	0.013
American Wigeon	-3.25	0.0001	0.82	0.01	0.001	0.463
Green-winged Teal	1.55	0.016	0.43	0.07	0.016	0.43
Gadwall	-	-	-	-0.01	0.064	0.006
Canvasback	-	-	-	0.39	0.029	0.238
Ruddy Duck	-	-	-	0.12	0.005	0.198
Mallard	-	-	-	-0.04	0.0001	0.014
Blue-winged Teal	2.96e-04	0.0004	0.01	-0.01	0.038	0.003

Table 5. Average egg volumes for each duck species according to PDSI category. A dash (-) indicates the lack of egg metrics data for that PDSI category.

	AVERAGE EGG VOLUME (cm^3) IN EACH PDSI CATEGORY						
	< -2.75	**-2.00 to -2.74**	**-1.25 to -1.99**	**-1.24 to 0.99**	**1.0 to 2.49**	**2.5 to 3.49**	**>3.5**
Northern Pintail	--	--	--	40.62	--	--	38.83
Northern Shoveler	--	55.44	38.00	52.72	52.49	--	52.28
American Wigeon	--	--	--	--	56.34	--	43.66
Green-winged Teal	--	--	--	25.73	28.73	--	--
Gadwall	39.13	--	--	--	44.84	--	41.04
Canvasback	--	--	56.92	54.47	56.91	--	--
Ruddy Duck	--	--	--	66.17	70.16	65.68	--
Mallard	--	--	50.73	59.75	50.00		46.83
Blue-winged Teal	--	--	--	45.47	47.13	47.36	46.25
Redhead	--	--	--	57.73	59.22	59.35	57.90
Lesser scaup	--	--	--	--	--	--	45.41
Wood duck	--	--	--	---	--	--	36.34