An Overview of the International Beaver Ecology and Management Workshop

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ABSTRACT On 9–12 October 2007, the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (WS) hosted the International Beaver Ecology and Management Workshop in Chandler, Arizona. The workshop was jointly sponsored by the Multi-City Sub-Regional Operations Group (SROG), Tres Rios Ecosystem Restoration and Flood Control Project and WS. The SROG management is comprised of representatives from the cities of Phoenix, Mesa, Glendale, Scottsdale, and Tempe. The workshop emphasized the management of beaver, their ecology, the part they play as a keystone species, and the issues they cause as an invasive species outside of the United States. The workshop began with a keynote address by Dr. Dale Arner on "Historical, economical, and ecological aspects of beaver restoration and management." The keynote address was followed by a session on beaver ecology throughout North America. The workshop participants were updated by several papers on "Developing Research Tools" wherein the latest advances in technology were presented. The 2nd day of the workshop began with a 2nd keynote address by Dr. Dietland Müller-Schwarze, "Knowing beaver behavior as a basis for good management." In North America, the perceived values of beaver range from negative (causing extensive damage) to positive (ecosystem engineer that promotes biological diversity); while attitudes towards beaver in South America may be more strongly negative as beaver are an invasive species that destroys native biodiversity. To address beaver damage, several papers addressed the use of individual beaver management techniques, cooperative programs, and changing beaver behavior. The workshop ended with the challenges and successes in developing population genetic models for beavers. Beaver management continues to be a worldwide affair with a number of success stories and a number of questions remaining to be answered. The workshop was well attended with 75 registrants representing 5 countries and 16 states.

KEY WORDS beaver, biological diversity, Canada, *Castor canadensis*, ecosystem engineer, management, North America, nuisance, South America

North American beaver (*Castor canadensis*), hereafter beaver(s), are ingrained in Native American culture in North America along with the wolf (*Canis lupus*), bison (*Bison bison*), and bald eagle (*Haliaeetus leucocephalus*). They also are a significant part of the culture of European settlers in North American as their images are found on coins, flags, and historical roadside markers. The quest for beaver pelts almost extirpated the species from North America in the 19th century; however, the conservation efforts of the 20th century that led to their recovery provide one of the greatest success stories in modern wildlife management. Despite their historical significance in North America, comparatively little scientific research has been published on beaver compared to other, perhaps more charismatic species. For example, in a simple search using scientific names in Scopus, July 2009, we found 426 articles containing "*Castor canadensis*" compared to 3,300 articles for "*Cervus elaphus*"; 2,147 for "*Odocoileus virginianus*"; and 1,637 for "*Canis lupus*". Additionally, we found only one book (Müller-Schwarze and Sun 2003) and one published proceedings (Busher and Dzięciołowski 1999) summarizing beaver research.

Throughout North America, management for beaver ranges from reintroduction of individuals for wetland restoration to lethal removal of individuals causing damage. Introduced North American beaver in Europe, along with their congener European beaver (*Castor fiber*), are managed similarly. Introduced beaver in South America are considered unwanted, exotic species that are destroying native diversity at an alarming rate. Where beaver cause damage at the human-wildlife interface, they are often referred to as nuisance beaver. Where their damming efforts are desirable, they are referred to as ecosystem engineers. Because of the competing values associated with beaver and the large number of laws, regulations, and opinions guiding their management or lack thereof, we felt it necessary to bring natural resource managers and policy makers together to discuss current and future beaver research and management topics.

On 9–12 October 2007, the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (WS) hosted the International Beaver Ecology and Management Workshop in Chandler, Arizona to exchange knowledge of current beaver management and research and to highlight work conducted on Tres Rios Ecosystem Restoration and Flood Control Project (see Taylor et al. 2008). The workshop was jointly sponsored by the Multi-City Sub-Regional Operations Group (SROG), Tres Rios Ecosystem Restoration and Flood Control Project, and WS. SROG management is comprised of representatives from the cities of Phoenix, Mesa, Glendale, Scottsdale, and Tempe. The workshop was well attended with 75 registrants. Thirty-four presentations were delivered including keynote addresses by 2 well-known beaver researchers: Dr. Dale Arner and Dr. Dietland Müller-Schwarze. Presenters and audience members represented local, state, federal, and provincial governments; non-profit organizations; and academia from 5 countries and 16 states.

In this paper, we summarize the key points of the presentations delivered at the workshop. Where research presented at the workshop has since been published, we refer to cited results accordingly. However, in the absence of published work, we have refrained from listing specific data of others presented at the workshop. Thus, our discussion of their presentations is limited to the general context of their abstracts. Presentations were given in the following sessions: beaver ecology; developing research tools; beaver biology and behavior; beaver as an invasive species; management; and genetics.

BEAVER ECOLOGY

Beaver are often referred to as wetland engineers because of their ability to create and maintain standing water through dam building. They also are described as a keystone species because of their significant impact on ecosystem structure and function. The wetlands created by beaver are well documented as habitat for other vertebrates. One speaker described the positive ecological value that beaver ponds have on bird diversity in the southeastern United States. In a study conducted on 5 paired sites in Mississippi, she reported that beaver wetlands supported more birds with declining populations and higher Partners in Flight conservation concern scores, and that their cumulative conservation value was 4-fold higher than that of birds in adjacent upland habitat. Another speaker described how beaver wetlands in the southeastern United States provide quality nesting, brood-rearing, foraging, resting, and roosting habitat for dabbling and perching ducks. He went on the describe how proper management of these wetlands through water control, planting, and selective tree harvesting can further improve habitat conditions for waterfowl throughout their annual cycle.

While reports of avian use of wetlands are found readily among published beaver literature, fewer studies have examined the influence of habitat modification by beaver on herpetofauna. One presenter reported significant reptile and amphibian use of permanent (i.e., swamps) and ephemeral (i.e., pools) wetlands created by beaver in the Interior Flatwoods Physiographic Region of Mississippi. She submitted that identification and protection of these areas may be necessary to promote diversity of herpetofauna on public lands in this region.

Beaver wetlands also promote habitat for other mammals. In the southeastern United States, beaver flooding and gnawing activity promote cavity formation in trees such as baldcypress (*Taxodium distichum*), sweetgum (*Liquidambar styraciflua*), and black tupelo (*Nyssa sylvatica*), which provide maternal and overwinter roost sites for at least 6 species of bats. These wetlands also support abundant flying insect communities and surface water for bat foraging and drinking. In a study conducted on 1,100 ha of bottomland hardwood forests on a national wildlife refuge in northeastern Mississippi, one presenter documented that bats used 12% of cavity trees surveyed. Included were 2 species of concern: Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and southeastern myotis (*Myotis austroriparius*).

Research studies have demonstrated both positive and negative effects that beaver dams have on fish assemblages. Effects vary with numerous physical factors and the fish species involved. In the Pacific Northwest, management efforts to promote federally threatened coho salmon (*Oncorhyncus kisutch*) recovery include management of complex in-stream habitats which beaver provide through dam building. Two speakers from a northwestern state department of fisheries and wildlife delivered presentations within the ecology section. The first spoke of the plans to increase public awareness, provide leadership and strategic direction, and secure funding to increase the beneficial effects of beaver in appropriate areas within the state. The second speaker presented the results of a model used to delineate beaver habitat based on aquatic habitat inventory data. His preliminary results indicated that some metrics captured in the inventory can be useful in predicting beaver presence. Furthermore, he recorded that beaver in this region can be grouped as 1) those that build dams in smaller streams and 2) those that occupy larger streams, forgo dam construction, and live in bank dens. He submitted that future research, restoration attempts, and development of management plans should recognize the impacts of these behavioral differences.

Beaver population growth is influenced by many factors. One presenter reported the results of a 6-year study comparing the ecology of beaver on 2 distinct study sites: riverine habitat in central Illinois and forested wetland complexes of southern Illinois. Based on over 600 captures and over 160 radio-tagged beavers, he reported density of both studied populations was at or near biological carrying capacity, and noted similarities among natality and causes of mortality. He reported differences among age-specific survival, seasonal home range size, and dispersal rates and distances.

Timber harvest practices can influence habitat conditions which affect beaver habitat quality and use. One presenter described how timber management guidelines in Ontario, Canada restrict timber harvest around water bodies to protect water quality and fish habitat, and how these doughnut-shaped forests may become dominated by conifers or shade tolerant hardwoods, thus reducing habitat quality for beavers. He presented a model to predict colony longevity based on the amount of shoreline adjacent to colonies that is clearcut.

DEVELOPING RESEARCH TOOLS

Radio telemetry has been used to monitor survival and movement of beaver; however, data collection has been hampered by the inability to keep external transmitters on individuals and the short range of internal transmitters. One presenter discussed a study which found modified ear-tag transmitters fitted with plastic sleeves were retained 3-times longer than previously reported (Arjo et al. 2008). She went on to report that the addition of a neoprene washer to the design increased retention time in the field by 89% (Arjo et al. 2008). This improvement to existing technology will allow researchers to monitor beaver for longer periods, thus utilizing more battery life and decreasing the need for frequent recapture to remark individuals.

Immobilizing and achieving anesthesia in beaver is necessary for certain field procedures, such as attaching or implanting radio transmitters. Two presenters discussed studies which evaluated immobilizing agents for anesthetizing beaver. The first evaluated Telazol® (tiletamine hydrolchloride and zolazepam hydrochloride) and found it effective for immobilizing beaver in the field with a mean induction time <5 minutes, although mean release time (129.5 min, SE = 11.3) was long (Swafford 2002). The presenter cautioned those using Telazol on beaver to be patient during the recovery period and not to release beaver too early. The second presenter on chemical immobilization discussed results of a study comparing 12 injectable anesthetic protocols and 6 reversal agent protocols using various doses of ketamine/xylazine, ketamine/medetomidine, ketamine/acepromazine, tiletamine/zolazepam, yohimbine, and atipamazole. He reported observing variable differences in physiological parameters and found ketamine/medetomidine was 100% and 88% predictable for high and medium dosage rates, respectively. He recommended using ketamine/medetomidine for injectable anesthesia and recommended reversal using atipamazole.

BEAVER BIOLOGY AND BEHAVIOR

Classic beaver literature suggests that beaver are monogamous and colonies consist of an adult pair and their first-order relatives. One presenter in this session found extra-pair mating between members of neighboring colonies and documented multiple paternity in 5 of 9 (56%) litters sampled in Illinois (Crawford et al. 2008). They found colonies composed primarily of 1st- and 2nd-order relatives but also found unrelated individuals in colonies (Crawford et al. 2008). Their findings shed new light on the classic literature and indicate that polygamy occurs in beaver populations and that colonies vary widely in composition.

Another study looked at beaver demographics in the southeastern United States. Data from 562 beaver collected in 7 states (AL, GA, MS, NC, SC, TN, and VA) were grouped by physiographic region (Mississippi alluvial valley, piedmont, and coastal plain) and age (1, 2, 3, 4, and >4 year-old). Colonies from all regions primarily consisted of 1, 2, and >4 year-old individuals. By weight and 3 morphometric measurements, beaver from the Mississippi alluvial valley were larger than those from other regions.

The final presentation in this session described beaver movement and behavior on a wetland restoration site in suburban Phoenix, Arizona. In this study, 43 adult beavers (31 females and 12 males) were captured, radio-marked, and monitored along a 14-km stretch located along the confluence of the Salt, Gila, and Agua Fria

Rivers. Only 2 individuals dispersed from the study site and these movements occurred during a major flood event. Beaver moved along the linear water course and mean movements of females from fall 2004 through summer 2007 were slightly greater than males. Mean beaver movement differed by age class with 1 year-olds moving farther than 2 year-olds and 3+ year-olds. All movements were shorter and less frequent from April through September. The presenter also noted the observation of multiple lactating females sharing communal den sites during kit-rearing periods (Fischer et al. *in press*; see genetics section below).

BEAVER AS AN INVASIVE SPECIES

As beavers were relocated across North America in the 1940s, they also were introduced to the Tierra del Fuego archipelago in the countries of Argentina and Chile in 1946 (Silva and Saavedra 2008). One presenter from this region described the history of beaver invasion and the impacts beaver have had on native biological diversity. She noted that the original 25 pairs of beaver have expanded to approximately 100,000 individuals and beaver have reached the main continent. Throughout their path, they have altered terrestrial and aquatic ecosystems through foraging and flooding. Their damage and destruction have transformed lotic into lentic systems, opened forest canopies, and altered soil fertility. The consequences have been restructuring of the vegetative communities, which has had cascading effects on native invertebrates and vertebrates. These alterations have provided suitable habitat for exploitation by other exotic species, such as muskrat (*Ondatra zibethicus*) and trout (*Salmo trutta*).

A second speaker from this region discussed the history of beaver management in Tierra del Fuego and efforts to eradicate beaver from the archipelago and the mainland. She described failed attempts to reduce beaver numbers through economic incentives and the pending ecological disaster following further expansion of beaver throughout continental South America. Faced with this threat, governments from Argentina and Chile convened 2 international workshops. From these workshops, a bi-national strategy for beaver eradication was agreed upon to address and correct the threat to biodiversity in South America.

Within the same timeframe that beaver were introduced into Tierra del Fuego, nutria (*Myocastor coypus*) from South America were introduced into several states in North America. One place where nutria were released and established was Maryland's Eastern Shore of the Chesapeake Bay. By the 1970s, feral populations of nutria were estimated in the tens of thousands and it was hypothesized their habitat use was destroying the marsh ecosystem. Their role in marsh erosion was confirmed in the 1990s and a program to eradicate nutria from the Delmarva Peninsula was initiated in 2002. The final presentation given in the invasive species session described this ongoing program to eradicate nutria, as it may be applicable to eradication of North American beaver in South America.

MANAGEMENT

The management session was the largest of the workshop and presentations ranged from hands-on demonstrations of trapping techniques to WS state program overviews to scientific research studies. The first presenter in this session discussed the tools and techniques used in trapping beaver and described in detail how improvements and modifications have been made over time to increase capture efficiency and improve animal welfare. He did an excellent job of describing how trapping terms and nomenclature are misused. For example, many trap models are mistakenly referred to as "Conibears" when they should be described by their specific manufacturer and model or in the group of "body-gripping traps". Cable devices also are mistakenly called snares which connote death by strangulation, when in fact cable devices can be used to safely live-capture individual animals. His presentation included demonstrations of specific tools and allowed audience members to interact.

The next 3 presentations described WS perspectives on beaver management in 3 regions of North America. The first described an overview of beaver management programs in the southeastern United States. In general, beaver populations were nearly extirpated throughout the Southeast by the turn of the 20th century. Following successful restoration efforts in the 1940s and '50s, beaver populations increased and recreational trapping for beaver pelts was popular. With decreasing fur prices and sport harvest, complaints about beaver damage have increased significantly with increased urbanization and human population growth. Sources of complaints include damage to property, highways, bridges, timber, and agriculture. Public demand for assistance has led to several approaches to reduce beaver damage. The first presenter gave an overview of techniques used in the Southeast. He described the failure of some approaches, such as attempts at local eradication and offering paid bounties for beaver capture to reduce problems. He went on to discuss multi-agency cooperative programs that are successful in reducing damage by beaver. These programs are made up of several state, federal, and private organizations which collectively aim to reduce human-wildlife conflicts.

The next presenter gave an overview of a cooperative multi-organization beaver management plan to protect coldwater ecosystems in a midwestern state. In Wisconsin, brook trout (*Salvelinus fontinalis*) are found in cold streams with very low gradient which can be negatively affected by beaver dams. Specifically the dams alter soil and water conditions, silt spawning areas, and block trout movement. He discussed unsuccessful early beaver management programs which included trapping and dam removal by contract trappers, allowing more liberal beaver harvests on classic trout streams, trapping by Wisconsin Department of Natural Resources and United State Forest Service personnel, and beaver subsidy payment programs (i.e., bounty harvest). He went on to describe how this cooperative program has benefitted the coexistence of trout, beaver, and humans over a large area in Wisconsin.

Understanding the history of beaver management is important in designing and implementing current and future management plans. Beaver are widely distributed in Arizona but are not overabundant in any area in the state. One presenter gave an overview of the history of beaver management in Arizona dating back to the mid-1820s (see Carrillo et al. 2009).

Removal or partial removal of beaver dams is a necessary tool used by natural resource managers. Hand removal of dams is labor intensive and the effects can be short-term, as small-scale dam breaches are often repaired overnight. Explosives are an efficient, cost effective, and safe tool for removing dams when used properly. Explosives can be used to reduce one or more complex dams simultaneously or to strategically place small breaches to place water control structures. In 1988, WS implemented a nationwide explosives use and safety program centered around standardized, application-specific training and certification requirements for WS explosives specialists. One speaker described this program, how it represents a model federal explosives safety and compliance program, and how it has led to certification of 225 explosives specialists in 26 states.

Several tools and techniques have been used for nonlethal control of beaver including repellents, physical barriers, and habitat modification; however, few studies have used a scientific design to evaluate their efficacy. Nolte et al. (2003) reported the feasibility of nonlethal approaches used to protect a wetland restoration site in Arizona. They compared treatments established in the water and on land, including an electronic frightening device, an electro-shocking device (water only), a textural repellent (land only), and fencing. The results were presented in this workshop, concluding that fencing was the only absolute measure for preventing herbivory by beaver in this study. Because fencing can be very expensive to install and maintain, managers must weigh the cost-benefits of this technique.

Human manipulation of water levels at beaver dams in North America can be traced back to at least the 1920s where Bailey (1927) used a 3-log drain to control water. With the resurgence of beaver later in the 20th century, Arner (1963) modified the 3-log drain concept to seasonally control water for increased production of waterfowl forage in beaver ponds. These devices were installed in June and July, and removed in October. More recently, controlling the flow of water through a beaver dam was made popular in 1989 by the development of the Clemson Beaver Pond Leveler by Dr. Gene Wood at Clemson University (Wood et al. 1992). The usefulness of the device has expanded from controlling water at dams to controlling water in other areas such as culverts at road crossings, and modifications have been made to allow fish passage (Close 2003). Nolte et al. (2000) found that management objectives associated with Clemson pond levelers were closely correlated with owner satisfaction. That is, devices installed to manage wetland for waterfowl habitat were generally considered successful while devices installed to provide water relief through perpetual flow were less successful (Nolte et al. 2000). Furthermore, Nolte et al. (2000) found that levelers placed in sites with high beaver activity in the absence of beaver removal, frequently failed. Another presenter in this session provided information on the Clemson Beaver Pond Leveler II. The design still minimizes the probability that currents of water flowing into the intake device can be detected by beaver; however, it is reportedly more user-friendly and less expensive.

In addition to Clemson Beaver Pond Levelers, several other coined names represent nonlethal tools to reduce beaver damage: Broad Brook Leveler, Cylindrical Fence System, Flexible Leveler, Trapezoidal Fence System, Cage Leveler, Beaver Deceiver, Pre-Dam, Beaver Baffler, Caster Master, and others. These tools either control water flow, obstruct beaver from an outlet such as a culvert, or provide a combination of the two. Two presenters from the Humane Society of the United States shared overviews of programs which utilized water flow control devices to alleviate beaver flooding problems. The first presenter discussed programs in Connecticut and Massachusetts, while the second presenter reported successful use of flow devices in the Coastal Plain of Virginia.

Conditioning beaver to avoid preferred food plants has been tested with little success (Harper et al. 2005). The final presentation in the management session discussed the results of a series of pen studies designed to evaluate beaver feeding responses to invasive saltcedar (*Tamarix* spp.) secondary metabolites. Kimball and Perry (2008) theorized that saltcedar palatability could be improved by topical application of fructose and polyethylene glycol, while palatability of desirable plants such as cottonwood (*Populus balsamifera*) and willow (*Salix scouleriana*) could be reduced by application of a repellent. They found that casein hydrolysate treatment of desirable riparian plants may promote beaver foraging of invasive tamarisk (Kimball and Perry 2008).

GENETICS

The final and smallest session within the workshop dealt with the emerging interest in population genetics of beaver. As discussed in the beaver biology and behavior session, genetics techniques were recently used by Crawford et al. (2008) to document polygamy in beavers. Simultaneous to Crawford et al.'s study, Pelz-Serrano et al. (2009) used genetic techniques for development of 9 new microsatellite loci for North American beaver. They found all loci were polymorphic except one, and average heterozygosity ranged from 0.13 to 0.86 per locus (Pelz-Serrano et al. 2009). These markers will be useful in future studies of the ecology and behavior of beavers.

Another presenter in this session described the population structure of beavers along the convergence zone of the Agua Fria, Gila, and Salt Rivers in Phoenix, Arizona. Using mitochondrial DNA sequences of the cytochrome b gene, she found the population came from a single maternal lineage. Combined with radio-telemetry data (see beaver biology and behavior section), genetic analyses revealed that multiple lactating females sharing communal dens were first-order relatives (Fisher et al. *in press*). These results challenge the traditional dogma of beaver colony composition and lead the way to future studies to gain new knowledge of beaver behavior.

DISCUSSION

To our knowledge this is the first time since the Euro-American Mammal Congress in 1998 that an international group has formed to discuss beaver research and management (see Busher and Dzięciołowski 1999). It was evident from the discussions at our workshop that new knowledge is emerging with respect to beaver ecology; developing research tools; biology and behavior; beaver as an invasive species; management; and genetics; however, research seems to be localized and unconnected. Furthermore, some results are not published because findings are anecdotal or ancillary. While management activities appear successful in reducing human-beaver conflicts, more research is needed to evaluate their efficacy. For example, the efficacy of a device to prevent blockage of a culvert cannot focus on the culvert alone, but must include the possible effects of beavers damming up- and downstream. One also must consider that a tool or technique that reduces damage in one area (e.g., watershed, state, region) may not be effective in others, as environmental factors and social values differ markedly between areas. For example, beaver management which benefits trout survival in the Midwest may not have the same effect with all fish assemblages in all physiographic regions.

Collaboration among groups interested in beaver research can expand the spatial scale at which studies are conducted and combine resources to explore multiple research hypotheses. One outlet to expand collaboration is through the National Wildlife Research Center's (NWRC) project management system (Bruggers et al. 2002). The NWRC project titled "Defining Impacts and Developing Strategies to Reduce Mammalian Damage in Forested and

Riparian Ecosystems" is stationed in Olympia, Washington but has the capacity to conduct national and international research. Since the workshop, WS has formed a beaver working group to address research needs across North America. The working group is planning multi-state research studies to develop and evaluate tools and techniques to reduce impacts by beavers based on cooperator input and prioritized by research needs. Research studies will be conducted collaboratively with WS operations and NWRC. Other researchers from academia, state government agencies, and federal government programs also are involved in research studies with the Olympia Field Station to determine impacts of beaver on roads, forests, and streams, and to evaluate tools and strategies to reduce damage.

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