Wetland issues affecting waterfowl conservation in North America

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Abstract

This paper summarises discussions by invited speakers during a special session at the 6th North American Duck Symposium on wetland issues that affect waterfowl, highlighting current ecosystem challenges and opportunities for the conservation of waterfowl in North America. Climate change, invasive species, U.S. agricultural policy (which can encourage wetland drainage and the expansion of row-crop agriculture into grasslands), cost and competition for water rights, and wetland management for non-waterfowl species were all considered to pose significant threats to waterfowl populations in the near future. Waterfowl populations were found to be faced with significant threats in several regions, including: the Central Valley of California, the

Playa Lakes Region of the south-central U.S., the Prairie Pothole Region of the northern U.S. and western and central Canada, the boreal forest of northern Canada, the Great Lakes region and Latin America. Apart from direct and indirect threats to habitat, presenters identified that accurate and current data on the location, distribution and diversity of wetlands are needed by waterfowl managers, environmental planners and regulatory agencies to ensure focussed, targeted and cost-effective wetland conservation. Although populations of many waterfowl species are currently at or above long-term average numbers, these populations are thought to be at risk of decline in the near future because of ongoing and predicted nesting habitat loss and wetland destruction in many areas of North America.

Key words: agriculture, climate change, dabbling duck, national wetlands inventory, playa, policy, prairie pothole.

To the casual observer, it might seem that wetland-dependent wildlife face few conservation issues at present in North America. Dahl (2006) showed a 0.3% gain in deepwater and wetland area in the continental United States (*i.e.* excepting Alaska and Hawaii) between 1998 and 2004. During the early 21st century, numbers of breeding ducks have remained at or above their long-term average population estimates, and populations of several species (*e.g.* Blue-winged Teal *Anas discors* and Northern Shoveler *A. clypeata*) are at all-time highs (USFWS 2013). Even Lesser Scaup *Aythya affinis* and Northern Pintail *Anas acuta* populations have reversed historical declines and seem to be steady or increasing in number. The abundance of ponds and wetlands containing water in May (*i.e.* "May ponds") in breeding areas surveyed annually by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service, which serves as an indicator of wetland habitat availability and waterfowl productivity, was 42% above the long-term average in summer 2013. Breeding populations and also the number of May ponds appear to be near or above levels observed in the early 1970s and late 1990s, both periods thought to be the "good old days" by waterfowl conservationists (Vrtiska *et al.* 2013). Moreover, waterfowl hunting regulations have remained liberal since the introduction of the Adaptive Harvest Management programme in 1995, allowing for maximum take (regulated by bag limits) of most species (Nichols *et al.* 2007; Vrtiska *et al.* 2013).

Despite currently large waterfowl population sizes, many threats loom that cause informed wetland and waterfowl conservationists to worry about the future. Dahl (2011) documented a loss in wetland area and only modest gains in the number of all wetlands and deepwater habitats combined during 2004–2009. Additionally, losses in vegetated wetlands have been largely offset by gains in agricultural and urban ponds and other non-vegetated wetlands, which likely are of less value to waterfowl, other waterbirds and other wildlife (Weller & Fredrickson 1974; Dahl

2011). Also of concern is that wetland losses have not been evenly distributed among regions and systems; for instance, losses in the Prairie Pothole Region and the lower Mississippi Alluvial Valley, which provide some of the most important habitat for breeding and wintering waterfowl in North America, have been more pronounced than in other regions (Dahl 2011; Johnston 2013). Unfortunately, we can expect that current May pond abundance and waterfowl breeding population size are facing probable declines in the future (Johnson *et al.* 2010; Johnston 2013). Agricultural policies that have long provided some protection for geographically-isolated wetlands through the "Swampbuster" provision in the U.S. Farm Bill now contain reduced or increasingly ineffective conservation provisions. Incentive-based wetland restoration, creation and protection programmes also face declining funding or elimination. Furthermore, mandates for ethanol production (*i.e.* the Renewable Fuels Standard) coupled with crop insurance policies have provided incentives for wetland drainage in the U.S. Great Plains (Reynolds *et al.* 2006; Johnston 2013). Reductions in federal spending and relatively high waterfowl populations may dissuade policy makers from prioritising wetland conservation policies in future Farm Bills. For these and many other reasons that will be highlighted subsequently, we deemed it necessary to convene a forum where scientists and conservation leaders could discuss current wetland policy and management issues that may affect waterfowl conservation efforts in the near future.

Recognising the ongoing and increasingly significant threats to wetlands and wetland wildlife, the Wetlands Working Group of the Wildlife Society held a special session at the 6th North American Duck Symposium – "Ecology and Conservation of North American Waterfowl", to describe and summarise issues affecting wetland conservation relating to waterfowl in North America. Here we present topics discussed at this session and provide an overview of current wetland issues affecting waterfowl conservation in North America. Our objectives are to: 1) outline the growing threats to wetlands and waterfowl in North America, 2) generally highlight current research and management that addresses these issues, and 3) provide recommendations for future actions that may benefit wetland and waterfowl conservation in North America.

Wetland policy

The United States

In the minds of biologists, hunters and the general public, waterfowl are stereotypically and appropriately linked to wetlands and other aquatic habitats. Yet, while the waterfowl management and scientific community has dedicated substantial resources to population and habitat management, there has been much less effort devoted to providing the scientific foundation for securing policies that maintain wetland habitats. The success or failure of these policies in maintaining the continent's wetland habitats will ultimately determine the level of success achievable by waterfowl conservationists.

The series of wetland status and trends reports produced by the United States Fish and Wildlife Service (USFWS) from the mid-1950s through to 2009 provides evidence of the impact of policies on wetlands in the U.S. The first report, examining the mid-1950s to the mid-1970s (Frayer *et al.* 1983), documented a loss of 113 million acres (*c.* 46 million ha) of wetlands with net losses approaching a half-million acres (*c.* 202,000 ha) annually. However, implementation of the Clean Water Act (CWA) in the mid-1970s provided some degree of federal protection to most wetlands, including the prairie potholes of the north-central United States and Canada, a key region for waterfowl production. The status and trends report for the mid-1970s to the mid-1980s (Dahl & Johnson 1991) documented a slowing of the national rate of net wetland loss to approximately one-third of pre-CWA rates. In 1985, the Swampbuster provision of the federal U.S. Farm Bill, which stopped agricultural subsidy payments to landowners who drained wetlands for farming (Dahl 2011; Johnston 2013), added another critical layer of protection to many wetlands at risk of being drained for agricultural uses.

To complement the regulatory protections of the Clean Water Act and disincentives of Swampbuster, voluntary incentive-based wetland conservation programmes such as the Wetland Reserve Program, the North American Wetlands Conservation Act, the Conservation Reserve Program and the USFWS Partners for the Fish and Wildlife Program were established in the late 1980s and 1990s. Concurrently, regulatory deceleration of wetland losses and the incentives towards maintaining and restoring wetlands were reflected in a net rate of loss 79% lower than that of the 1950s–1970s (Dahl 2000). The trend of increasing broad and protective wetland policies continued through the early 1990s, and by 2004 the net loss rate of wetlands most important to waterfowl and other wildlife had declined to approximately 80,000 acres (*c.* 32,000 ha) per year (Dahl 2006).

However, the tide of wetland conservation policy turned in 2001 with the U.S. Supreme Court in favour of the Solid Waste Agency of Northern Cook County's (SWANCC) appeal against the presence of migratory birds being used as the sole determinant for the U.S. Army Corps of Engineers' (USACE) jurisdiction over waters of the United States (SWANCC *versus* USACE). The Supreme Court's decision greatly narrowed the perceived jurisdiction of the Corps to regulate the drainage and infilling of wetlands not adjacent to open and clearly navigable waters (Dahl 2011). In response, the U.S. Environmental Protection Agency and USACE withdrew federal Clean Water Act protections from broad swaths of wetland categories, including so-called "geographically isolated wetlands" such as the prairie potholes, rainwater basins and playa wetlands of the Great Plains (Haukos & Smith 2003). At the same time, funding for many of the incentive-based conservation programmes peaked and has since declined.

The findings of the most recent assessment of wetland status and trends (Dahl 2011) mirrored this shift in conservation policy. For the first time in 50 years, wetland loss accelerated, increasing by 140% compared with 1998–2004. Policy-based funding for wetland conservation programmes has continued to decline, and changes to Farm Bill policy place *c.* 1.4 million wetlands in the Prairie Pothole Region of North and South Dakota at high risk of being drained and lost (Reynolds *et al.* 2006).

Canada

In the Prairie Pothole Region of Canada, wetlands represent a significant obstacle to production agriculture. As a result, wetland drainage continues to occur despite growing evidence of ecological goods and services that wetlands provide, including flood protection, carbon storage and groundwater recharge (Millar 1989). The jurisdiction for Canadian wetland policy resides at the provincial level (Rubec *et al.* 1998). As a result, effective policies that protect existing wetlands must be developed for each provincial jurisdiction if wetlands across Canadian landscapes important to waterfowl, such as the Prairie Pothole Region, are to be protected effectively.

High commodity prices and several years of above normal precipitation have resulted in high rates of wetland drainage to facilitate increased areas being put to agricultural production across the Prairie Pothole Region. For example, Ducks Unlimited Canada recently estimated that in Saskatchewan alone > 6,000 ha of wetlands were being drained on an annual basis (Ducks Unlimited Canada, unpubl. data). When contemporary cost estimates for wetland restoration are applied, the costs of restoring those drained wetlands would be > US$65 million. This rate of wetland loss makes maintaining an adequate wetland base to support healthy populations of breeding ducks impossible without wetland regulations that reduce loss rates.

In Alberta, implementation of a new wetland policy provides some wetland protection and requires mitigation at a ratio determined by the value of the affected wetland. However, although the new policy is largely enforced for developers and the energy sector, it is not applied consistently to agriculture (S. Stephens, pers. comm.). In Saskatchewan, policy prohibits the drainage of water from wetlands from an individual's property onto another landowner; however, these regulations have been poorly enforced, resulting in conflicts between neighbouring producers and significant unauthorised drainage across Saskatchewan. In Manitoba, existing policy protects semi-permanent and permanent ponds and lakes (Stewart & Kantrud 1971), but shallower and more ephemeral wetlands remain unprotected from drainage.

Given the different stages of progress on and viewpoints regarding wetland policy amongst the three provincial governments spanning prairie Canada, unique strategies for improving wetland policy and subsequent enforcement of regulations require diverse and nuanced approaches for each province. Currently, conservation advocates such as Ducks Unlimited Canada pursue strategies such as building a network of grassroots advocates and developing an understanding of how best to engage with those grassroots advocates in the process, providing support to affected landowners, building coalitions with agricultural industry groups around support for wetland policy, building stronger relationships with provincial staff and ministers in key ministries, developing new science to support the economic and ecological case for wetland regulation and developing a wetland monitoring system to facilitate measuring the impact of new wetland policies or lack thereof.

Latin America

Latin American countries have only relatively recently come to recognise the importance and value of their wetlands and begun to focus more attention on wetland conservation. In this region, earlier public policy efforts directed at natural resource conservation focused primarily on establishing systems of state and federal protected areas, but wetland protection was not usually a driving force behind site designations. As a result, past wetland conservation tended to be largely coincidental.

More recently, the Ramsar Convention's initiative to identify and protect Wetlands of International Importance ("Ramsar Sites") has become an important mechanism for promoting explicit recognition of the importance of wetlands and has focussed additional attention on wetland conservation in Latin America. In countries including Mexico, Colombia, Venezuela, Argentina, Chile and Brazil, government interest in the designation of Ramsar Sites has been responsible for spurring the development of national wetlands inventories and classification systems. For example, Mexico has made considerable progress in recording and classifying habitats across the entire country, with an explicit emphasis and priority being placed on regions with significant wetlands. Once in place, these inventories may prove useful as the foundation for promoting subsequent conservation activities by local, state and federal governmental entities, as well as non-governmental conservation organisations. Additionally, inventories provide guidance to outside funding institutions that can help target the allocation of resources to places and activities that can generate the greatest conservation return for their investment.

To optimise wetland and waterfowl conservation in the Latin American and Caribbean region, these nations and funding organisations should consider directing significant public policy effort toward the development of national conservation plans that include wetlands inventory data. These conservation plans should identify the most important habitats, provide information regarding the most significant site-specific conservation challenges, and propose pragmatic actions and policies that will need to be implemented to ensure long-term conservation and sustainable use of these wetlands and other wildlife habitats. The continued loss and degradation of many important wetland ecosystems, despite the existence of various international agreements and national policies, underscores the importance of developing realistic but effective conservation plans that involve and acknowledge the needs of all stakeholders in Latin America.

Important wetlands at-risk

Playa wetlands

Playas are dynamic, small, recharge wetlands located in the High Plains region of the western Great Plains in the central U.S. With ecological conditions that reflect the harsh, unpredictable environment of the High Plains, playas form a complex system providing numerous ecological functions and services, including habitat for migratory waterfowl (Haukos & Smith 1994). Essential to playa function is the erratic fluctuation between wet and dry states that creates a diversity of playa conditions or habitats throughout the entire High Plains (Smith *et al.* 2012). Inundation patterns and hydroperiods of playas vary annually with the average playa being inundated during January once every eleven years in Texas and New Mexico (Johnson *et al.* 2011a).

Playas provide habitat for migrating, wintering and breeding waterfowl (Ray *et al.* 2003; Baar *et al.* 2008; Haukos 2008). The number of inundated playas during winter determines the number of wintering waterfowl; Johnson *et al.* (2011a) reported that the percent of inundated playas varied from near zero in dry years to > 50% in wet years. During wet years, overwinter survival of Mallard *Anas platyrhynchos* and Northern Pintail in the High Plains is greater than for any other wintering area in North America (Bergan & Smith 1993; Moon & Haukos 2006). Estimated numbers of wintering ducks using southern playas during January ranges between 200,000 and 3 million depending on environmental conditions such as precipitation levels and winter temperatures (USFWS 1988; Haukos 2008).

The historical number of playas is unknown because of extensive landscape alteration in the High Plains during the past century (Smith *et al.* 2012). Recent estimates of playas vary greatly depending on the source and associated methodology used to identify playas, with published figures ranging from 30,000–80,000 playas (Smith *et al.* 2012; D. Haukos, pers. comm.). Although the large number of playas reported as present on the landscape gives the mistaken impression that there are sufficient functional playas capable of providing ecological services for waterfowl, Johnson *et al.* (2012) estimated that 17% of historical playas are no longer detectable on the southern Great Plains (Oklahoma, Texas and New Mexico). In addition, only 0.2% of existing playas have no wetland or watershed modification. Further, Johnson *et al.* (2012) estimated that 38.5% of historical playas had been lost from the landscape or experienced cultivation of the hydric soils, which can greatly reduce or eliminate natural forage for waterfowl. The greatest threat to playas is unsustainable sediment accumulation (Luo 1997; Smith 2003; Tsai 2007). Combining physical wetland loss, direct wetland cultivation and fill due to sediment accumulation results in an estimated 60% of historical playas that are no longer available to provide habitat for waterfowl (Johnson *et al.* 2012). Of the remaining playas on the southern Great Plains, none are fully functional (Johnson 2011b). These impacts to playa ecosystems likely contributed to the 32% decline in average body condition of Northern Pintail from the mid-1980s to early 2000s (Moon *et al.* 2007), with potential associated cross-seasonal effects on survival and reproductive capacity (Mattson *et al.* 2012).

Despite the acknowledged value of playas to waterfowl, conservation efforts have been stymied during the past three decades.

The vast number of playas, and the lack of perceptible physical differences in their characteristics (excepting inundation frequency) which provide value as wildlife habitat or contribute to ecological goods and services, have paralysed efforts to conserve these wetlands. The value of playas is greatest when they are considered in aggregate and regionally, although this approach is rarely used in conservation efforts (Smith *et al.* 2011; Johnson *et al.* 2012). Finally, there is lack of federal and state regulations or incentives to encourage the protection of playas, and no requirement to mitigate for any negative impacts on playa wetlands (Haukos & Smith 2003; Johnson *et al.* 2011b). The U.S. Department of Agriculture's Conservation Reserve Program, which has limited focus on wetlands compared with other habitats within the programme, is the main conservation initiative affecting playas on the High Plains. Unfortunately, playas in Conservation Reserve Program watersheds have altered hydrology characterised by reduced inundation frequency and hydroperiod possibly resulting from use of non-native vegetation in CRP plantings (Cariveau *et al.* 2011; Bartuszevige *et al.* 2012; O'Connell *et al.* 2012).

Conservation efforts should be coordinated at larger spatial and temporal scales to identify accurately the value of an individual playa. Moreover, conservation programmes need to be tailored specifically to playas as current efforts are not effective (Bartuszevige *et al.* 2012; O'Connell *et al.* 2012). Efforts to conserve playas will benefit from recognition that extreme environmental conditions are normal, and that these actually drive playa ecosystems. Relatively long temporal periods may exist between ecological states that provide high quality habitat for waterfowl. Finally, any conservation effort must consider the role and contribution of individual playas to the entire system when prioritising playas for conservation. Despite recognition of use of playas by waterfowl, the capacity of the playa system to support waterfowl is declining (Moon & Haukos 2006; Moon *et al.* 2007; Smith *et al.* 2011). Consequently, a multifaceted approach is needed to develop a playa conservation strategy that includes: 1) an educational effort to accumulate support for playa conservation, 2) modification of current conservation programmes so that playas are competitive for funding, and 3) greatly accelerating research efforts to accumulate knowledge relative to playa ecology, management and their status across the landscape.

Boreal forest wetlands

North America's boreal forest (hereafter, Boreal) is part of the largest terrestrial biome and unspoiled wetland and forest ecosystem in the world. This 600 million ha landscape stretches from western Alaska to Labrador and accounts for > 35% of the continent's forest-cover (Wells & Blancher 2011). Wetlands comprise 6% of the earth's land-cover, yet Canada alone has 25% of the world's wetlands (PEG 2011). Most of Canada's wetlands (> 85%) are in the Boreal, including bogs, fens, swamps, marshes and open water basins. Alaska's Boreal has > 2,000 rivers and streams that feed a water-rich wetland landscape. North America's Boreal holds 25% of the freshwater and

> 30% of soil carbon on the planet (PEG 2011). Despite their former isolation and vast coverage, North America's Boreal wetlands face increasing threats from climate change and expansion of industrial activities.

Prairie and boreal wetlands provide breeding habitat for the majority of duck pairs across North America (Slattery *et al.* 2011). Breeding season population estimates for the western Boreal region alone are 13–15 million birds, with many species having ≥ 50% of their breeding populations in the Boreal (Wells & Blancher 2011). The prairie and boreal biomes are arguably integrated ecologically as ducks may use the Boreal for nesting during prairie droughts and annual wing moult (Baldassarre & Bolen 2006). Consequently, extensive changes to boreal waterfowl habitat could have continental-level implications for waterfowl conservation objectives.

The perception of a pristine Boreal has changed rapidly because of the wide range of development activities occurring there, and development is predicted to increase substantially into the future (Bradshaw *et al.* 2009; Wells 2011). Seven distinct anthropogenic pressures threaten the North American Boreal, including agricultural expansion, petroleum exploration and development, forestry, hydroelectric development, mining, acid precipitation and climate change. Few regions have already and are expected to experience greater changes in mean temperatures than the Boreal (Soja *et al.* 2007; Bradshaw *et al.* 2009; Stocker *et al.* 2013), yet this biome has a great influence on global temperature and carbon storage (Bonan 2008). Impacts on Boreal wetlands may include loss of lakes and wetlands (> 40 ha in area) due to the melting of permafrost, increased evaporation and transpiration rates, and aggregation of floating emergent vegetation and associated inorganic sediments, resulting in regional decreases in surface water area (Smith *et al.* 2005; Riordan *et al.* 2006; Roach *et al.* 2011). The extent of these changes across the Boreal is currently unknown, but substantial increases are expected.

While increasing temperature may represent a threat beyond the control of classic waterfowl conservation mechanisms, other more direct anthropogenic landscape changes may be more amenable to sustainable development. Changes to hydrology can result in long-term drying (*e.g.* Bennett Dam on the Peace-Athabasca Delta) or flooding (*e.g.* Ramparts Dam proposed for the Yukon River and also several large operations in Quebec). Water pollution can potentially reach large blocks of watersheds because Boreal wetlands are often hydrologically connected through subsurface flow (Smerdon *et al.* 2005). Timber harvest may increase runoff and thus local flooding, and this can have a direct effect on the breeding success of cavity-nesting birds. Road construction can impound or drain water flowing to or from wetlands. We are only just beginning to understand the impact of these factors on waterfowl and their habitats, which challenges conservation efforts and necessitates a cautious approach to development and wildlife management in the region.

Protection of water quality, quantity and hydrologic patterns appears critical to conservation of waterfowl habitat within the Boreal. Because most Boreal wetlands recharge through lacustrine or riverine processes, those in the Alaskan boreal forest are protected under the U.S. Clean Water Act, but recent Supreme Court decisions (*e.g.* SWANCC *versus* USACE) have muddied the jurisdictional waters for many wetlands not immediately adjacent to navigable rivers or streams. In contrast there is almost no broad wetland protection in Boreal Canada, either at the federal or provincial/territorial levels, although recent legislation in Alberta may provide some level of protection. Widespread and enforceable legislative protections are critical to ensuring that the Boreal can support key North American waterfowl populations into the future.

Prairie wetlands

Wetlands potentially represent the most critical and limiting components of the landscape for breeding waterfowl (Kantrud & Stewart 1977). The Prairie Pothole Region of the north-central United States and south central Canada produces up to 75% of waterfowl in North America (Smith *et al.* 1964; Mitsch & Gosselink 2007). Wetland density in this region ranges from 4–38 potholes/km^2 (Baldassarre & Bolen 2006), but more than half of the original wetlands in the region have been lost or highly modified, principally for agriculture (Mitsch & Gosselink 2007). Moreover, conversion of native grassland and pastures to row-crop agriculture can have a dramatic effect on wetland integrity by increasing sediment and chemical runoff within the watershed (Zedler 2003). A myriad of factors including agricultural policy, changing wetland regulations, improved farming and land clearing technology, and climate change threaten wetland function and value for waterfowl in the Prairie Pothole Region (Johnston 2013; Wright & Wimberly 2013).

Prairie wetlands have been identified as particularly vulnerable to climate change. Evidence for this conclusion has come from an inter-institutional and multi-disciplinary team of investigators which has developed and used two simulation models, WETLAND SIMULATOR and WETLANDSCAPE, to project future consequences of climate change on prairie wetlands and waterfowl (*e.g.* Poiani & Johnson 1991; Poiani *et al.* 1995, 1996; Johnson *et al.* 2005, 2010; Werner *et al.* 2013). These researchers have reached four main conclusions after 20 years of research on the subject: 1) temperature matters, 2) geography matters, 3) impacts may have already occurred, and 4) threshold effects may yield future surprises. A representative simulation using weather data (1986–1989) from the Orchid Meadows field site demonstrated the effect of increasing air temperature on the length of time that water stands (hydroperiod) in a semi-permanent wetland basin (Johnson *et al.* 2004, 2010). Raising the temperature a modest 2°C shifted wetland permanence type from semi-permanent (not dry during the 4-year simulation) to seasonal (drying annually). A 4°C increase changed the wetland into one more typical of a temporary wetland that dried by late spring or mid-summer each year. This simulation, and hundreds more that have been completed across the Prairie Pothole Region (*e.g.* Poiani *et al.* 1996; Poiani & Johnson 2003), clearly illustrate how sensitive prairie wetland hydrology is to air temperature.

The Prairie Pothole Region is of modest geographic area, comprising *c.* 800,000 km^2 in the U.S. and Canada. Despite its size, a strong northwest to southeast climatic gradient exists within the region; mean annual temperature ranges from about 0–10°C and mean annual precipitation from about 35–90 cm (Millett *et al.* 2009). The intersection of these two climatic gradients produces different sub-regional climates, wetland functional dynamics and responsiveness to climatic change. Model simulations using data from regional weather stations with long-term records (≥ 100 years) show that the response of wetlands to climate change will be highly variable geographically (Johnson *et al.* 2010). The most favourable climate in the Prairie Pothole Region for wetland productivity during the 20th century is projected to shift eastward where there are fewer un-drained wetland basins and much less grassland available as nesting habitat for waterfowl. The naturally drier western edge of the Prairie Pothole Region, described as a "boom or bust" region for waterfowl production, may become largely a "bust" should the future climate be more arid as projected (Johnson *et al.* 2010). This possible future "mismatch" between the location of a productive wetland climate and functional wetland basins stands as a current challenge for wetland managers as they develop future plans to allocate resources for wetland conservation and management across the Prairie Pothole Region.

The northwest portion of the Prairie Pothole Region (west-Canadian prairies) warmed and dried late in the 20th Century (Millett *et al.* 2009). A hindcast simulation was conducted to determine if the change in climate between two 30-year periods (1946–1975 and 1976–2005) was sufficient to have affected wetland productivity. If so, the analysis would provide evidence that trends for warming and drying projected earlier for the mid 21st century (Johnson *et al.* 2005) may already have started in the late 20th century. The model indicated that climate changes were sufficient to have affected the wetland cover cycle, a major indicator of wetland productivity quantified by a cover cycle index (Werner *et al.* 2013). This analysis is the first to present evidence that climate change may already have affected wetland productivity in part of the Prairie Pothole Region.

Climate changes that exceed ecological thresholds can produce rapid and surprising changes in the functioning of natural ecosystems (*e.g.* Holling 1973; CCSP 2009). The most productive semi-permanent prairie wetlands pass through three stages during weather cycles: dry marsh, lake marsh and hemi-marsh (which includes both regenerating and degenerating sub-stages; van der Valk & Davis 1978). Climatic thresholds associated with drought must be reached and exceeded for habitats to enter the dry marsh stage, as must those associated with a precipitation deluge needed to enter the lake marsh stage. Between these two extremes, the most productive hemi-marsh stage is reached. Ratios that produce the highest indices for wetland productivity over decadal time intervals are approximately: 25:50:25 (dry, hemi and lake, respectively). Climate changes that cause wetlands to be "stuck" in either the lake or dry marsh extremes stop vegetation cycling and decrease productivity. Because the majority of ducks produced in North America are reared in Prairie Pothole Region wetlands, biologists are concerned that wetlands responsible for past high rates of waterfowl production could become drier and fail in the future by never or rarely reaching the lake marsh and hemi-marsh stages of the cycle (Sorenson *et al.* 1998; Johnson *et al.* 2010).

Twenty years of modelling and field research have found that prairie wetlands are highly sensitive to changes in climate and that they respond differently to wide-ranging sub-climates across the Prairie Pothole Region. Moreover, they may already have been negatively affected by climate warming in the Canadian prairies, and may not reach water level thresholds under a warmer climate needed to maintain historic dynamics and productivity. We suggest development of an early warning system to detect the onset of climate change across the Prairie Pothole Region by conducting simulation modelling and field monitoring in tandem to provide further understanding of changes to date and to improve accuracy in predicting for future changes in Prairie Pothole Region wetlands.

Prairie wetland conservation policy

Despite a changing climate and anthropogenic denudation of large areas of the landscape, all is not lost in the Prairie Pothole Region. To help protect critical habitat for waterfowl, visionary waterfowl biologists and managers recognised the importance of the region and initiated the USFWS's Small Wetlands Acquisition Program (SWAP) in 1958 with an amendment to the 1934 "Duck Stamp Act" (legislative documents:16 U.S.C. 718-718j, 48 Stat.452; P.L. 85-585; 72 Stat. 486) (Loesch *et al.* 2012). The SWAP amendment authorised that proceeds from the sale of duck stamps and the import duties on ammunition and firearms should be used for the acquisition of fee title (*i.e.* absolute ownership) or limited-interest title (restricted ownership) of Waterfowl Production Areas, and also for purchasing limited interest easements over Waterfowl Production Areas in Prairie Pothole Region states (USFWS 2013).

Over the past 50 years, the USFWS and its partners (*e.g.* sportsmen and women, private landowners and non-profit conservation organisations) have acquired ownership of nearly 0.7 million ha in National Wildlife Refuges and Waterfowl Production Areas and easements over an additional 1.1 million ha of Waterfowl Production Areas in the U.S. Prairie Pothole Region. The SWAP has thus acquired easements to conserve a network of privately owned wetlands and grasslands which provide nesting sites for breeding birds in proximity to larger Waterfowl Production Area wetland basins purchased for their importance as brood-rearing habitat. During the first 35 years, habitat was acquired by USFWS biologists who applied their knowledge of the area to prioritise acquisitions. More recently, spatially explicit habitat and biological data have been used to develop statistical models used by the USFWS to assess the Prairie Pothole Region landscape (Stephens *et al.* 2008). Habitat conservation efforts are then focused toward areas that produce the greatest benefits for migratory bird benefits, given the limited conservation funds (Reynolds *et al.* 2006; Niemuth *et al.* 2008).

In addition to traditional measures of conservation progress (*e.g.* money expended for land acquisitions and the number of acres protected), the success of the SWAP is assessed using measurable biological outcomes such as the abundance of waterfowl pairs and their breeding success. Through the purchase of wetland and grassland easements on private lands, the USFWS and its partners have secured breeding habitat for an estimated 1.1 million waterfowl pairs across 13 species of waterfowl. The resultant effort contributes approximately 708,000 recruits annually for Mallard, Northern Pintail, Gadwall *A. strepera*, Blue-winged Teal and Northern Shoveler annually (Cowardin *et al.* 1995; USFWS Habitat & Population Evaluation Team unpubl. data). While this large landscape-scale approach to waterfowl conservation has been highly successful, an additional 3.8 million ha of grassland (88% of the remaining grassland) and 0.7 million ha of wetlands (75% of the remaining wetlands) in the U.S. Prairie Pothole Region have been prioritised for protection (Ringleman 2005). In 2012, land values averaged across the northern plains states from North Dakota to Kansas were US$5,831/ha (USDA 2012) and, if applied to the 4.5 million-ha goals, would require > US$2.6 trillion in fee-title acquisition costs.

Through various partnership efforts including the Migratory Bird Conservation Fund, the Land and Water Conservation Fund and funding under the North American Wetlands Conservation Act, the USFWS and its partners continue to be active in pursuing conservation goals in order to maintain North America's waterfowl populations. Meeting existing wetland and grassland conservation goals is a daunting challenge (Doherty *et al.* 2013). Only through collaborative and complementary efforts, which incorporate a science-based approach to determining the best places in the landscape for directing conservation resources in the face of habitat loss, will effective conservation of wetlands in the Prairie Pothole Region be achieved.

Lower Great Lakes marshes

The lower Great Lakes coastal marshes are valuable areas for staging and wintering waterfowl and are among the most biologically significant wetlands within the Great Lakes region. These marshes have long been recognised for their importance in providing habitat for a wide variety of flora and fauna, and in particular for migratory birds. As an example, the coastal wetlands of northwest Ohio alone support *c.* 500,000 itinerant waterfowl during autumn migration (Ohio Division of Wildlife, unpubl. data). These marshes are also subject to a great number of anthropogenic stressors, including dredging, nutrient/pollutant loading, altered hydrological regimes and the introduction of non-native species. Today, a majority of the region's coastal marshes and wetlands have been drained or replaced by shoreline development or have been further degraded by altered hydrology and sediment deposition. Only 5% of the original 121,000 ha of Lake Erie marshes and swamps in northwest Ohio remain (Bookhout *et al.* 1989), and habitat loss continues to reduce the area available for diverse wetland plant communities capable of supporting waterfowl populations. Habitat loss of this magnitude underscores the importance of maintaining the remaining habitat at the highest level of quality possible.

A wide variety of invasive species now dominate wetland flora in many lower Great Lakes coastal marshes, having displaced native vegetation and in many cases important waterfowl resources (Mills *et al.* 1994; Zedler & Kercher 2004). In fact, invasive species are now considered the primary cause of wetland degradation in the region. The most abundant, widespread and harmful invasive plant species within these wetlands include Common Reed *Phragmites australis*, Reed Canary Grass *Phalaris arundinacea*, Curly Pondweed *Potamogeton crispus*, Eurasian Watermilfoil *Myriophyllum spicatum*, and non-native Cattail *Typha angustifolia* and *T. glauca*. Other less widespread but significant invasive species include European Frog-bit *Hydrocharis morsus-ranae*, Japanese Knotweed *Polygonum cuspidatum*, Yellow Flag Iris *Iris pseudacorus*, Purple Loosestrife *Lythrum salicaria* and Water Chestnut *Trapa natans*. Invasive species outbreaks continue to occur in this region and relative newcomers such as Flowering Rush *Butomus umbellatus* are quickly becoming established at nuisance levels.

In most cases, invasive plant species alter the biotic and abiotic environment of wetlands by excluding native plants, reducing plant diversity and modifying wetland processes (Drake *et al.* 1989; Davis *et al.* 1999; Meyerson *et al.* 1999; Windham & Lathrop 1999; Rooth *et al.* 2003). However, the indirect effects of invasive plants on wildlife are less well understood. For example, only a handful of studies have shown the effects of Common Reed on wildlife use and diversity, including studies on turtles (Bolton & Brooks 2010), toads (Greenberg & Green 2013), passerine birds (Meyer *et al.* 2010) and other wetland wildlife (Schummer *et al.* 2012). In contrast, a substantial research base of Common Reed biology, proliferation and management exists in the form of peer-reviewed articles, white papers and websites (*e.g.* http://www.greatlakesphragmites.net). Extensive research into chemical and biological control measures for Purple Loosestrife similarly led to the release of beetles *Galerucella* sp. as a highly successful biological control during the 1990s, despite a lack of data to show that the plant had negative impacts on the environment (Hager & McCoy 1998; Treberg & Husband 1999).

While no single management strategy can be employed to treat infestations of these diverse invasive plants, similarities do exist among species. Most often, managers employ an Integrated Pest Management (IPM) strategy that combines one or more techniques including mowing or harvesting, smothering, drowning, herbicide treatments, biological control agents, controlled burns and reseeding with native species (Radosevich 2007; Holt 2009). With the exception of Purple Loosestrife, where biological control proved successful, the most effective and widely used strategies typically include herbicide application within the IPM strategy. As an example, the most effective control of Common Reed includes a late-summer application of glyphosphate herbicide followed by a spring burn or other thatch removal method (J. Simpson, unpubl. data; MDEQ 2008). Variations of this method have also been applied effectively for many other emergent invasive plants. Other aquatic-approved herbicides, such as those formulated with imazypyr, are equally effective at removing invasive plants, but residual action limits subsequent regeneration of native species. Submerged or floating-leaved vegetation is typically managed with granular or similar broadcast herbicides in conjunction with mechanical mowing or harvesting. Ironically, some success has been also demonstrated by using non-native Common Carp *Cyprinus carpio* to reduce monocultures of submersed invasive plants (Kroll 2006), but carp often become established and can remove desirable native vegetation (Bajer *et al.* 2009).

In response to the logistical and financial hurdles associated with managing large non-native plant invasions, stakeholders in the Great Lakes Region of the U.S. and elsewhere have united to form cooperative weed management areas. These diverse groups now exist in most Great Lakes states and provinces and represent a cross section of government agencies, local units of government, non-profit conservation groups, community associations and individual landowners. In many cases, these associations form to address ecological, social and economic problems linked to vegetation management along developed shorelines and within recreational sites. Using private and government grant funds, these cooperative weed management areas have made progress by identifying and prioritising treatment sites, providing management tools, implementing post-treatment monitoring and research, and organising and educating landowners.

Invasive wetland plants are widespread and continually establishing across coastal and inland wetlands within the Great Lakes region. Management of invasive plants is unavoidable in order to continue providing quality wetland habitat for waterfowl and other wetland-dependent species. Management strategies continue to be refined, tested and researched, but research into the biological implications of these species should continue. Up-front research demonstrating the negative impacts of these species is essential for prioritising their management and focusing effort on species of greatest concern. Additionally, a greater understanding of the indirect effects of these plant species on waterfowl and other wetland-dependent wildlife is required to avoid expending exhaustive control measures on species whose ecological consequences are unproven.

Central Valley of California

The Central Valley of California supports an average of about 5.5 million wintering waterfowl annually, making it one of the most important regions for waterfowl in North America. However, the Central Valley has lost approximately 95% of its original wetlands due to flood control, urbanisation and conversion to agriculture (Fleskes 2012). During the past 20 years, conservation programmes such as the Wetlands Reserve Program, the North American Wetlands Conservation Act, the Migratory Bird Conservation Fund and the state's Inland Wetlands Conservation Program have provided a means to protect, enhance or restore former and existing wetlands throughout the Central Valley. Additionally, intensive management of remaining wetlands for food production, along with flooded grain (especially rice), has helped to mitigate for wetland loss and allowed continued support of large numbers of waterfowl.

While partners of the Central Valley Joint Venture have made considerable progress towards habitat goals of the North American Waterfowl Management Plan, changing policies and demand for limited resources, such as water, hinders management of existing wetlands and could impair farming practices that benefit nesting and wintering waterfowl. Water supply for certain National Wildlife Refuges and State Wildlife Areas, as well as other wetland complexes, was required under the provisions of the 1992 Central Valley Project Improvement Act. However, the full allocation of water required under the Act has been achieved only once in the past 20 years (G. Yarris, pers. comm.). In-stream flow requirements for fish species protected under various state and federal plans are competing pressures on the water available for wetland management, such as winter-flooding of rice fields, in the Central Valley. Moreover, the Clean Water Act, which protects wetland resources throughout the United States, increases management complexity in certain situations. Because of the altered hydrology of the Central Valley, most wetlands are managed with controlled flooding and drainage and thus are subject to the same regulations as other water diverters and dischargers. Current or proposed regulations will limit the discharge of contaminants and require expensive monitoring programmes to demonstrate compliance. Additionally, wetlands and flooded rice fields are ideal environments for methylation of mercury – the form of mercury which readily bioaccumulates and is toxic to humans and wildlife (Ackerman & Eagles-Smith 2010). Mercury is a legacy contaminant from the gold rush of the 1800s and is widespread throughout northern Central Valley watersheds. Regulations restricting methylmercury discharge into the San Joaquin-Sacramento Delta may inhibit wetland restoration and management and discourage flooding of rice fields during autumn and winter.

Ongoing conservation planning efforts in the Sacramento-San Joaquin Delta region of the Central Valley emphasise the restoration of anadromous fish runs (*e.g.* salmon *Salmo* and *Oncorhynchus* sp.) and other endangered fish (*e.g.* Delta Smelt *Hypomesus transpacificus*), possibly at the expense of waterfowl habitat. For example, proposed breaching of levees of some managed wetlands in the Suisun Marsh to restore tidal action and provide fish habitat will reduce managed wetlands in the region and require the restoration or creation of new managed wetlands elsewhere to compensate for this loss. The use of tidal wetlands by dabbling ducks is low compared to managed wetlands (Coates *et al.* 2012). Thus, tidal restoration may reduce the waterfowl carrying capacity of the Suisun Marsh, decreasing its importance for ducks in the Pacific Flyway.

Another recent constraint to wetland management is the mosquito abatement policies of vector control districts. Because many wetlands in California are near urban areas, summer irrigation for waterfowl food plant production, early autumn flooding for shorebird migration and other management activities that may produce mosquitoes are discouraged. Although alternative wetland management strategies are being developed in some cases (Washburn 2012), costs associated with mosquito control have created a disincentive to implement wetland management practices on both public and private wetlands (Olson 2010). For example, mosquito control costs have tripled on State Wildlife Areas since concerns of public exposure to West Nile Virus have come to the fore (B. Burkholder, pers. comm.).

Constraints, restrictions and regulations on wetlands and flooded agriculture in the Central Valley likely will continue into the future as the demand for water increases. Creative solutions to wetland restoration and management, and especially increased participation in policy development, will be critical for advancing the goals of the Central Valley Joint Venture and ensuring that sufficient habitat exists for all wetland-dependent species in the Pacific Flyway.

Looking ahead

Challenges

During our session, a number of key points and challenges to wetland conservation and waterfowl management became apparent. Firstly, unless there is an immediate and significant change in a) wetland protection measures, and b) agricultural policies that provide a disincentive to wetland drainage and conversion, the recent "good old days" of abundant wetlands for waterfowl are likely coming to a close. Secondly, the fate of large scale wetland conservation lies with private landowners – public land and areas protected by conservation easements will likely not sustain the current breeding populations of waterfowl in most of North America. Thirdly, wetland conservation policies and objectives must be robust to the wide variety of political, societal and environmental shifts or vagaries. One such environmental factor important to conservation priorities is changing climate, where simulations have shown potential changes in waterbird productivity and impacts on wetland availability when certain climate thresholds are exceeded. Fourthly, increasing demand for water due to urban and population growth, irrigated agriculture, and other commercial uses (*e.g.* hydraulic fracturing) combined with expected impacts of climate change will increase competition for and cost of water for managed wetlands and waterfowl habitats. Fifthly, increased wetland drainage for agriculture followed by increased crop irrigation increases water requirements while reducing the opportunities for aquifer recharge. Sixthly, updating and improving existing data on wetland distribution and quality for waterfowl is needed but will be difficult given declining government budgets and changes in agency priorities. Overall, managing waterfowl populations and their associated habitats in the face of climate change, invasive species and other biotic stressors will be challenging.

Opportunities

In spite of these challenges, there are also a number of opportunities in the near future that may directly or indirectly affect wetland and waterfowl conservation.

National wetlands inventory

Strategic conservation is critical to achieve significant progress towards wetland conservation goals (Stephens *et al.* 2008) and accurate information on the location, type and status and trends of wetlands is vital to this effort. In 1974, the USFWS established the National Wetlands Inventory Program (NWI) to provide information on the location, distribution and characteristics of U.S. wetlands. By late 2014, the NWI is expected to be complete for the lower 48 states, yet by that time much of the data will be > 25 years old. While NWI maps and geospatial data showing wetland types (Cowardin *et al.* 1979) have helped promote wetland conservation, continual updating and additional information (*e.g.* hydrogeomorphic properties) is needed to use NWI data for predicting wetland functions and determining more readily their value to organisms of interest (*e.g.* waterfowl). Recognising this need, the USFWS recently developed descriptors for landscape position, landform, water flow path and waterbody type (LLWW descriptors; Tiner 2003, 2011) to supplement NWI data on a case-by-case basis. When the Federal Geographic Data Committee established its wetland mapping standard (FGDCWS 2009) for the federal government, it suggested adding these attributes to increase the functionality of the NWI database.

When LLWW descriptors are added to existing NWI data, a "NWI+ database" is created. The NWI+ database is used to predict 11 functions of existing wetlands and, in some cases, potential function for wetland restoration sites. For each function, wetlands providing the function at high or moderate levels are predicted based on certain properties included in the database. Correlations between database features and functions were developed first by consulting the literature and then by peer review from regional scientists. For provision of waterfowl and waterbird habitat, in addition to the high and moderate categories, a third category for Wood Duck *Aix sponsa* habitat was created because this species frequents wooded swamps along rivers and streams as opposed to more open water wetlands (*e.g.* marshes) occupied by most other waterfowl and waterbirds. NWI+ data and the results of NWI+ analyses are displayed via an online map (NWI+ web mapper at http://aswm.org/wetland-science/wetlands-one-stop-mapping); NWI+ reports are also posted. This tool provides users with a first approximation of wetland functions across large geographic areas. To date, such data are available or will soon be posted for five entire states (CT, DE, MA, NJ and RI) while pilot or special projects are completed or are in progress for parts of other states (AK, CA, MD, MS, NH, NY, PA, SC, TX, VA, VT and WY).

The NWI+ data provide a better characterisation of wetlands, an expanded geospatial database and a preliminary landscape-level assessment of wetland functions. This information is valuable to fish and wildlife biologists, conservation planners, ecosystem modellers, regulatory personnel and the general public. Limited NWI funds do not allow these data to be produced nationwide, so NWI+ data are project area-focused. With further budget reductions imminent, such data, as well as updated traditional NWI data, will likely come mainly from user-funded initiatives. Other agencies/organisations have produced or are producing NWI+ data for parts of many states (MI, MN, MT, NM, OR, WI), while some states (CT, DE, NY, and PA) have funded NWI+ work in their state. NWI+ data will provide new opportunities for assessing and assigning functional values to wetlands at the time that they are mapped, and have the potential to increase the efficiency of conservation planning for target species or groups (*e.g.* dabbling ducks, wood ducks).

Influencing policy

Scientists, wetland managers and other conservationists should not simply react to policy shifts that influence wetland loss, but must also work to influence them. There are many opportunities to incorporate science into the policy debates that are shaping the future of waterfowl management. Waterfowl scientists and managers can, and must, focus increased efforts on providing information that can influence the future of wetland conservation policies, such as the Clean Water Act, that hold in the balance the future of tens of millions of acres of waterfowl habitat. Moreover, waterfowl conservationists should engage private landowners and convey to them the importance of wetlands for waterfowl as well as the myriad of other functions and benefits that these habitats provide for society. Although government restrictions on advocacy can limit the participation of many scientists in policy debates, experts should nonetheless have input to discussions regarding the anticipated effects of new and ongoing policies on wetlands.

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Photograph: Mallard and Northern Pintail in a seasonal emergent wetland in the Illinois River Valley, Illinois, USA, by Heath Hagy.