CSIRO PUBLISHING

Wildlife Research, 2020, **47**, 279–295
https://doi.org/10.1071/WR19100

Sources and dynamics of international funding for waterfowl conservation in the Prairie Pothole Region of North America

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Abstract

Context. Funding for habitat-management programs to maintain population viability is critical for conservation of migratory species; however, such financial resources are limited and can vary greatly over time. The Prairie Pothole Region (PPR) of North America is an excellent system for examining spatiotemporal patterns of funding for waterfowl conservation, because this transboundary region is crucial for reproduction and migration of many duck species.

Aims. We examine large-scale spatiotemporal variation in funding for waterfowl habitat conservation in the PPR during 2007–2016. Specifically, we quantify major sources of funding and how funds were directed towards particular geographies within Canada and the USA. We further examine how sources and magnitude of funding changed over time and in relation to numbers of hunters.

Methods. We assembled data from multiple sources to quantify funding (in US$, 2016 values) from (1) USA states and non-government organisations (NGOs), (2) Canadian government and NGOs, and (3) major USA-based federal funding sources to the Canadian and US portions of the PPR between 2007 and 2016. We fit linear regressions to examine spatiotemporal variation in funding and in numbers of active waterfowl hunters in the USA.

Key results. Whereas annual funding for the Canadian portion was comparatively stable throughout the 10 years (range: US$25–41 million), funding for the US portion was dynamic and increased between the first (range: US$36–48 million) and second (range: US$43–117 million) 5-year intervals, despite concurrent declines in the number of active waterfowl hunters in the USA.

Conclusions. We discovered contrasting trends and dynamics in multiple streams of funding for habitat conservation on each side of the border bisecting the PPR. These findings and approaches warrant closer attention by wildlife professionals. Work is needed to analyse past and future funding for habitat conservation, which can then be used to refine plans for maintaining or recovering populations of migratory species.

Implications. Although funding for waterfowl habitat conservation in the PPR increased over the past decade, trends were inconsistent among subregions and uncertain for some major funding sources. Better understanding of the complexities in funding will help inform more efficient long-term planning efforts for conservation of waterfowl and other migratory species.

Additional keywords: breeding, conservation, human dimensions, migration, population management, wildlife economics.

Received 17 June 2019, accepted 2 November 2019, published online 13 May 2020

Introduction

Efficient and effective allocation of resources to conserve highly mobile species is challenged by complex spatiotemporal dynamics linked to life-history strategies and changes in climate and land use (Faaborg *et al.* 2010; Miller 2011). These challenges are compounded when animals traverse political borders, requiring coordination and cooperation to achieve cost-effective and internationally coordinated management for achieving conservation objectives (López-Hoffman *et al.* 2017). Funding is important to ensure that habitats are managed in a way that maintains population viability, but such financial resources are limited and can vary greatly over time and often in unexpected ways (Association of Fish and Wildlife Agencies 2017; Congressional Research Service 2016). The purpose of the present paper is to provide an improved understanding of the spatiotemporal patterns in funding for an international conservation effort. This is an important step towards rigorously assessing and improving the implementation of international conservation efforts.

A growing body of literature has demonstrated important spatial patterns of funding for conservation efforts. Fundraising and conservation investments by The Nature Conservancy (TNC), a non-government organisation (NGO) and the largest environmental non-profit organisation in the Americas, for example, have been investigated from multiple perspectives. Fee simple acquisitions on private land align well with scientifically defined priority areas, but less so for easements, which sets up questions about how different sources and amounts of funding might affect this pattern (Fisher and Dills 2012). Another study has shown that investments are better explained by species richness than land cost (Fishburn *et al.* 2013). Areas where conservation efforts are invested are strongly correlated with amounts of funds raised locally, despite large predicted gains from reallocating a portion of this funding across space (Larson *et al.* 2016). By contrast, donations to TNC were highest around major metropolitan areas where there are fewer opportunities to spend the money locally (Fovargue *et al.* 2019). These last two studies define 'locally' very differently, illustrating the importance of considering funding at multiple scales.

Beyond NGOs, conservation-oriented ballot measures tend to occur in areas with high biodiversity, and nationally coordinated referenda are expected to have substantial efficiency gains for endangered-species conservation over the existing localised approach (Kroetz *et al.* 2014). Along the USA Pacific coast, local factors, including the number of NGOs and county employees, are correlated with conservation easement activity, but funding sources were not investigated (Williamson *et al.* 2018). These are some of the only examples of investigating the influence of government funding on the spatial arrangement of conservation. This points to emerging opportunities for investigating spatial patterns of the sources and destinations of government-based funds for conservation from regional to bilateral scales. Still missing are empirical investigations of systems where conservation funds from disparate sources are allocated among regions, away from where the funds are raised or generated. Such funding mechanisms are crucial for migratory species that can require conservation investment across political borders and major socioeconomic gradients. No previous work has investigated spatial patterns in conservation funding across international borders.

Examining funding of habitat conservation for game species in North America is an interesting case study, because some of this funding is being transferred across the international border between the USA and Canada. The North American Waterfowl Management Plan (NAWMP 2018) is the foundation for continental-scale conservation of waterfowl species. This effort involves thousands of partners and funders, who set the stage for funding conservation of waterfowl habitat across USA, Canada and Mexico (Anderson and Padding 2015).

The formerly glaciated region of central North America, also known as the Prairie Pothole Region (PPR), is an excellent system for examining spatial and temporal patterns of funding for waterfowl conservation. Breeding habitat in this region plays a crucial role in supporting migratory duck populations wintering in the southern and western USA (Batt *et al.* 1989; Hatvany 2017; Doherty *et al.* 2018). Despite containing only 10% of the continent's breeding habitat, the PPR is thought to produce 50–80% of North America's harvested duck species (Batt *et al.* 1989; Baldassarre and Bolen 2006). As such, the Canadian portion has been the focus of cross-border initiatives to fund habitat conservation dating back to the early 1930s, with the formation of the More Game Birds in America Foundation (the precursor to Ducks Unlimited). More recently, continued habitat loss in the PPR has been a strong motivation for the founding of NAWMP in 1986 (USFWS and Environment Canada 1986), involving Canada and the USA initially, with Mexico joining in 1994 (NAWMP 2018).

The success of NAWMP has hinged on the USA *North American Wetlands Conservation Act* (NAWCA) of 1989, which provides 50–70% matching grants to non-federal USA sources (e.g. state grants and NGO contributions) for the protection and management of wetland habitats for migratory birds and other wetland-associated species in the USA, Canada and Mexico (USFWS 2018*c*). States provide an important source of matching funds required by NAWCA that are then delivered to Canadian provinces (Anderson and Padding 2015). Unknown is the stability of these matching funds, and how likely the required match will be achieved in the future.

The *North American Wetlands Conservation Act* has been a driving force in promoting international conservation partnerships to leverage funding for waterfowl habitat conservation in the Canadian PPR. For most waterfowl species in the PPR, current conservation planning under the NAWMP is aimed at maintaining existing habitat and increasing waterfowl carrying capacity through restoration of high-quality wetlands and nesting habitat. Investments in conservation programs in the region are generally targeted both regionally and locally for maximal impact on breeding waterfowl over multiple years within the Prairie Habitat Joint Venture (PHJV 2014) in Canada and the Prairie Pothole Joint Venture (PPJV 2017) in the USA.

The waterfowl management community is concerned about future losses of conservation funding owing to declining participation in waterfowl hunting (Vrtiska *et al.* 2013; Wait 2017), along with a growing disconnect between people and nature (e.g. Louv 2008; Kellert *et al.* 2017). In addition to negatively affecting the status of prairie-nesting waterfowl, declines in funding for waterfowl conservation will potentially affect other wildlife species dependent on wetland and grassland habitats and could lead to further losses of ecosystem services provided

by PPR habitats, such as supplying clean water, recharging groundwater, lessening soil erosion, and attenuating runoff and reducing flood damage (e.g. Olewiler 2004).

Recent research has quantified the spatial flows of economic benefits derived from a cross-border migratory waterfowl species (Bagstad *et al.* 2019), but no comparable work has investigated whether flows of conservation funding reflect these benefits. Despite the importance of financial resources for conservation of waterfowl and associated ecosystem services, to our knowledge, there has been limited awareness and understanding of spatial or temporal patterns among funding streams. We are unaware of studies quantitatively examining hypotheses about temporal patterns in funding, although such an examination would provide useful insights into predicting future trends in funding to inform optimal allocation strategies (McDonald-Madden *et al.* 2008). We are also unaware of studies examining spatial patterns in funding sources, which would permit a more complete understanding and accounting of the costs and benefits of multi-jurisdictional conservation of migratory species.

Our main goal, then, is to examine spatial and temporal variation in bilateral funding for conservation of habitat for a group of migratory species. We focus on waterfowl habitat in the PPR as a case study. In doing so, we quantify major funding sources and determine how funds are directed towards particular geographies within Canada and the United States. We also examine relationships between the number of hunters per state and payments from states to Canadian PPR provinces. Further, we quantify temporal trends in funding from several sources. Last, we provide recommendations to make future predictions of funding for waterfowl habitat conservation in the PPR and link these predictions with improved management decisions.

Methods

Focal geographies and years

The PPR spans the USA–Canada border and closely follows the northern grasslands ecoregion including parts of the States of Montana, North and South Dakota, Minnesota and Iowa, along with the southern portions of the Canadian provinces, Alberta, Saskatchewan and Manitoba (Doherty *et al.* 2018). Formerly, extensive areas of grassland and diverse wetlands have provided ideal habitat for successful waterfowl reproduction in the PPR but, since human settlement, vast areas have been largely converted for intensive crop production that rivals that of other agricultural regions of the world (Foley *et al.* 2005; Johnston 2014; Doherty *et al.* 2018). To examine trends in funding sources during the most recent decade, we limited our investigation to the period from 2007 to 2016.

Predictions about funding dynamics

Based on a combination of literature and our own observations and logic, we developed predictions regarding past variation in annual funding for waterfowl habitat conservation on each side of the border bisecting the PPR. Recognising the observed decline in hunters (Vrtiska *et al.* 2013) and assuming this to be the sole or primary source of funding, Prediction 1 is that finances for waterfowl habitat conservation have also declined. Alternatively, considering that some funding for waterfowl habitat conservation in the PPR originates from compensations for damages to wetlands caused by expanding oil development (Heimlich *et al.* 1989; Faaborg *et al.* 2010; USFWS 2015*a*), Prediction 2 is that these have offset the losses of hunters and that funding for waterfowl habitat conservation has shown no consistent trend. Prediction 3 is that the observed increase in wildlife viewing within the USA (USFWS 2016*b*) has led to increased revenue from 'duck stamps' (i.e. stamps typically associated with the sale of state and federal hunting licenses but also purchased by conservation enthusiasts including birdwatchers) or increases of donations or lobbying for waterfowl conservation funding (Cooperation 2015). This increase in non-hunting-based contributions could also compensate for the decline in hunters. Recognising multiple funding sources for the USA PPR, trends in proportional contributions may differ from trends in magnitudes and provide insights about shifts in dominance among sources (Prediction 4). Prediction 5 is that any trend in funding is similar among provinces receiving funds from states and is similar across the border, because the Canadian PPR is recognised as an entire ecoregion critical for waterfowl populations irrespective of the political border (Hatvany 2017; Doherty *et al.* 2018). Under Prediction 6, trends are divergent because sources of funding differ across the border (Anderson and Padding 2015) or among provinces. To evaluate these predictions, we quantified trends in each major stream of revenue for waterfowl habitat conservation throughout the PPR.

We considered additional predictions when analysing funding for waterfowl habitat conservation in the Canadian PPR. Based on our observations, there is heterogeneity among states in how they determine the proportion of state duck-stamp revenues allocated to Canada (Table S1, available as Supplementary material to this paper). To examine this heterogeneity, we evaluated whether trends in state contributions are driven by the numbers of hunters (and the associated duck-stamp revenue) in each state delivering funding to a PPR province (Prediction 7). By contrast, nearly all (98%) revenues from sales of federal duck stamps fund conservation of waterfowl habitat in the United States. We, therefore, considered only this prediction when analysing funds related to revenues from state duck-stamp programs.

Response variables and candidate models

We identified seven response variables for the Canadian portion and eight response variables for the US portion of the PPR (Tables 1, 2). For each response variable, we identified a series of hypotheses that were associated with the predictions. The models cumulatively included three predictors, including two continuous variables (i.e. year and number of hunters) and one categorical variable (i.e. province).

Overview of focal funding and data sources

Funds for wildlife habitat conservation in North America originate from both participation-based and appropriation-based sources. Participation-based funds stem from hunters making financial contributions to conservation activities and entities supporting their sport. These contributions have traditionally comprised fees associated with state, provincial and federal hunting licences, and membership fees for wildlife-related organisations (i.e. NGOs). In the USA, participation-based

Table 1. Hypotheses, predictions and models with untransformed variables for explaining variation in funding allocated to the Canadian (CN) portion of the Prairie Pothole Region (PPR)

Hypotheses without predictions were part of the *post hoc* analysis. Response variables included years 2007–2016, unless otherwise noted. Variable indexes: t, year; p, province. AB, Alberta; β, regression parameter to be estimated; CA, California; hunters, hunters in states sending payments to focal province; IL, Illinois; NAWCA, *North American Wetland Conservation Act*; SK, Saskatchewan; pays, state payments to PPR provinces

Hypothesis	Predictions	Model
NAWCA funds for the CN PPR:		$CN\_NAWCA_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0
Payments from states:		$pays_{t,p} =$
vary by year and by province[A]	1, 6	$\beta_0 + t \cdot \beta_1 + \beta_{2,p} + t \cdot \beta_{3,p}$
vary with number of hunters[A]	1, 3, 7	$\beta_0 + hunters_t \cdot \beta_1 + \beta_{2,p} + hunters_t \cdot \beta_{3,p}$
vary by province[A]	6	$\beta_0 + \beta_{1,p}$
vary neither by year, province, nor number of hunters	2, 5	β_0
Number of IL hunters:		$ILhunters_t =$
varies over time		$\beta_0 + t \cdot \beta_1$
does not vary over time		β_0
Number of CA hunters:		$CAhunters_t =$
varies over time		$\beta_0 + t \cdot \beta_1$
does not vary over time		β_0
Payments from IL to SK:		$IL\_pays\_SK_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0
Payments from CA to AB:		$CA\_pays\_AB_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0
Payments from CA to AB from 2010 through 2016:		$CA\_pays\_AB\_2010\_2016_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0

[A]The regression term $\beta_{2,p}$ represents the fixed effect of province as a categorical predictor.

funds also stem from domestic sales of firearms and ammunition, as specified by the *Pittman-Robertson Act* of 1937 (Anderson and Padding 2015), and from revenues associated with import duties on firearms and ammunition as part of the Migratory Bird Conservation Fund (USFWS 2018*b*).

Appropriation-based funds for game habitat conservation are based on annual appropriations by state and federal government programs (e.g. USFWS 2017*a*, 2018*c*; Congressional Research Service 2016; CA Department of Fish and Wildlife 2018; Environment and Climate Change Canada 2018), which are not necessarily related to the number of hunters or gun owners. In contrast with participation-based funding, appropriation-based funding sources are strongly subject to political will and can change abruptly from one year to the next. Appropriation-based and participation-based sources of funding collectively provide the means of protecting and managing habitat for hunted wildlife (Organ *et al.* 2012). Funding is not often directed towards a single species but, rather, habitats are acquired and managed to improve the status for groups of taxa (e.g. ungulates, furbearers, waterfowl).

When considering funding for waterfowl conservation in North America, there are three primary sources of participation-based funding. The first is directly tied to hunters. To hunt waterfowl in the USA, all individuals 16 years of age or older must purchase a federal Migratory Bird Hunting and Conservation Stamp (i.e. duck stamp) issued annually by the USA Fish and Wildlife Service (USFWS; Anderson and Padding 2015; USFWS 2018*a*). Ninety-eight per cent of the purchase price of these stamps goes towards fee-title purchase and easements of lands important for waterfowl in the USA. Likewise, waterfowl hunters in Canada are required to purchase a federal Migratory Game Bird Hunting Permit with a Canadian Wildlife Habitat Conservation Stamp. Revenues provide financial assistance to conservation projects related to waterfowl and migratory bird management in Canada (Anderson and Padding 2015).

Second, many states in the USA require individuals to pay an additional fee (henceforth, state duck stamp) to hunt waterfowl in the respective states. Some of these states contribute a portion of these funds for waterfowl habitat conservation in Canada, recognising the importance of breeding areas, especially within the Canadian portion of the Prairie Pothole Region (Anderson and Padding 2015). The number of waterfowl hunters in the USA and Canada has declined steadily since the 1970s (Wait 2017), as has the sale of federal duck stamps (Vrtiska *et al.* 2013; Environment and Climate Change Canada 2017), which, in turn, has had a direct negative effect on revenues from the federal and state duck-stamp programs. Third, voluntary contributions for waterfowl conservation from private individuals and industry flow through waterfowl-focussed NGOs that operate in multiple countries (e.g. Ducks Unlimited; Anderson and Padding 2015).

Appropriation-based funding sources for waterfowl conservation stem from annual appropriations by state, provincial and USA and Canadian federal government programs. These sources can vary annually, sometimes dramatically, depending on revenues generated (e.g. taxes, royalties, penalties) and administrative and legislative branch budget priorities (e.g. Congressional

Table 2. Hypotheses, predictions and models with untransformed variables for explaining variation in funding allocated to the US portion of the Prairie Pothole Region

Variable indexes: t, year; s, funding source. AICc, Akaike's information criterion corrected for small sample size; β, regression parameter to be estimated; FDS, federal duck stamp; MBCF, Migratory Bird Conservation Fund; licence, licence-based; OLS, ordinary least-squares regression; TLS, Tukey's ladder of powers transformation of response variable

Hypothesis	Predictions	Model
USA PPR funds:		$USPPRfunds_{t,s} =$
vary across years and by funding source	1, 3	$\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}$
vary by funding source	4	$\beta_0 + \beta_{1,s}$
vary neither across years nor by funding source	2	β_0
Amount of MBCF:		$MBCF_{t,s} =$
varies across years and by funding source	1, 3	$\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}$
varies by funding source	4	$\beta_0 + \beta_{1,s}$
varies neither across years nor by funding source	2	β_0
Proportional contribution of US PPR funds:		$USPPRfunds_{t,s}/USPPRfunds_{t,\bullet} =$
varies across years and by funding source	1, 3	$\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}$
varies by funding source	4	$\beta_0 + \beta_{1,s}$
varies neither across years nor by funding source	2	β_0
Proportional contribution of the MBCF:		$MBCF_{t,s}/MBCF_{t,\bullet} =$
varies across years and by funding source	1, 3	$\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}$
varies by funding source	4	$\beta_0 + \beta_{1,s}$
varies neither across years nor by funding source	2	β_0
Amount of MBCF under a back-cast scenario[A]:		$Backcast\_MBCF_{t,\bullet} =$
varies over time	1, 3	$\beta_0 + t \cdot \beta_1$
does not vary over time	2	β_0
Amounts of MBCF sources under a back-cast scenario[A]:		$Backcast\_MBCF_{t,s} =$
vary across years and by funding source	1, 3	$\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}$
vary by funding source	4	$\beta_0 + \beta_s$
vary neither across years nor by funding source	2	β_0
Licence-based sales of FDS:		$License\_FDS\_sales_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0
Non-licence-based sales of FDS:		$Non\_License\_FDS\_sales_t =$
vary over time	1, 3	$\beta_0 + t \cdot \beta_1$
do not vary over time	2	β_0

[A]Back-cast scenario where the allocation of MBCF did not increase to 70%.

Research Service 2016). Examining past trends in these appropriation-based and participation-based funding sources can provide a basis for making future predictions of financial resources that support waterfowl conservation planning (Vrtiska *et al.* 2013).

There is no single database tracking all annual funding sources for waterfowl conservation in North America, but annual funds are documented by individual conservation programs within each country. Examining all funding sources is beyond the scope of the present paper. Instead, we focussed on the major funding sources (Table 3, Fig. S1, available as Supplementary material to this paper), which we defined as those contributing >US$100 000 during the majority of years in the study period.

Funding for Canadian portion of PPR

To calculate annual funding for waterfowl habitat conservation in the Canadian PPR, we began by quantifying the annual estimated NAWCA allocation sent to Canada including matching funds (D. Smith, Woodwarter Consulting, pers. comm.). Release of NAWCA funds to Canada depends on the availability of 50 : 50 matching funds from both USA non-federal sources and all Canadian sources. Of the NAWCA funds released to Canada, ~70% is annually earmarked by the North American Wetlands Conservation Council (NAWCC) of Canada for expenditure in the Canadian PPR through the Prairie Habitat Joint Venture (NAWCC Canada 2010; PHJV 2019). The NAWCC justifies this allocation based on the high importance of this region for waterfowl conservation. NGO land trusts (e.g. Ducks Unlimited Canada, Nature Conservancy Canada), as well as arms-length governmental agencies (e.g. Manitoba Habitat Heritage Corporation), are primary PHJV partners. These are recipients of the bulk of conservation funds that are invested in land restoration and securement through land purchase, perpetual conservation easements and term agreements (minimum of 10 years).

Eligible USA non-federal matching funds included the combination of state, NGO, industry and private contributions for wetland and waterfowl habitat conservation in Canada (Anderson and Padding 2015; PHJV 2019). Eligible NAWCA matching funds in Canada included federal, provincial, Canadian NGOs, industry, and private contributions for waterfowl habitat conservation. The matching formula requires a collective match of US$0.50 from USA non-federal sources and

Table 3. Annual USA federal funds available for waterfowl habitat conservation in the Prairie Pothole Region of North America

Name	Abbreviation	Description	Reference
Migratory Bird Conservation Fund	MBCF (USA only)	Includes funds from federal duck stamp program, import duties collected on arms and ammunition, receipts from the sale of products from rights-of-way across national wildlife refuges, and reverted federal aid funds[A]	(USFWS 2018*b*)
Land and Water Conservation Fund	LWCF (USA only)	Funds from earnings from offshore oil and gas leasing	(Congressional Research Service 2016)
North American Wetlands Conservation Act funds	NAWCA funds (USA and Canada)	Includes funds from direct congressional appropriations; interest from receipts in the Federal Aid in Wildlife Restoration (*Pittman–Robertson Act*) account where funds are derived from an 11% federal excise tax on sporting arms, ammunition and archery equipment, and a 10% tax on handguns; revenues from fines, penalties and forfeitures resulting from violations of the *Migratory Bird Treaty Act* (e.g. BP oil spill); and receipts from the Sport Fish Restoration account for USA coastal projects (not available for PPR)	(USFWS 2018*c*)

[A]Reverted Federal Aid consists of revenues from the Pittman Robertson fund that, if not used within 2 years by the states, revert back to the Federal government to be used for carrying out provisions of the *Migratory Bird Conservation Act*.

US$0.50 from Canadian sources for every NAWCA dollar (D. Smith, pers. comm.). Thus, for every US$1 contributed by NAWCA sources (Table 3), there is an additional US$1 leveraged by matching funds for waterfowl habitat conservation in the Canadian PPR each year. In addition to NAWCA and matching funds, we included unpublished annual funds from Ducks Unlimited Canada that were allocated to the Canadian PPR, irrespective of the NAWCA matching process.

We used the following three annual datasets for modelling trends in annual payments from individual states to Canadian PPR provinces, as part of the USA non-federal contribution towards NAWCA matching funds (henceforth, state-based funding): (1) payments to a corresponding province, (2) face value of a state duck stamp, and (3) number of hunters. Payments and stamp values were converted to US$ (based on 2016 values) to account for annual inflation (https://www.bls.gov/data/inflation_calculator.htm, accessed 7 February 2020). Annual payments were available from 2007 to 2016 from 24 states (D. Smith, unpubl. data), and stamp values were available for all years in which they were sold. None of the other 26 states contributed funding during the study period. The number of hunters was based on annual reports of harvest and hunter activity during the study period (e.g. USFWS 2017*b*). We multiplied the number of hunters by the stamp values to estimate annual revenue associated with purchases of state duck stamps associated with waterfowl hunting licenses.

To explore drivers of state payments to Canada, we identified individual states contributing, collectively, ≥75% of total payments to a given province summed over the study period. We then constructed an additional set of single-covariate candidate models to examine relationships between payments received by a province and the following covariates: (1) state-specific observations of payments delivered, and (2) numbers of active waterfowl hunters (hereafter, hunters).

Funding for US portion of the PPR

To model trends in annual funding for waterfowl habitat conservation within the US portion of the PPR, we used the following eight annual datasets (Table 3): (1) number of active waterfowl hunters in the USA (USFWS 2017*b*); (2) face value of a USA federal duck stamp (FDS; S. Fellows, unpubl. data); (3) disbursements by the Migratory Bird Conservation Fund (MBCF); (4) duties from USA imports of firearms and ammunition (henceforth, arms imports); (5) disbursements by the Land and Water Conservation Fund; (6) funding for NAWCA projects, including the required 1 : 1 match from non-USA-federal partners (USFWS 2014); (7) funding for NAWCA projects beyond the required 1 : 1 match (henceforth, surplus matching funds); and (8) proportion of MBCF allocated to the USA PPR. Unless otherwise noted, data were not publicly available and were provided by the USFWS National Wildlife Refuge Division of Realty or the USFWS Migratory Bird Program Division of Bird Habitat Conservation. Matching funds for NAWCA projects in the USA were generated from a similar diversity of partners as in Canada. States and wetland conservation NGOs (e.g. Ducks Unlimited) played a major role. These NGOs aggregated funding from many partners, including private individuals and industry (Anderson and Padding 2015; USFWS 2015*b*).

A policy was implemented in 2012, whereby 70% of the total annual MBCF was to be allocated to the USA PPR (USFWS 2012). To examine the effect of this increase on received funds, we conducted a back-casting analysis that began by calculating the median of this annual allocation from 2007 to 2011. We then levelled the allocation by replacing the observed allocations from 2012 to 2016 with the median of earlier allocations (henceforth, back-casting scenario).

The MBCF includes revenues from sales of FDSs and duties on arms imports, along with other sources (USFWS 2018*b*). We distinguished purchases of FDSs as required for waterfowl hunting licenses (henceforth, licence-based FDS purchases) from voluntary purchasing of stamps (henceforth, non-licence-based FDS purchases) by stamp collectors and waterfowl enthusiasts, including those by waterfowl hunters who purchase >1 FDS. In this way, we were able to examine the contributions of waterfowl hunters to funding for waterfowl conservation. Annual revenues from licence-based purchases of FDSs were

calculated as the number of active waterfowl hunters times the face value of the FDS. Annual revenues from non-licence-based purchases of FDSs were calculated as total FDS sales minus the number of active waterfowl hunters times the face value of the stamp. Dollar estimates were converted to US$ (based on 2016 value) by using USA Bureau of Labour Statistics Consumer Price Index Inflation Calculator (https://data.bls.gov/cgi-bin/cpicalc.pl, accessed 7 February 2020).

Model fitting

To examine the hypotheses and predictions, we used generalised linear models (GLMs) and generalised additive models (GAMs). These have become standard techniques for time-series analysis (Imai *et al.* 2015; Wooldridge 2015; Liboschik *et al.* 2017). We began the model-fitting process by inspecting the homoscedasticity and normality of residuals when regressing the untransformed response variable with the full set of predictors. We started with a normal link function for analysing magnitudes in funding. If there was substantial deviation of residuals from normality for a given model, we tried three general approaches. First, we fitted the model using Tukey's ladder of powers (TLP) transformation (Mangiafico 2016). Compared with the more well known Box–Cox transformation (Box and Cox 1964), TLP transformation yields similar levels of normality and has a more straightforward transformation. This led to models meeting the regression assumptions for all response variables except for magnitudes of main sources of funding for the USA PPR. For this untransformed response variable, we used quantile regression. This semiparametric approach assumes that fixed effects are asymptotically normal, but there is no distributional assumption for the residuals (Cade and Noon 2003). This method is especially suitable for investigating complex phenomena when only some covariates are known and included. Here, we examined the 50th percentile (i.e. median) rather than the mean of the predicted relationships between predictors and funding.

For predicting untransformed magnitudes of funding, we also tried fitting GLMs by using discrete distributions, acknowledging that these could exceed performance levels of linear or β regression. Although financial data are scalable and have a continuous nature (i.e. they can be expressed in multiple units such as dollars or millions of dollars), we tried fitting the Poisson distribution with a log link to observed trends in amounts of funding. We also tried fitting the binomial distribution with a logit link to observed trends in proportional contributions of individual funding sources to waterfowl conservation in the USA PPR. Based on the deviance and Chi-squared tests of goodness-of-fit (Agresti 1990) using $\alpha = 0.05$, there was strong evidence for overdispersion when fitting these discrete distributions.

Finally, recognising that funding levels can be only positive but are essentially continuous, we tried fitting a gamma distribution with a log link and with an identity link to the untransformed response variables. Under both gamma models, the residuals differed substantially from normal. We, therefore, opted to use the TLP transformation for analysing trends in magnitudes of funding. We confirmed the absence of temporal autocorrelation via visual inspection of plots generated by function acr in the stats package for program R (R Core Team 2019). To analyse proportional contributions among individual sources to total funding, we used β regression (Cribari-Neto and Zeileis 2010).

Assessing model performance and making inferences

To compare model performance, we calculated the Akaike's information criterion corrected for small sample size (AICc) and considered models with a ΔAICc value of ≤4 to be the top-performing models (Burnham and Anderson 2002). For some response variables (e.g. NAWCA funding for Canada and numbers of USA hunters), we investigated only a temporal trend, and, so, we made inferences based on the single (trend) model if it outperformed the null model. If the 95% confidence interval (CI) surrounding the year effect excluded zero, then we inferred a significant trend. We derived predictions from the top-performing model or models, and we used these for plotting and for reporting regression-based estimates for any significant trends. To represent the CI for the year effect on proportional contributions, we used the distance between the 2.5th and 97.5th percentiles of the modelled β distribution. Symmetrical CIs (i.e. from untransformed normal regression) are presented as mean ± CI, and asymmetrical CIs are presented as '[lower, upper]'. If predicted magnitudes or proportional contributions of funding differed by ≥10%, then these were considered to be meaningful. We used program R version 3.5.3 (R Core Team 2019) for all statistical analyses, and monetary values are reported in US$ (based on 2016 values) unless otherwise noted.

Results

From 2007 to 2011, annual funds for waterfowl habitat conservation were similar for the Canadian and US portions of the PPR (annual averages: US$34 million and US$44 million respectively; Fig. 1, Table 4). During 2012–2016, the average annual funding for the Canadian portion (US$30 million) was similar to funding in the previous period, whereas funding for the USA portion nearly doubled (US$82 million). Likewise, annual funding for the entire PPR increased between time periods from an average of US$78–115 million.

Funding for Canadian portion of PPR

Despite observed interannual variation (Table 4), the null model was best (Tables 5, S2) for explaining variation in annual funds from NAWCA delivered to the Canadian portion of the PPR (US $15.3 million ± 2.3 million). Total annual funding, including the non-federal US and Canadian contributions, averaged US$34.4 million during 2007–2011 and US$33.2 million during 2012–2016. The only top-performing model for explaining variation in state payments was one that included an interaction of year and province. Saskatchewan received the most payments, followed by Manitoba and Alberta (Fig. 2). Trends in annual payments from states varied among the receiving PPR provinces; from 2007 to 2016, there was an estimated 26% increase in payments to Saskatchewan (from US$1.5 million to US$1.9 million), 9% decrease in Manitoba (from US$667 000 to US$607 000), and a 67% decrease in Alberta (from US$425 000 to US$140 000; Fig. 2).

California was the largest contributor to Alberta (Table S3). The trend in annual payments from California declined by 69%, from US$334 000 to US$102 000, during which time the trend in

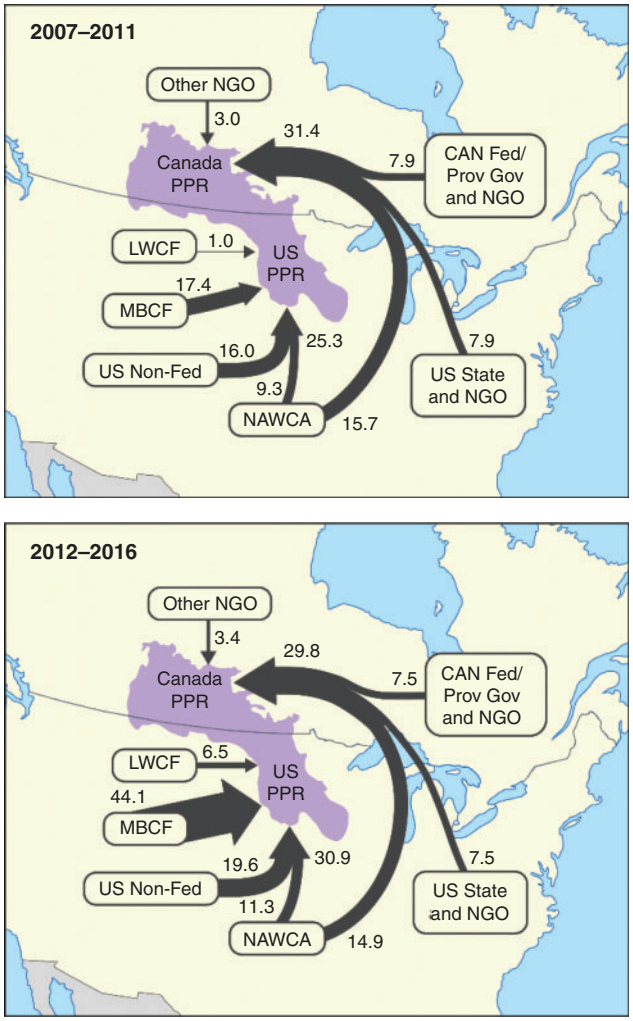

Fig. 1. Comparison of observed funding levels for waterfowl habitat conservation in the Prairie Pothole Region (PPR) of USA and Canada in 2007–2011 and 2012–2016. Thickness of arrows scale with the magnitude of funding, which ranged from US$1.0 million to US$44.1 million (based on 2016 value). Funding for waterfowl conservation efforts beyond the PPR are not shown. CAN, Canada; Fed, federal; Gov, government; LWCF, Land and Water Conservation Fund; MBCF, Migratory Bird Conservation Fund; NAWCA, *North American Wetland Conservation Act* funds; NGO, non-governmental organisation funds; Prov, provincial.

number of hunters in California decreased by 19% from 58 000 to 47 000 (Fig. 3). The decline in payments from California included an ~50% decrease in observed payments from US$345 000 to US$173 000 between 2009 and 2010. From 2010 to 2016, the trend in payments from California decreased by an estimated 15%, from US$171 000 to US$145 000 (Fig. S2).

Illinois was the largest contributor to Saskatchewan (Table S3). From 2007 to 2016, the trend in payments from Illinois to Saskatchewan increased by 36%, from US$409 000 to US$557 000 during which time the number of hunters in Illinois decreased by 32%, from 44 000 to 30 000 (Fig. 3). The increase in payments from Illinois corresponded with an increase in the face value of an individual Illinois duck stamp from US$10 to US$15.50 between 2010 and 2011. From 2011 to 2016, payments from Illinois remained between US$512 000 and US$549 000.

Funding for US portion of the PPR

Based on the top model, variation in funding for the USA PPR varied over years and among sources (Tables 6, S4). The largest source was MBCF, followed by NAWCA and LWCF (Table 4). From 2007 to 2016, the trends in annual amounts of MBCF and LWCF increased from US$19 million to US$60 million and from US$1.2 million to US$14.5 million respectively (Fig. 4). Although not statistically significant, the trend in NAWCA increased during the period from US$16 million to US$25 million. We detected no trend in surplus matching funds for NAWCA, which were highly variable and averaged US$6.4 million (US$0.8 million, US$21.6 million). The trend in proportional contribution from LWCF increased from 4.8% to 14.4%, whereas that from NAWCA decreased from 38% to 25% (Fig. S3). We detected no trend in the proportional contribution of surplus matching funds for NAWCA, which were highly variable and averaged 9.9% (2.4%, 21.8%). Although being not statistically significant, the trend in proportional contribution from MBCF increased from 47% to 56%.

An important driver of the strong increase in magnitude of MBCF was the proportion of the national-level MBCF being directed to the PPR. This allocation ranged from 40% to 72% and corresponded with a 2012 policy to increase the allocation to the PPR (USFWS 2012). The median annual allocation before the increase was 46%. Under the back-casting scenario, the trend in MBCF increased from US$17 million to US$53 million (Fig. S5), such that the maximum of the mean trend was US$7 million less than the empirical maximum of US$60 million.

The largest source of MBCF was duties on imported arms and ammunition into the USA, followed by licence- and non-licence-based sales of FDS (Table 4). The number of active hunters (equivalent to the number of licence-based FDS sales) in the USA declined steadily, starting from 1999, and the decline continued during 2007–2016 from 1.2 million to 1.0 million per year (Fig. S7). Despite this decline, all main sources of MBCF showed strong positive trends; funds from duties on arms imports more than tripled (US$10 million to US$35 million), revenues from licence-based FDS sales nearly doubled (US$7.0 million to US$13.3 million), and non-licence-based sales of FDSs more than tripled (US$2.4 million to US$7.7 million; Fig. 5). Starting in 2015, revenue from licence-based FDS sales rose further, due to an increase in the price of a federal stamp from US$15 to US$25. Under the back-casting scenario of levelling the MBCF allocation to the USA PPR, licence-based FDS sales no longer showed a significant trend (Fig. S6). The remaining sources of funding retained slower, but still significant, trends compared with the empirical results.

The trend in proportional contributions from licence-based FDS sales decreased (36% to 22%), whereas those from arms increased (52% to 60%; Fig. S4). Although being statistically significant, the increase in proportional contributions from rights-of-way was small and not meaningful (0.0% to 0.2%). We detected no trend in proportional contributions of non-licence-based sales of FDS (mean = 13% [7.8%, 19.8%]).

Table 4. Annual funding levels (in millions of US$, based on 2016 values) for waterfowl habitat conservation in the Prairie Pothole Region (PPR) of North America

LWCF, Land and Water Conservation Fund; MBCF, Migratory Bird Conservation Fund; NAWCA, *North American Wetland Conservation Act*; NGO, non-government organisation; PPR, prairie pothole region

Source	2007–2011			2012–2016		
	Mean	Min.	Max.	Mean	Min.	Max.
Funding for Canadian portion of PPR						
NAWCA awards and 1 : 1 match						
USA federal government	15.7	14.1	16.6	14.9	14.0	16.3
Canadian federal government and NGO	7.9	7.1	8.3	7.5	7.0	8.2
State and US NGO	7.9	7.1	8.3	7.5	7.0	8.2
Other NGO[A]	3.0	−2.3	8.0	3.4	−3.0	13.7
Subtotal	34.4	25.9	41.2	33.2	25.0	46.3
Funding for US portion of PPR						
MBCF	17.4	15.4	19.4	44.1	26.4	54.6
LWCF	1.0	0.0	2.2	6.5	0.9	11.8
NAWCA awards and match[B]						
USA federal government	9.3	8.3	7.3	11.3	7.3	15.3
States and USA NGOs	16.0	12.0	19.5	19.6	8.5	35.3
Subtotal	43.7	35.7	48.4	81.5	43.1	117.0
Total	78.1	61.6	89.6	114.7	68.1	163.3
Main MBCF sources[C]						
Federal duck stamp, licence-based	5.9	4.9	6.5	10.3	6.8	14.3
Federal duck stamp, non-licence-based	2.2	1.7	2.7	5.8	3.5	7.0
Arms imports	9.2	8.0	10.9	25.9	16.1	30.6
Subtotal	17.2	14.6	20.1	42.1	26.4	51.9

[A]Negative values indicate deficits in years when NGOs contributed less than the required 1 : 2 NAWCA match; positive values indicate surpluses during years when NGOs contributed more than the required NAWCA match.
[B]Funds for NAWCA projects include match of at least 1 : 1 from non-USA federal partners.
[C]Minor sources are excluded from the list of major sources of MBCF, and, therefore, the subtotal is less than the MBCF total.

Discussion

Funding for waterfowl habitat conservation in the US and Canadian portions of the PPR is complex, temporally dynamic and spatially heterogeneous. We have provided the first system-wide analysis of conservation funding for this critical waterfowl breeding habitat, showing strong contrasts in funding for waterfowl habitat conservation over the past decade. Funding for Canada PPR has been comparatively stable (Prediction 2). By contrast, multiple funding streams for the USA PPR have sharply risen, despite declines in the number of active waterfowl hunters in the United States (Prediction 3). Funding levels were similar between US and Canadian portions of the PPR in 2007 (Prediction 5). By 2016, funds for the USA PPR tended to exceed those of Canada PPR (Prediction 6). In addition to identifying trends, we also detected a substantial amount of statistical uncertainty surrounding these trends. Taken together, our findings support the hypothesis that trends in funding are divergent between countries, owing to the diverse and independent sources for funding directed towards the US portion of the PPR. Considering the entire study period, our results contradict Predictions 1 and 2 that funding for the PPR has decreased or remained static. Understanding these contrasts and dynamics is important for future conservation planning, so that practitioners have a better sense of what kinds of changes can occur within a 10-year period on either side of the border.

Funding for Canadian portion of PPR

Knowledge about variation in funding among PPR provinces is important for habitat conservation planning. These conservation efforts tend to be spatially explicit and must account for landscape heterogeneity across the Canadian PPR (PHJV 2014). Total funding across provinces remained constant among years (Prediction 2). However, trends in payments from states to individual PPR provinces diverged across time and among provinces (Predictions 1, 2 and 6). This spatiotemporal variation in funding is explained by changes in funding from a small subset of states that annually contribute the majority of these funds. Although discrepancies in annual state payments among provinces can be compensated by other NAWCA matching sources (i.e. NGO and Canadian government), a substantial decrease in total state payments would prevent acquisition of the necessary sum of matching funds, thus reducing total conservation investment.

Trends in state payments to PPR provinces were often non-linear and apparently driven by abrupt changes in policy. Such juxtaposed trends in funding challenge long-term conservation planning and, in particular, optimal allocations of resources among and within provinces. In California (CA), the largest contributor to Alberta, there was a substantial drop in payments from 2009 to 2010 and then payments slowly declined afterward. In 2008, a ballot measure (Proposition 99) was approved that eliminated the budget item under the CA Comprehensive

Table 5. Model selection information for numbers of hunters in paying states and funding allocated to the Canadian (CN) portion of the Prairie Pothole Region (PPR)

Response variables include years 2007–2016 unless otherwise noted. Model with the lowest AICc value per response variable is highlighted in bold. Variable indexes: *t*, year, *p*, province. Adj., adjusted (a negative adjusted R^2 indicates negligible ability of the model to predict the data.); AICc, Akaike's information criterion corrected for small sample size; AB, Alberta; CA, California; hunters, hunters in states sending payments to focal province; IL, Illinois; NAWCA, *North American Wetland Conservation Act*; SK, Saskatchewan; pays, state payments to PPR provinces; TLS, Tukey's ladder of powers transformation of response variable

Model	Figure	Regression type	d.f.	Adj. R^2	Log-likelihood	AICc	ΔAICc	AICc weight
$CN\_NAWCA_t =$	n.a.	Normal						
$\boldsymbol{\beta_0}$			**2**	**0.00**	**−13.2**	**32.2**	**0.0**	**0.834**
$\beta_0 + t \cdot \beta_1$			3	−0.01	−12.7	35.4	3.2	0.166
$pays_{t,p} =$	2	Quantile						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,p} + t \cdot \beta_{3,p}}$			**6**	**0.98**	**−373.6**	**762.8**	**0.0**	**0.999**
$\beta_0 + hunters_t \cdot \beta_1 + \beta_{2,p} + hunters_t \cdot \beta_{3,p}$			6	0.97	−381.1	777.8	15.0	0.001
$\beta_0 + \beta_{2,p}$			3	0.96	−390.7	788.4	25.5	0.000
β_0			1	0.00	−444.0	890.1	127.2	0.000
$ILhunters_t =$	3	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.76**	**−92.1**	**194.1**	**0.0**	**0.996**
β_0			2	0.00	−99.7	205.1	11.0	0.004
$CAhunters_t =$	3	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.55**	**−93.3**	**196.5**	**0.0**	**0.923**
β_0			2	0.00	−97.9	201.5	5.0	0.077
$IL\_pays\_SK_t =$	3	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.59**	**−119.0**	**248**	**0.0**	**0.950**
β_0			2	0.00	−124.1	253.9	5.9	0.050
$CA\_pays\_AB_t =$	3	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.67**	**−121.5**	**252.9**	**0.0**	**0.982**
β_0			2	0.00	−127.6	260.9	8.0	0.018
$CA\_pays\_AB\_2010\_2016_t =$	S2	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**2**	**0.48**	**−75.1**	**157.2**	**0.0**	**0.634**
β_0			3	0.00	−72.2	158.3	1.1	0.366

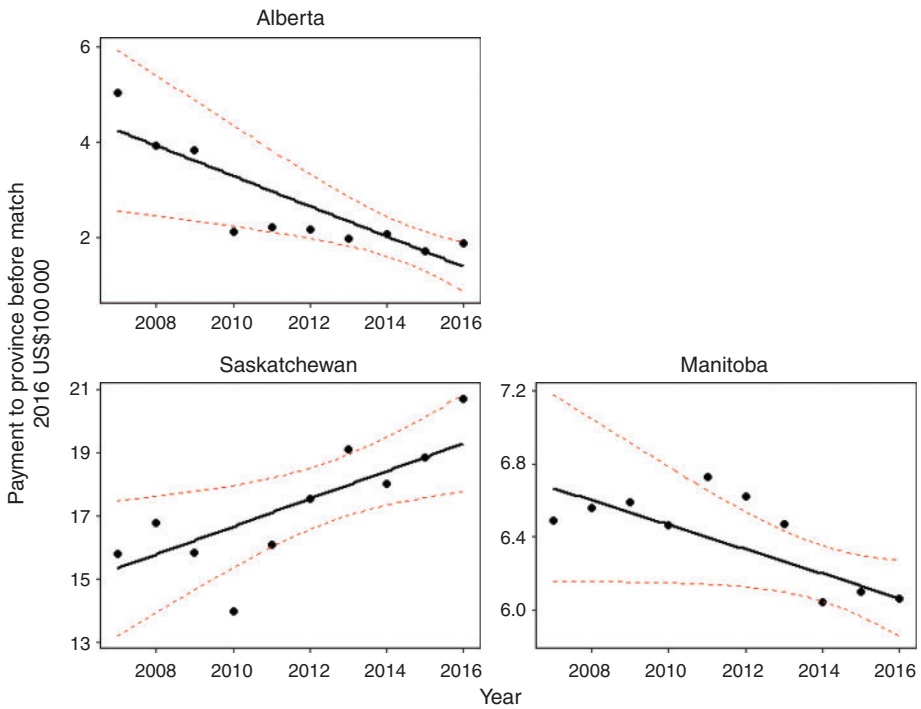

Fig. 2. Trend in payments from USA states for waterfowl habitat conservation in Canadian provinces within the prairie pothole region from 2007 to 2016. Monetary values do not include matching funds from Ducks Unlimited nor USA federal sources. Solid line is the best fit, and the dashed lines are the upper and lower 95% confidence limits.

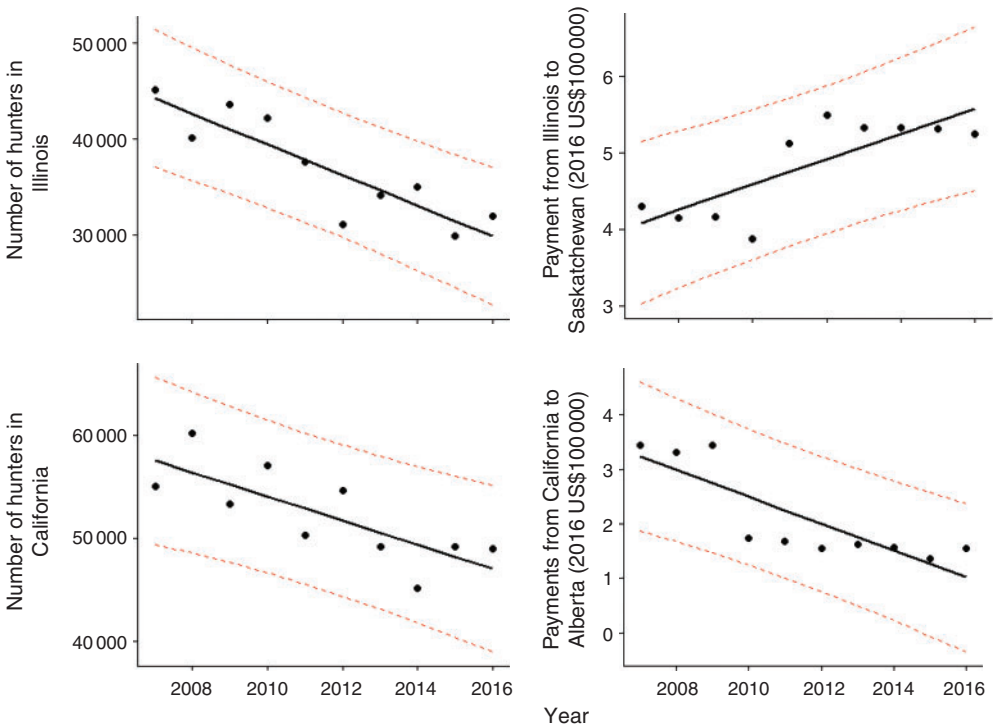

Fig. 3. Changes in annual numbers of hunters and payments from states contributing the most to waterfowl conservation in the Canadian portion of the Prairie Pothole Region from 2007 to 2016.

Wetlands Program, which specified annual financial contributions towards waterfowl habitat conservation in Alberta (M. Weaver, CA Department of Fish and Wildlife, pers. comm.). This change went into effect in 2010, causing the observed decrease in payments. The subsequent and slow decline in payments from CA to Alberta was expected for two reasons. The number of hunters in CA declined during this period, and the CA legislature specified that a fixed amount of funds per state duck-stamp sale was to be delivered to Canada (CA Department of Fish and Wildlife 2018).

By contrast, annual payments from Illinois, which make up the largest annual payment to Canada of any state, were decoupled from the observed decrease in the number of waterfowl hunters within the state. This decoupling has been attributed to a substantial annual surplus in the state duck-stamp fund carried over every year, allowing the state to contribute a consistent annual amount to Canada (R. Smith, Illinois Department of Natural Resources, pers. comm.). However, the annual payment is subject to the price of an individual state duck stamp, which was increased from US$10 to US$15.50 in 2011. This increased stamp price led to a large increase in funding transfers from 2010 to 2011. Since then, annual payments have remained constant despite the continued decline of waterfowl hunters. Waterfowl conservation payments from states in the USA to Canada are not explicitly linked to revenues from licensing fees charged to waterfowl hunters in several other states, including Arizona, Idaho, Louisiana, Missouri and Nevada (L. Naylor, J. Knetter, L. Reynolds, A. Raedeke, and R. Woolstenhulme respectively, pers. comm.). Payments to Canada from these states are, therefore, decoupled from participation in waterfowl hunting, at least to some degree. Taken together, these findings contradict the hypothesis that trends in state contributions are driven by the numbers of active waterfowl hunters in those states.

Funding for the US portion of the PPR

The dominant funding stream for the USA PPR over the past decade has remained the MBCF, and there have been large increases in this fund and its sources (Prediction 3). When considering component funding sources of the MBCF, the largest increase was duties from imports of arms to the USA (henceforth, arms duties). We did not expect that arms duties, which are not directly tied to waterfowl conservation, have become the dominant source of funding within the MBCF. We had expected that revenues from sales of FDSs (including those based on hunting license purchases) would have been the dominant funding source. The increase in arms imports may be at least partly attributed to increased gun sales following tightened federal gun-control measures (Aisch and Keller 2016; Gius and Paulson 2018). We postulate that this 'gun-control paradox' is a likely contributor towards trends in funding for waterfowl habitat conservation. This counterintuitive knock-on effect has not previously been identified or anticipated, and this is an important insight that can be gained only through analysis of funding flows. We had not anticipated that arms imports would have a strong influence on trend in funding for habitat conservation, and, so, we identified no *a priori* hypotheses about this effect.

Revenues from both types of FDS purchases (i.e. licence-based and non-licence-based) increased, but to a lesser extent than those from arms duties. These streams of revenue associated with sales of FDSs increased at a similar rate. The

Table 6. Model selection information for annual funding allocated to the US portion of the Prairie Pothole Region (2007–2016)
Model with the lowest AICc value per response variable is highlighted in bold. Variable indexes: *t*, year; *p*, province. Adj., adjusted; AICc, Akaike's information criterion corrected for small sample size; FDS, federal duck stamp; licence, licence-based; like., likelihood; MBCF, Migratory Bird Conservation Fund; TLP, Tukey's ladder of powers transformation of response variable

Model	Figure	Regression type	d.f.	Adj. R^2	Log like.	AICc	ΔAICc	AICc weight
$USPPRfunds_{t,s}^{1/3} =$	4	TLP						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}}$			**9**	**0.84**	**−189.5**	**403.0**	**0.0**	**1.000**
$\beta_0 + \beta_{2,s}$			5	0.70	−205.7	423.2	20.2	0.000
β_0			2	0.00	−229.9	464.2	61.2	0.000
$MBCF_{t,s}^{1/2} =$	5	TLP						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}}$			**9**	**0.97**	**−278.0**	**580.0**	**0.0**	**1.000**
$\beta_0 + \beta_{2,s}$			5	0.85	−311.4	634.6	54.5	0.000
β_0			2	0.00	−350.6	705.5	125.5	0.000
$USPPRfunds_{t,s}/USPPRfunds_{t,\bullet} =$	S3	Beta						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}}$			**9**	**0.84**[A]	**63.2**	**−102.4**	**0.0**	**0.671**
$\beta_0 + \beta_{2,s}$			5	0.77[A]	56.1	−100.5	1.9	0.261
β_0			2	0.00	18.4	−32.4	70.0	0.000
$MBCF_{t,s}/MBCF_{t,\bullet} =$	S4	Beta						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}}$			**9**	**0.97**	**87.6**	**−151.3**	**0.0**	**0.999**
$\beta_0 + \beta_{2,s}$			5	0.94	74.2	−136.7	14.6	0.001
β_0			2	0.00	5.9	−7.4	143.9	0.000
$Backcast\_MBCF_{t,\bullet} =$	S5	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.83**	**−168.9**	**347.9**	**0.0**	**1.000**
β_0			2	0.00	−178.7	363.2	15.3	0.000
$Backcast\_MBCF_{t,s}^{1/2} =$	S6	TLP						
$\boldsymbol{\beta_0 + t \cdot \beta_1 + \beta_{2,s} + t \cdot \beta_{3,s}}$			**9**	**0.97**	**−265.9**	**555.7**	**0.0**	**1.000**
$\beta_0 + \beta_{2,s}$			5	0.94	−284.6	581	25.3	0.000
β_0			2	0.00	−342.9	690.2	134.4	0.000
$License\_FDS\_sales_t =$	S7	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.78**	**−215.1**	**438.0**	**0.0**	**1.000**
β_0			2	0.00	−233.5	471.8	33.8	0.000
$Non\_License\_FDS\_sales_t =$	S7	Normal						
$\boldsymbol{\beta_0 + t \cdot \beta_1}$			**3**	**0.81**	**−228.7**	**465.0**	**0.0**	**0.998**
β_0			2	0.00	−236.6	478.0	13.0	0.002

[A]Pseudo R^2 is reported for models fit using β regression.

concordant trends contradict Prediction 2 that increased sales of non-licence-based FDSs have offset losses in sales of FDSs associated with a decline in the number of hunters.

Recognising that the annual number of licence-based FDS purchases have continued to decline, the increases in MBCF for the USA PPR are largely due to increased allocation of national-level MBCF funds annually delivered to the USA PPR. This allocation increased from <50% to 70%, starting in 2013 (USFWS 2012), along with an increase in FDS cost from US$15 to US$25, starting in 2015. The back-casting analysis indicated that the increased allocation led to a US$7 million annual benefit as of 2016. Political decisions about allocations of MBCF funds, therefore, play a crucial role in waterfowl habitat conservation efforts in the PPR. We also had not anticipated that this shift in allocation and FDS price would have a dominant influence on the trend in MBCF for the US portion of the PPR.

When examining past trends in duck populations, waterfowl hunters and FDS sales, Vrtiska *et al*. (2013) provided evidence for the decoupling of these human and natural systems since the 1990s. Before this period, cycles of increasing and decreasing FDS sales corresponded with fluctuations in duck populations. Despite an apparent decoupling of hunters from duck populations during our study period (2007–2016), the decline in licence-based purchases by waterfowl hunters appears to be offset by an increase in FDS sales unrelated to hunting licences.

Although coupled human and natural systems have received much attention recently (Liu *et al.* 2007; Carter *et al.* 2014), dynamic coupling and decoupling of funding for the management of ecological systems has (to our knowledge) not been considered beyond the context of waterfowl management. Based on our analysis and the findings from previous studies, it appears that the system of waterfowl hunters and duck populations in North America is influenced by dynamic coupling and decoupling of hunting activity from funding for waterfowl habitat conservation. This dynamic system of hunters and duck populations can provide a basis for generating new theories to explain the dynamics of conservation funding.

Considering funding sources beyond MBCF, another prominent increase was in the LWCF (derived from revenues from offshore oil and gas leasing). The increase was evident when considering not only the magnitude of funding, but also the proportional contribution of LWCF to total funds. This finding further supports the hypothesis that increases in non-hunting-based contributions can offset losses of revenue from FDS sales because of the decline in hunters. Allocation of LWCF to the

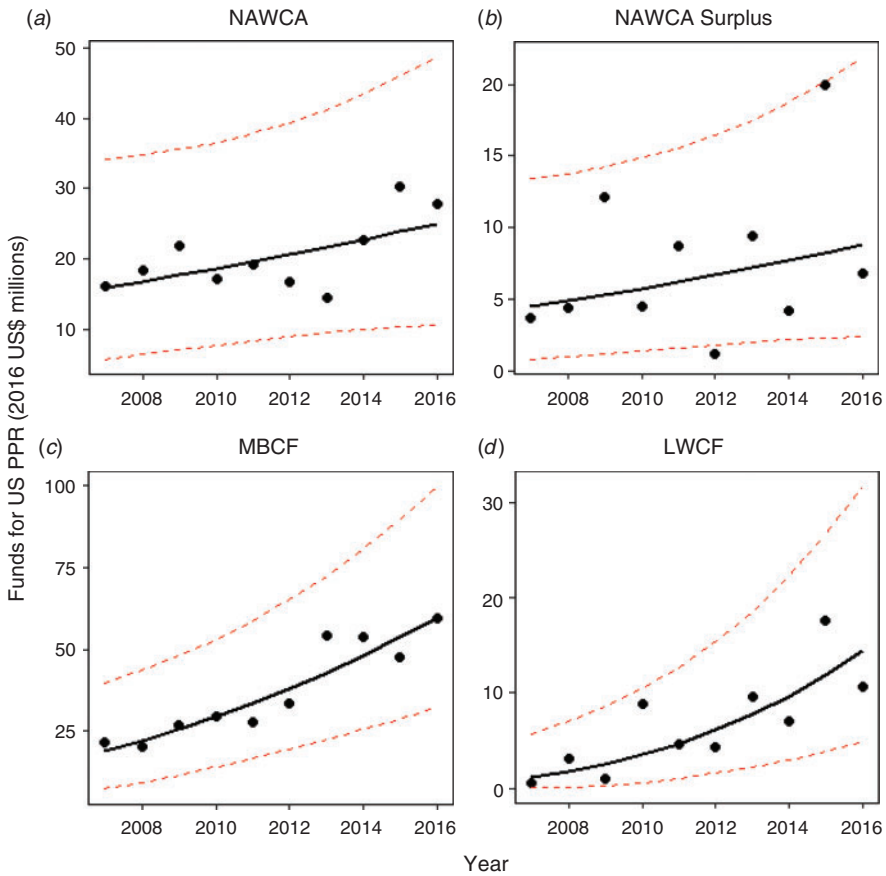

Fig. 4. Trends in main funding sources for waterfowl habitat conservation in the US portion of the Prairie Pothole Region (PPR) from 2007 to 2016: (*a*) *North American Wetland Conservation Act* (NAWCA) funds including 1 : 1 match; (*b*) matching funds for NAWCA exceeding 1 : 1; (*c*) Migratory Bird Conservation Fund (MBCF); and (*d*) Land and Water Conservation Fund (LWCF). Note the differing *y*-axes. Solid line is the best fit, and the dashed lines are the upper and lower 95% confidence limits.

USA PPR increased in 2013 because of increased support from the USA Executive Office and director of the USA Department of the Interior for conservation of the PPR (G. Langer, USFWS, pers. comm.). Use of the Targeted Resource Acquisition Comparison Tool (TRACT; USFWS 2016*a*), a scoring system for conservation funding allocation, began in 2016. TRACT ranked the PPR as having a higher biological value than other regions; therefore, LWCF appropriations to the PPR were maintained. TRACT ranks land acquisitions based on each of the following three independently assessed priorities: (1) recovery of threatened and endangered species; (2) implementing the North American Waterfowl Management Plan (NAWMP); and (3) conserving migratory birds of conservation concern. The former tool (Land Acquisition Priority System) did not explicitly consider NAWMP (USFWS 2014). Additional factors have been considered in the allocation of LWCF funds, including leveraging of funds, participation of conservation partners, and urgency to implement projects (USFWS 2016*a*). Neither scoring system has been described in detail in the peer-reviewed literature. The increased funding through NAWCA in the latter time period was largely attributed to criminal penalties related to the Deepwater Horizon oil spill along the Gulf Coast in 2010 being allocated to the PPR, totalling US$20 million from 2014–2016 (N. Siak, unpubl. data).

Prospects for the future

We observed a high amount of annual and spatial heterogeneity among funding sources directed towards waterfowl habitat conservation. This heterogeneity is likely to be attributable to shifts in political decisions or recovering damages (e.g. Deepwater Horizon spill; USFWS 2015*a*) that in many cases have little or no connection with participation in waterfowl hunting. The one exception is increases in the price of a FDS. During our study period, there was a single increase in FDS price from US$15 to US$25 in 2015 that corresponded with an increase in total FDS revenues. Given this variation, which often appeared stochastic and was occasionally substantial in magnitude, generating reliable predictions of future funding levels at this time is problematic. Nonetheless, making predictions for future trends in funding would be useful to inform optimal allocations of funding (McBride *et al.* 2007; McDonald-Madden *et al.* 2008).

Conservation plans developed for the PPR by Migratory Bird Joint Ventures (PHJV 2014; PPJV 2017) provide spatial

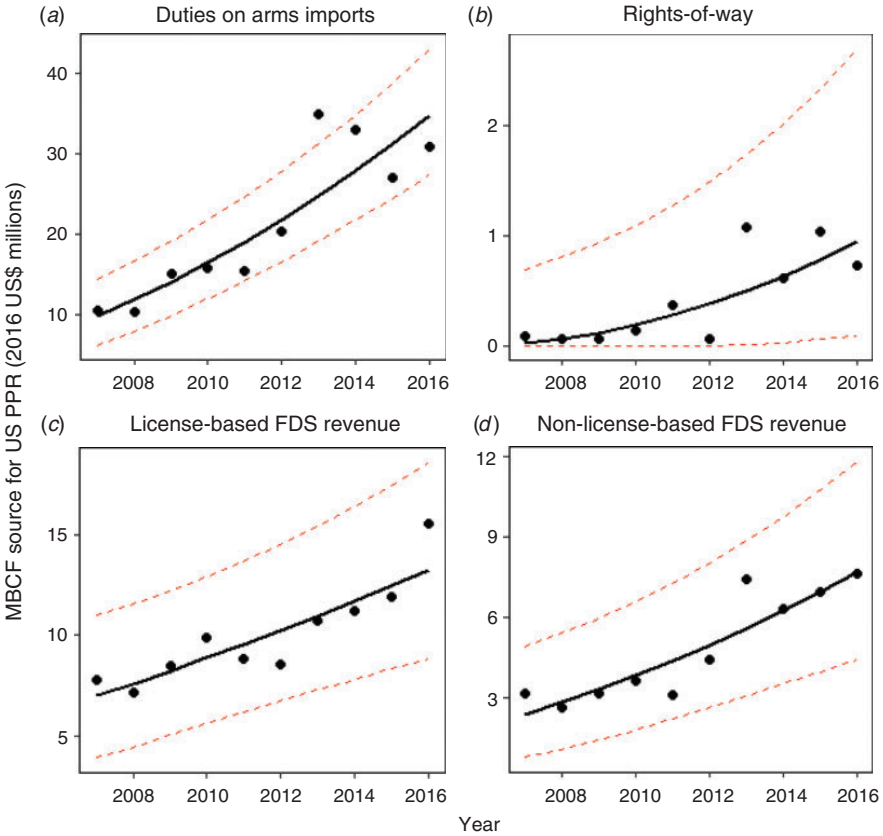

Fig. 5. Trends in sources for Migratory Bird Conservation Fund (MBCF) for waterfowl habitat conservation in the US portion of the Prairie Pothole Region (PPR) from 2007 to 2016: (*a*) duties on arms imports into the USA; (*b*) sales of products from rights-of-way across national wildlife refuges; (*c*) licence-based sales of federal duck stamps (FDSs); and (*d*) non- licence-based sales of FDSs. Note the differing y-axes. Solid line is the best fit, and the dashed lines are the upper and lower 95% confidence limits.

prioritisations of habitats that should be acquired, leased or managed to cost-effectively achieve objectives based on biological requirements of waterfowl. Efficient allocation of conservation resources under these plans is challenged by uncertainties about funding and other socioeconomic changes such as shifts in land values (and, therefore, costs of acquiring lands and securing easements) and spatial distribution of willing landowners. Knowing the likely magnitude of annual funding for habitat programs during several years into the future would better allow managers to retain the appropriate number of personnel to conduct work and optimise activities to achieve those objectives.

In the absence of knowledge about future funding, allocating resources in a way that assumes the minimum expected level of funding would align with the precautionary principle of conservation, informed optimism and robust decision making (Noss *et al.* 2002; McDonald-Madden *et al.* 2008). Although this approach is suboptimal for achieving population objectives when future funding is actually more than expected, it avoids missing short-term opportunities for habitat conservation within a single year. Informed opportunism leads to allocation of resources for clear short-term gains in habitat conservation in an effort to achieve long-term population objectives in the face of great uncertainty about future funding.

When considering future funding in the USA PPR, a critical assumption is that the allocation of MBCF to the USA PPR will remain at 70% of the total annual appropriation (USFWS 2012). This policy is currently set to expire in 2021 (Ashe 2016). If this fraction were to decrease, there would be a sharp reduction in funding for waterfowl habitat conservation in the USA PPR. If, instead, the allocation remains constant, we expect a gradual decline in total funding. This expectation is predicated on an assumption that active waterfowl hunters in the USA continue to decline, whereas other sources of funding (especially LWCF and duties from arms imports) stabilise instead of continuing to increase.

The observed increase in non-licence-based purchases of FDSs may be explained by an increase of 700 000 in the number of wildlife watchers in the USA between 2006 and 2016, and, in 2016, nearly half of these were waterfowl watchers (USFWS 2016*b*, pp. 89, 114). Another investigation found no significant increase in the number of wildlife viewers in the USA during our study period (Outdoor Foundation 2018), and, so, there is uncertainty about this trend. A putative rise in waterfowl viewing and non-licence-based purchases of FDSs may be too slow to compensate for future declines in licence-based FDS purchases. Outreach campaigns for waterfowl habitat conservation, bolstered by arguments about willingness-to-pay for

enhanced ecosystem services (e.g. carbon sequestration, pollination; Johnson *et al.* 2016; Haefele *et al.* 2019), could help accelerate the trend in non-licence-based purchases of FDS revenues. Additionally, programs encouraging participation in waterfowl hunting (Gassett 2018) may slow or reverse the negative trend in licence-based FDS purchases.

Reverted federal aid (RFA) funds (i.e. unspent tax revenue from sales of guns and ammunition as authorised by the *Pittman–Robertson Act*) are a substantial component of the MBCF (annual funds ranged from US$0.5 million to US$3.6 million), but these funds were unavailable for spending until 2015. Although RFA funds were authorised in 1979 (Office of the Law Revision Counsel 2019), no funds were allocated to the MBCF from 2002 to 2013. Assuming that these funds continue to be available in future years, they will likely be important for waterfowl habitat conservation in the USA PPR during the coming decade.

Future research and conclusions

Our analysis revealed important insights about funding for habitat conservation in a transboundary region that is crucial for supporting breeding and migrating waterfowl throughout North America. We quantified multiple streams of funding for the transboundary PPR, showing that funds going to the US portion of the PPR were highly variable and showed an increasing trend from US$36 million in 2007 to US$100 million in 2016. On the US side, we also discovered a recent shift in funding from hunter-based to non-hunter-based sources (i.e. duties on imports of arms, revenues from oil and gas leasing, and non-licence-based FDS purchases). By contrast, funds for the Canadian portion were stable and averaged US$31 million per year. This constancy owes to a consistent allocation of NAWCA funds and a consistent 1 : 1 match from non-federal US partners and Canadian sources. Although existing literature has identified some of the main sources of funding for waterfowl conservation in North America, we now have quantified recent spatiotemporal dynamics in each of the major funding sources and how they compare among geographies of the PPR.

Future work should focus on a series of innovations. First, research on funding flows for conservation can build on the present work and existing literature (e.g. Vrtiska *et al.* 2013; Anderson and Padding 2015) to gain a better understanding of future funding for habitat conservation for migratory species. We have a limited understanding of the social drivers of funding dynamics, which would improve reliability of funding forecasts. For example, a comprehensive analysis linking waterfowl-based recreation (i.e. hunting and viewing) with funding for waterfowl habitat conservation remains to be undertaken. Another example is investigating the relationship between habitat available for conservation investment among PPR provinces and decisions by states to send money to Canada and the decision by the PHJV on where to spend that money. Second, unknown is the effect of changes in FDS prices on FDS sales and revenues for the MBCF, which is critical for predicting future funding for waterfowl habitat conservation. Funding scenarios can then be linked to forecasts for habitat conservation and associated population dynamics (e.g. Mattsson *et al.* 2012).

Third, comparing current patterns of funding to estimates of spatial subsidies associated with ecosystem services (e.g. López-Hoffman *et al.* 2017; Bagstad *et al.* 2019) being transferred by migrating waterfowl will provide important insights into potential mismatches in allocations among regions. Last, developing a common database tracking the major sources of funding for habitat conservation would enable scientists and practitioners to regularly assess and update our understanding in this emerging field of research. This tracking would allow for more efficient and effective jurisdictional conservation planning that takes into account anticipated and observed shifts in funding. These approaches can also be applied to fill gaps in understanding about dynamics among multiple streams of funding for conserving other migratory species or waterfowl in other regions of the world.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

This work was funded by a National Science Foundation award (DEB-1118975) to López-Hoffman. We thank K. Bagstad, four anonymous reviewers, and the Editor in Chief for their helpful comments and suggestions on previous versions of the manuscript. We also thank the following individuals and USFWS programs for providing data: K. Fowler and S. Hutchcroft (Division of Realty, National Wildlife Refuges, Mountain Prairie Region); N. Siak (Gulf Restoration Program, South-east Region); S. Fellows, R. Levin, and R. Sullivan (Migratory Bird Program). In addition, we thank D. Smith (Association of Fish and Wildlife Agencies), D. Mehlman (The Nature Conservancy), along with P. Kehoe, D. Kostersky, and H. Thomas (Ducks Unlimited Canada) for providing data and information about funding. Furthermore, we are grateful for the following state representatives of USFWS Migratory Bird Flyways who provided information about state duck stamps: J. O'Dell (AZ), L. Naylor (AR), M. Weaver (CA), A. Fanning (FL), O. Jones (IA), J. Knetter (ID), R. Smith (IL), T. Bidrowski (KS), J. Brunjes (KY), L. Reynolds (LA), S. Cordts (MN), A. Raedeke (MO), H. Havens (MS), C. Wightman (MT), M. Vrtiska (NE), R. Woolstenhulme (NV), R. Murano (s.d.), J. Feddersen (TN), and T. Finger (WI).

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