FINAL REPORT WY-17/07F

EVALUATION OF WETLAND MITIGATION IN THE GREATER YELLOWSTONE ECOSYSTEM: WILDLIFE POPULATION AND COMMUNITY RESPONSES

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METRIC CONVERSION CHART

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

AIC – Akaike's information criterion
AICc – Akaike's information criterion corrected for small sample size
BR – Blackrock study area
CI – Confidence Interval
DF – Degrees of freedom
f – Per-capita adult recruitment rate from Pradel model
FHWA – Federal Highway Administration
GYE – Greater Yellowstone Ecosystem
N – Abundance
SD – Standard deviation
SE – Standard error
TOG – Togwotee Pass study area
USFS – United States Forest Service
WYDOT – Wyoming Department of Transportation

CHAPTER 1: EXECUTIVE SUMMARY

The landscape around the Blackrock Ranger Station and nearby Togwotee Pass in Teton County, Wyoming, provides an excellent natural laboratory to assess wetland mitigation efforts. This area has an abundance of natural wetland sites, wetlands that have been impacted by construction, and wetlands that have been created as mitigation sites. The purpose of this study is to provide WYDOT with information on differences among wetlands created to mitigate for wetland loss (n=10), wetlands impacted but not destroyed (n=7), and nautral wetlands (n=16), relative to aspects of wildlife that use these habitats. Although long-term efforts are necessary to quantify the ultimate success of created wetland sites, our study provides short term information about a suite of species (4 amphibians, birds, invertebrates, and a pathogen, the amphibian chytrid fungus) and their association with these created and impacted sites relative to nearby natural sites. At Blackrock, the Phase I created wetland, Quarry (QU, built in 2008), has characteristics attractive to these groups of wildlife, especially amphibians: variable depth and a range of microhabitats (e.g., warm shallow areas [i.e., attractive breeding habitat], and retention of water into late summer); an intermediate hydroperiod (defined here as how long water is retained); and emergent vegetation (sedges and young willows) that increase habitat complexity. Swan Pond (SP), the oldest created site at Blackrock, seems the least attractive to our focal species, likely because it is deep and cold relative to QU and receives intermittent flowing water from Blackrock Creek. These man-controlled circumstances lead to extremely variable hydroperiods from year to year and colder temperatures. Created wetlands were generally shallower and had less emergent vegetation than natural wetlands, and invertebrate and amphibian communities differed between them. At Togwotee Pass, most of the created wetlands were too shallow to retain water long enough for successful amphibian reproduction, but there was little difference between natural and impacted wetlands in depth. For example, amphibian and invertebrate communities in impacted wetlands at Togwotee Pass (on average) were not different from natural wetlands, suggesting that if the impact is minimal (e.g., < 25%), wetlands retain their full suite of natural functions.

We assessed several demographic parameters for boreal toads at three natural and three created wetlands at Blackrock to determine if survival and recruitment varied relative to wetland type. We also estimated survival and recruitment for chorus frogs at the one created site (QU). Survival estimates for boreal toads were generally high at both created and natural wetlands; however, demographic parameter estimates were driven primarily by Oxbow (OX, natural) and QU (created) because populations were largest at these sites. The toad population at OX was affected by high river flows in 2011 that breached the levee between the Oxbow and the Buffalo Fork River, subsequently reducing the amount of standing water available to amphibians (habitat especially important for breeding). This event reduced apparent survival of toads considerably in 2011, reduced recruitment, and increased emigration away from the site. QU provided shallows (and thus warm habitat for egg development and tadpole growth), and deep water to prevent drying so that larvae had adequate time to metamorphose. QU is also near to other amphibian breeding sites, which facilitated rapid colonization. QU was highly productive and likely represents an optimum design for amphibian habitat. Chorus frog survival at QU was also high and within the range of other survival estimates in similar habitat. Calling activity of chorus frogs began earliest at created sites, notably QU, likely because of the shallow water and warm temperatures. Calling was most intense at QU and most variable at SP. QU was the only created wetland where we found evidence of breeding by spotted frogs, likely because it had emergent vegetation in areas of shallow water. Impacted wetlands at Togwotee Pass had similar numbers of spotted frog egg masses as natural wetlands.

The pathogenic amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, Bd) has been linked with decline of amphibians globally, including declines of boreal toads in the Rocky Mountains and at Blackrock. We tested boreal toads, spotted frogs, chorus frogs, and tiger salamanders for the presence of this fungus using molecular methods. Prevalence of the fungus was generally high (>50%) for all species. We found no difference in prevalence in boreal toads between natural and created wetlands (the only species we had enough data to formally test for differences based on wetland type).

We also assessed variation in wetland occupancy by amphibians (i.e., presence of a breeding population) relative to wetland type at Togwotee Pass. For chorus frogs and spotted frogs, the probability of occupancy depended on wetland type. No created wetlands were occupied by spotted frogs. Similarly, wetlands were less than half as likely to be occupied by chorus frogs as were natural and impacted sites. Colonization and extinction rates were the same for both species across all wetland types. Occupancy of tiger salamanders did not differ among wetland types at Togwotee Pass, but extinction rates in salamanders were high. Boreal toads were too rare at Togwotee Pass wetlands to formally assess occupancy, but the only two wetlands where we detected boreal toad larvae at Togwotee were created wetlands that were colonized <1 year after they were created.

In addition to amphibian-focused metrics, we also assessed how invertebrates and birds responded to wetland mitigation. For invertebrates, we identified 63 taxa from 13 orders of invertebrates. On average, natural and impacted wetlands had higher species richness (both taxa) than created wetlands. QU (the oldest created wetland) was a notable exception because it had the highest species richness of any site — this observation further supports our conclusion that QU (prior to the creation of the nearby "mitigation lake") provides a good model for mitigation wetlands. We also assessed the use of natural versus created wetlands by songbirds, focusing on riparian-obligate or riparian-dependent species. OX and Heron (HE) (both natural) sites had the highest mean bird species richness, although Qu (created) was similar.

Understanding how "non-focal" animals use created wetlands sites is critical to understanding the efficacy of mitigation efforts, but also to conservation, and the potential importance of created sites when natural events catastrophically reduce breeding habitat. This report provides baseline data for continued monitoring of these created sites and highlights characteristics in created sites that are advantageous to multiple species that are perhaps "non-focal", but important members of the natural community.

CHAPTER 2. INTRODUCTION AND PROBLEM DESCRIPTION

Freshwater wetlands perform numerous essential abiotic and biotic functions, including water purification, flood protection, carbon storage, and the provision of habitat for flora and fauna across taxa (Contanza et al. 1997). Human activities such as urban development, agriculture, and road construction have caused a large-scale reduction in wetland area worldwide (Zedler and Kercher 2005). For example, of the estimated 89 million acres of wetlands present in the contiguous United States in the 1780s, over half have been drained, dredged, or filled (Johnston 1994). Conservation education and legislation have slowed this trend in recent years (Dahl 2011), and mitigation of wetland loss from large-scale projects like road construction and industrial development is now required under *Section 404 of the Clean Water Act* (Hough and Robertson 2008). Discharge of dredged or fill materials into waters of the United States, including most wetlands, is also prohibited without a permit from the U.S. Army Corps of Engineers, and is largely guided by the 1989 executive policy of "no net loss" of wetlands: loss of wetlands area and function must be mitigated by an equal or greater number of acres of gains, achieved either through wetland restoration or construction (Turner et al. 2001). Through this policy and others, several million hectares of wetlands have been created and restored in North America, representing an investment of over $70 billion (Copeland 2010). Nevertheless, the capacity of mitigation wetlands to replace natural wetland functions remains uncertain (Moreno-Mateos et al. 2012).

While providing habitat for wildlife is a critical wetland function, most compensatory mitigation permits require only limited monitoring of vegetation and hydrology (Matthews and Endress 2008). As a result, the capacity for mitigation wetlands to provide quality habitat for wildlife, including invertebrates and amphibians, remains uncertain. Amphibian decline is a problem of local and global importance, with over 40% of species considered at risk worldwide (Stuart et al. 2004). In Wyoming, the Wyoming toad (*Anaxyrus baxteri*) has been extirpated in the wild and is federally-endangered (U.S. Fish and Wildlife Service 2015), the boreal toad (*A. boreas*) is currently being assessed for federal listing and is a state species of special concern (Lewis 2011), and the northern leopard frog has disappeared from the Greater Yellowstone Ecosystem (Ray et al. 2014). Habitat loss is a primary cause of most amphibian declines, (Pounds and Masters 2009), but declines have been noted in protected areas as well (Adams et al. 2013). Disease is one factor that is linked with population declines even in areas with little habitat loss (Muths et al. 2003). Thus, evaluating the use of created and restored wetland habitat by amphibians and other wildlife is critically important, even in pristine areas.

The 62 km reconstruction of U.S. Highway 26/287 over Togwotee Pass between Dubois and Moran, Wyoming began in 2006, and was completed in 2013. The Wyoming Department of Transportation (WYDOT) added shoulders and passing lanes, as well as underpasses for wildlife and snowmobilers, to improve safety on the popular route into Yellowstone and Grand Teton National Parks. Because the road bisects wetland and riparian areas, widening the road affected several acres of natural wetlands, including the destruction of some wetlands. To comply with U.S. Army Corps of Engineers permit conditions, WYDOT completed construction or restoration of 38 mitigation wetlands along the Highway 26/287 corridor and at the aggregate pit site at the U.S. Forest Service Blackrock Ranger Station (Blackrock).

The Phase I wetland mitigation site (aka, Quarry or QU) excavated near the aggregate pit was designed to provide woody riparian scrub-shrub wetland as mitigation for area lost due to road construction. Quarry was constructed in 2007 and vegetated in 2008. Since then, Phase II and III mitigation wetlands have been constructed both at Blackrock and along highway 26/287, with the final wetlands completed in 2014. Permit conditions required monitoring of vegetation and hydrology in mitigation for 5 years or until they are determined to be “successful”. Success is determined by a high percent cover of desirable wetland plant species and evidence of hydric soils which are permanently or seasonally saturated with water (Johnson and Martinson 2014).

In 2012, we received funding from WYDOT to evaluate and quantify the success of QU in providing adequate replacement habitat for amphibians and other wildlife, as an addition to the metrics required by the permit. The construction of Phase II and III mitigation wetlands Highway 26/287 provided the opportunity to expand our efforts significantly to assess the success of mitigation wetlands at a landscape scale, at no additional cost to WYDOT. Because most previous studies of amphibian use of created wetlands have taken place in the eastern United States, this project is important as a case study in the Intermountain West, where conditions are quite different (high elevation, harsh, cold climate) (Ruhí et al. 2012). We were able to incorporate information from research at Blackrock from 2003 to augment the short-term information that was gathered for this project. This added information added a long-term component to these comparisons and allowed a quantitative look at amphibian demography at focal sites. Although long-term efforts are necessary to quantify the ultimate success of wetland mitigation sites, in a project of minimum time-frame, we illustrate differences among natural, impacted, and created sites, and highlight some characteristics of created sites that are advantageous to “non-focal”, but important, species the wetland community.

CHAPTER 3: OBJECTIVES

The overall objective of this study was to evaluate the use of recently constructed mitigation wetlands by amphibians and other species (birds and invertebrates) relative to natural and impacted wetlands at selected sites along the Highway 26/287 reconstruction project. Our specific objectives were to:

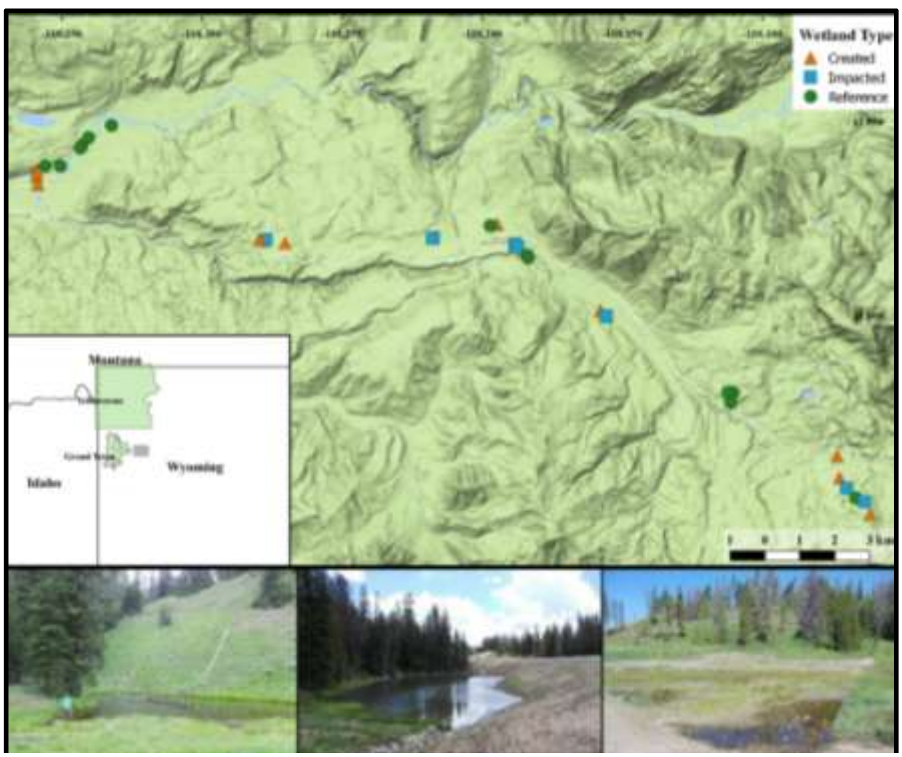
1) Habitat characteristics: Compare habitat characteristics including depth, vegetation, size, and water chemistry (pH and specific conductance) among natural, impacted, and created wetlands.
2) Amphibian demographics: Estimate population parameters for two amphibian species (survival and abundance). Test for difference among these metrics between created and natural wetlands.
3) Amphibian chytrid fungus: Assess prevalence of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, Bd) in natural and created wetlands.
4) Lanscape occupancy of amphibians: Assess landscape occupancy of amphibians in natural, impacted, and created wetlands.
5) Amphibian breeding phenology: Assess differences in amphibian (i.e., chorus frog) breeding phenology between created and natural wetlands using data from automated call recording units.
6) Invertebrate species richness and composition: Compare invertebrate species richness and composition among created, natural and impacted wetlands.
7) Bird species richness and composition: Compare bird species richness and composition between created and natural wetlands using data from automated call recording units.

CHAPTER 4: METHODS

We address the methods for each objective (1 – 7 above), preceded by a brief description of the study site and species to provide context.

Study Area

This study focuses on natural, impacted, and created wetlands in the Bridger-Teton National Forest along U.S. Highway 26/287 between Moran, Wyoming and Togwotee Pass, 12 km east of Grand Teton National Park (Figure 1). This area is within the Greater Yellowstone Ecosystem (GYE), one of the largest nearly intact temperate ecosystems in the world. Wetlands in the GYE comprise only three percent of the total land area, but provide habitat for a disproportionate number of plant, bird, mammal, amphibian, reptile, and invertebrates (Elliot and Heckner 2000, Nicoloff 2003). Despite their importance, wetlands have been understudied in the GYE and throughout the Intermountain West (Copeland et al. 2010). While wetland construction and restoration projects have taken place throughout this region, we know little about the response of faunal communities to these projects.



Source: The map was developed by the authors using QGIS version 2.18.3 (open source GIS software)

Figure 1. *Locations of study wetlands and examples of wetland types (left to right: natural, impacted, created). Orange triangles represent created wetlands (n = 10), blue squares represent impacted wetlands (n = 7), and green circles represent natural wetlands (n =13). The white line is U.S. Highway 26/287. Inset map shows general location. Photo credit – Leah Swartz*

Natural wetlands did not sustain impacts from road construction and were used to provide a baseline against which to compare constructed and impacted sites. Wetland elevations ranged from 2,100 to 3,050 m (6889 – 10,006 ft.). **Impacted wetlands** were partially filled or modified during road construction, but were not completely destroyed. **Created wetlands** were built by the Wyoming Department of Transportation to mitigate wetland loss from a recent road reconstruction project and were constructed between 2005 and 2013 (Table 1). Created wetlands were built in formerly upland areas along the highway corridor and were excavated down to the water table using heavy equipment, then planted with a wetland seed mix and willow cuttings. Wetland elevations ranged from 2,100 to 3,050 m (6889 – 10,006 ft.)

Surrounding vegetation is dominated by a mixture of lodgepole pine (*Pinus contorta*), whitebark pine (*P. albicaulis*), Engelmann spruce (*Picea engelmannii*), and Douglas fir (*Pseudotsuga menziesii*) at higher elevations and mixed sagebrush (*Artemesia tridentata*) – grassland vegetation, at lower elevations. This area is characterized by long, cold winters with heavy snowfall and short, cool summers. Precipitation in this area averages 59.66 cm (23.49 in) annually, falling primarily as snow between November and April. Temperatures vary considerably throughout the year, with an average January high temperature of -3.61 C° (25.5 F°) and average July high temperature of 25.3 C° (77.6 F°) (http://usclimatedata.com/). Average annual snowfall is 369.57 cm (145.5 in) and snow generally persists until late April or early May at low elevations, and as late as July at the top of Togwotee Pass.

Table 1: *Blackrock (BR) and Togwotee Pass (TOG) sites and coordinates (WGS84 datum), ordered by wetland type. An * indicates sites where automated recording units were installed to record calling amphibians and birds. Sites in bold are focal wetlands where demographic parameters were estimated.*

Site	Location	Wetland Type	Elevation (m)	Year Constructed/Impacted	Latitude	Longitude
ML	BR	Created	2089	2014	43.831606	-110.355237
QU*	BR	Created	2089	2008	43.832974	-110.355041
SP*	BR	Created	2093	2005	43.829612	-110.354863
12DC	TOG	Created	2416	2012	43.815439	-110.275797
13AC	TOG	Created	2407	2012	43.814402	-110.266661
16BC	TOG	Created	2644	2010	43.819328	-110.190969
19AC	TOG	Created	2648	2012	43.796993	-110.154039
24CC	TOG	Created	2907	2012	43.759320	-110.069501
25AC	TOG	Created	2934	2012	43.753764	-110.068727
26BC	TOG	Created	2902	2012	43.744350	-110.057735
12CI	TOG	Impacted	2419	2011	43.815183	-110.273461
15AI	TOG	Impacted	2570	2008	43.815647	-110.213866
17AI	TOG	Impacted	2639	2008	43.814075	-110.184459
17BI	TOG	Impacted	2632	2008	43.813512	-110.183592
19BI	TOG	Impacted	2648	2008	43.795557	-110.152028
25BI	TOG	Impacted	2918	2009	43.751002	-110.066158
26AI	TOG	Impacted	2921	2009	43.747511	-110.059788
CH	BR	Natural	2094	NA	43.843675	-110.327600
HE*	BR	Natural	2094	NA	43.844790	-110.328555
MA	BR	Natural	2091	NA	43.835158	-110.338405
MW	BR	Natural	2088	NA	43.834256	-110.352186
ND	BR	Natural	2092	NA	43.839625	-110.339132
OX*	BR	Natural	2092	NA	43.834279	-110.346806
RP	BR	Natural	2091	NA	43.846631	-110.340833
RW	BR	Natural	2093	NA	43.841629	-110.336703
SD	BR	Natural	2092	NA	43.838913	-110.339649
16CR	TOG	Natural	2640	NA	43.818868	-110.193403
17DR	TOG	Natural	2632	NA	43.811254	-110.180287
17ER	TOG	Natural	2632	NA	43.810598	-110.179795
21AR	TOG	Natural	2832	NA	43.775742	-110.106756
21BR	TOG	Natural	2819	NA	43.775807	-110.108568
21CR	TOG	Natural	2808	NA	43.773119	-110.107553
25CR	TOG	Natural	2908	NA	43.748537	-110.062961

Study Species

Amphibians: Four species of amphibians occur in this region: boreal toads *(Anaxyrus boreas),* barred tiger salamanders *(Ambystoma mavortium),* boreal chorus frogs *(Pseudacris maculata),* and Columbia spotted frogs *(Rana luteiventris*). A fifth species, the northern leopard frog (*Rana pipens*), historically occurred in the area, but has been extirpated (Ray et al. 2014). All four species require standing water for breeding, oviposition, and juvenile development, but spend the majority of their adult lives in the terrestrial environment surrounding breeding ponds.

Figure 2: *Amphibian study species from left to right, boreal chorus frog, boreal toad, Columbia spotted frog, and barred tiger salamander (Photo credit – Leah Swartz).*

Boreal toads have declined throughout large portions of their historic range, including the Greater Yellowstone Ecosystem (GYE) (Ray et al. 2014), and now occupy only two to five percent of available breeding sites in Yellowstone National Park (Corn et al. 2005, Hossack et al. 2015). Our previous research indicates that the toad population at Blackrock is declining at five to six percent per year and that the infectious disease chytridiomycosis is contributing to this decline (Muths et al. 2008, Murphy et al. 2009, Pilliod et al. 2010). This fungal disease is not particular to Wyoming but is having devastating effects on amphibian populations worldwide (Muths et al. 2003, 2008, Skerratt et al. 2007).

Barred tiger salamanders occupy relatively few sites in the GYE and their conservation status is less understood than other species due to low detection probabilities (Gould et al. 2012). Even so, long-term occupancy monitoring by the U.S. Geological Survey (USGS) and the National Park Service (NPS) has shown a 50 percent decline in tiger salamander occupancy from 2006 to 2011 (Hossack et al. 2015). In contrast to the three anuran species in the GYE, tiger salamanders can overwinter as larvae, retain larval characteristics as paedomorphic adults, or complete metamorphoses in one season (Werner et al. 2004). Both larvae and adults are voracious, gape-limited predators of invertebrates and amphibian larvae (Swartz et al. 2014).

Boreal chorus frogs and Columbia spotted frogs are widespread and relatively common throughout the GYE. Both species occupy and breed in a wide range of habitats, from temporary to permanent wetlands, though larvae are susceptible to predation by fish. As with the other two amphibian species in the region, chorus frogs and spotted frogs have both experienced declines in recent years, a pattern that is associated with increasing drought frequency and pond desiccation (Gould et al. 2012).

Invertebrates: Aquatic invertebrate communities are often used to assess the quality of lotic habitats (Barbour et al. 1998), but their responses to environmental stressors in wetlands is less clear than for many other taxa (Batzer 2013). In wetlands, invertebrates play a critical role in cycling nutrients through food webs by foraging on aquatic vegetation and detritus, as well as being important prey items for amphibians, birds, and other wildlife (Batzer et al. 1999). Because invertebrates compose the most diverse portion of most wetlands (Batzer et al. 1999), they may provide a good surrogate for comparing wetland function between created and natural wetlands (Balcombe et al. 2005).

Birds: Many bird species depend on wetland and riparian areas to complete all or part of their lifecycles. Wetland vegetation such as willows, deciduous trees, cattails, rushes and sedges provide structure and cover for nesting while the high density of macroinvertebrates provides a high quality and abundant source of food. In Wyoming, about 70 percentof bird species are considered wetland or riparian obligates (Nicholoff 2003). As with amphibians, many wetland- and riparian-dependent bird species in the Intermountain West are declining, largely due to habitat loss (Smith and Wachob 2006).

Objective 1: Habitat Characteristics

In 2015, we began taking detailed habitat measurements to characterize physical differences among wetland types that may influence the probability of colonization and persistence of amphibians, invertebrates, and birds. We measured total wetland area and wetted wetland area (the portion of the wetland that held water in early June) using the area estimation tool in a Garmin e-trex Global Position System (GPS). We defined total wetland area as the high water line or boundary of wetland creation disturbance (i.e., willow plantings in created wetlands).

We measured maximum depth of each wetland in late May (Blackrock) or early June (Togwotee). We also measured depth at a fixed point in each wetland every two weeks to document dry down throughout the summer. We assessed water chemistry by measuring pH and specific conductance (YSI Multimeter, model 63) biweekly throughout the summer.

We sampled vegetation in late July, using a one by one meter quadrat every 80 meters along the wetland shore, both at 1 meter and 5 meters out from the bank. In each quadrat, we estimated percent cover of woody, emergent, free floating, rooted floating leaved, submersed, and terrestrial vegetation. To document seasonal changes in wetland size and emergent vegetation, we identified an exact physical location using GPS and compass for each wetland at Blackrock and Togwotee Pass in 2013. Photographs were then taken at that spot, using the same camera and default settings and zoom for each picture. Each photo site at Blackrock was photographed every two weeks from May through July 2013 - 2016. Photo sites at Togwotee Pass were photographed once per summer in early July. Additionally, we recorded whether or not we detected fish (visually or in traps) for each visit. We considered fish to be present at wetlands if they were detected at least once.

Objective 2: Amphibian Demographics

Boreal toads and Chorus frogs: Capture-recapture survey methods provide data necessary to estimate a number of demographic parameters including survival and population size. During capture-recapture surveys, amphibians are captured, given a unique mark and released to be captured again on a later occasion. We have been conducting nighttime capture-recapture surveys for boreal toads at the Blackrock Oxbow (OX) since 2003 as part of long term USGS research effort. In 2010, we expanded our effort to include the newly constructed mitigation wetland (QU). To gain a better understanding of how boreal toads were using mitigation wetlands relative to natural wetlands at a landscape scale, we began capture-recapture surveys at an additional two natural wetlands (HE and MW) and two created wetlands (SP and ML) in 2012 (Table 1). We visited each of six focal boreal toad capture-recapture sites (in bold, Table 1) at Blackrock three to four times per year during the breeding season (mid-May – early June). We have also conducted nighttime capture-recapture surveys for boreal chorus frogs at QU since 2010. We visited QU three to four times per year during the breeding season (late April – early May). During night-time capture sessions for both species, two or more workers searched the entire wetland area, and captured all observed individuals using clean latex or nitrile gloves. Animals were held in single-use plastic bags. We determined mass, measured, and marked all captured individuals and released them at the wetland where they were captured within 3-6 hrs (All methods detailed in Pilliod et al. 2010).

Analysis: *Demographic parameter estimates*. Capture-recapture surveys yielded data in the format of Pollock's robust design (Kendall and Nichols, 1995; Pollock, 1982) that were used to estimate survival, recruitment, abundance, and population growth rate (site-level). Data collected under Pollock's robust design are characterized by two temporal scales (Kendall et al., 1997). 1) Secondary occasions (i.e., a set of capture occasions = night survey events) conducted over a relatively short time period during which individuals are assumed to be neither added to, nor lost from, the population; and 2) Primary periods (i.e., a period of time beginning at the start of breeding [i.e., first capture occasion] in year *t* to the start of breeding [i.e., first capture occasion] in year *t* + 1. Primary periods are long enough that individuals could be added or lost to the population. Note that primary periods cover one set of secondary occasions. We used the f-parameterization of the Pradel model (Pradel, 1996, Williams et al., 2002) and Program MARK (White and Burnham, 1999) to assess the capture-recapture data and estimate apparent survival and recruitment over primary periods for each site.

Apparent survival (S) is the probability of surviving and remaining on the study area over a primary period. Thus, temporary emigration cannot be distinguished from death and the occurrence of emigration can bias estimates of survival negatively (Williams et al., 2002; Schmidt et al., 2007). Because we observed toads moving among sites on > 200 occasions (some within breeding seasons), our estimates for survival are likely to be low, and we designate these estimates as apparent survival. Recruitment is the per capita number of adults added to a breeding population each year. Toads do not reach sexual maturity until they are 3-4 years old, thus, recruitment estimates reflect conditions 3 to 4 years prior to the year of recruitment. We included fixed effects of year in the single model used to estimate each of the parameters (survival, f). Also within the Pradel model (above), we used the closed population models of Otis et al. (1978) to model capture and recapture probabilities and estimate abundance (N),within each set of secondary occasions (Williams et al., 2002). Capture probability (p) is the probability that an individual is initially captured within a primary period. Recapture probability (c) is the probability that an individual is recaptured. We assumed that capture and recapture probabilities were equal (e.g., Pilliod et al. 2010), and included fixed effects of sampling occasion in modeling p. Also within Program MARK, we used annual estimates of apparent survival and recruitment from this analysis to derive estimates of the population growth rate and standard errors. Concerns about confounded parameters led us to report a subset of the estimated lambda values (Williams et al., 2002).

Survival at created versus natural sites. To test for a difference in survival between created and natural wetlands, we used the Cormack-Jolly-Seber (CJS) model in Program MARK (Lebreton et al., 1992; White and Burnham, 1999). The CJS model contains two parameters: apparent survival and capture probability. We fit models with no effects (intercept only) and included fixed effects of site (natural vs mitigation wetland) and year (Table 3). We computed model-averaged estimates of an aggregate apparent survival for mitigation and natural sites.

Columbia spotted frogs: We estimated abundance of Columbia spotted frogs from 2014 to 2016 by counting egg masses at each wetland on three to five occasions during the breeding season. Spotted frog females lay one egg mass per year, providing a reliable index of the number of breeding females in a population (Licht 1975). Each egg mass survey was conducted by walking the entire shoreline and other shallow areas of each wetland. The egg masses generally float at the water's surface and are typically laid communally near shore, making them easy to detect. To reduce counting errors, each egg mass was marked with a colored toothpick and a pin flag labeled with the date and count of egg masses for that date (Scherer 2008). We visited each wetland at least once per week until the count of masses did not change for two consecutive visits and there was no change in counts in neighboring wetlands. We began surveying each wetland as soon as ice melted (late April/ early May).

Analysis: We were unable to model the effect of wetland type (natural, impacted, created) on the number of egg masses because created wetlands had very few (at most two) egg masses. Instead, we averaged the number of egg masses observed for each wetland across years.

Objective 3: Amphibian chytrid fungus

We assessed a random subset of amphibians (~10 per site) captured during capture-recapture surveys for the presence of the pathogenic chytrid fungus, *Batrachochytrium dendrobatidis* (Bd) that causes a lethal disease called chytridiomycosis (Voyles et al. 2009). After the animal was caught (using clean gloves for each animal) the ventral skin of the body and hind feet of the animal were swabbed with a sterile swab. The swab was tested using molecular methods (i.e., polymerase chain reaction PCR) (Hyatt et al. 2007) for the presence of this pathogen. We sealed each sample swab in a vial with 70% eTOH and placed each vial in an individual plastic bag. Swabs were assessed at one of two laboratories (Washington State University or South Dakota State University) for the presence of DNA from Bd.

Analysis: We used a mixed-effects logistic regression model (R Package, https://www.r-project.org/) with wetland type as a fixed effect to determine whether there was a difference in Bd prevalence between natural and created wetlands. We also included lab as a fixed effect, and site and year as random effects to account for their potential effects on Bd prevalence. The only species with adequate data for this analysis was boreal toads. For all other species, we determined naïve prevalence of Bd (the number that tested positive / the number tested) for each wetland type. Although the two laboratories provided results using slightly different metrics, we report non-quantitative results that focus on whether the pathogen is present (positive) or undetected (presumed negative).

Objective 4: Landscape occupancy of amphibians

In 2013 and 2014, we conducted double-observer visual encounter surveys (Dodd 2010) to assess amphibian occupancy in natural, impacted, and created wetlands at Togwotee Pass. We visited all sites once per field season when amphibian larvae were expected to be present and easily detectable (Hossack et al. 2015). Survey methods were designed to satisfy two key assumptions of occupancy modeling: occupancy did not change over the course of the sampling period, and detection histories were independent (MacKenzie et al. 2006). Wetlands were considered occupied if eggs, larvae, breeding adults or recently metamorphosed juveniles were observed.

In 2015 and 2016, we modified our methods by using unbaited minnow traps to detect larval amphibians (Dodd 2010). Traps were placed in shallow water every 20 m around the perimeter of each wetland. We left traps open for two consecutive 24 hour periods and counted the number of each species of larval amphibian in each trap. Because some species may be more likely to enter traps than others, we also conducted a dip-net sweep 1 m from each trap (Mazerolle et al. 2007). For these data, each day, rather than each observer, represented an independent replicate.

Analysis: We estimated occupancy, colonization, extinction, and detection probabilities for all four amphibian species using dynamic occupancy models in the R package Unmarked (MacKenzie et al 2003, Fiske and Chandler 2011). These models estimate the probability that a wetland was occupied in year 1 of the study (initial occupancy); extinction probability (ε), the probability that a site occupied in season t is unoccupied by the species in season t+1; and colonization probability (γ), the probability that an unoccupied site in season t is occupied by the species in season t+1. For each species, we used a two part modeling procedure. First, we set all parameters except detection probability to be constant and considered four models for detection: detection allowed to vary a) by year, b) by survey method, c) by wetland type, or d) to remain constant. We ranked each model based on Akaike's Information Criterion (AIC) (Burnham and Anderson 2002). Next, using the best model for detection probability for each species, we considered models where the probability of occupancy, colonization, and extinction varied by a) wetland type, b) year, or c) remained constant. Again, we ranked each model based on AIC.

Objective 5: Amphibian breeding phenology

We installed automated recording units (ARUs) at two natural wetlands (HE and OX) and two created wetlands (SP and QU) from May through July in 2013 – 2015 to record chorus frog breeding choruses and bird vocalizations. ARUs were located on the edge of each wetland close to where we had observed amphibian breeding or suspected that it would occur (warm, shallow waters). ARUs were set to record for eight, 1-minute intervals every hour starting at sunset (and ending around 4:00 am) to capture amphibian breeding choruses. Chorus frogs were selected because boreal toads do not "chorus", emitting only very quiet release chirps, Columbia spotted frogs also have a very soft call and salamanders do not vocalize.

Analysis: We processed amphibian recordings using Song Scope software (V4, Wildlife Acoustics Inc.). Trained personnel identified amphibian vocalizations by listening to each one-minute recording and visually examining the spectrogram (Waddle et al. 2009). We used number of minutes detected per night (out of eight possible) as a proxy for calling intensity and compared this number among sites.

Objective 6: Invertebrate species richness and composition

We sampled invertebrates, at a subset of wetlands at Blackrock and at Togwotee Pass (2013 to 2015) to determine if species richness and community composition of invertebrates differed among natural, impacted, and created wetlands (Table 2). Site selection was initiated by targeting created wetlands that had water. To collect a representative sample of invertebrates in each wetland, we conducted nine, 1.5 meter sweeps using a D-framed net (500 um mesh) (Radar et al. 2001). We conducted two sweeps along each axis of the wetland (north-south, and east-west) at a shallow point and a mid-depth point, as well as one in the deepest part of the wetland. We sampled all wetlands in late July when invertebrate diversity should be highest and many immature invertebrates should be developed enough to identify (Duffy 1999). Invertebrates from the nine sweeps were pooled into a single container and preserved in 70 percent ethanol for later identification to the lowest taxonomic level practical (Merritt and Cummins 1996, Larsen et al. 2000, Wiggins 2015). Amphipoda, Mollusca, Ephemeroptera, and Coleoptera were identified to genus level, while Diptera, Hemiptera, Odonata, and Hirundinea were identified to family level. We did not identify Collembola, Oligochaeta, and Hydracarina to lower taxonomic levels. When some members of a group were identified to a lower taxonomic level (i.e., species, genus) than others, we lumped up so that within each order or class taxonomic resolution was consistent across all sites and our estimate of richness was not artificially inflated. For example, snails of the genus *Lymnaea* were sometimes identified just to genus and sometimes to species (*Lymnaea elodes* and *Lymnaea stagnalis*).

Analysis: We estimated taxa richness for each wetland using the program SPECRICH (Hines 1996). SPECRICH uses observed relative abundance of each taxa to calculate estimated richness and standard error, while accounting for heterogeneous detection probabilities among species (Burnham and Overton 1979). We tested for differences in log-transformed taxa richness among wetland types using a linear mixed effects model implemented in the R package nlme (non-linear mixed effects, Pinheiro et al. 2016) with wetland type and elevation as explanatory variables. To improve model fit, we center-scaled elevation at a mean of zero. We included site as a random effect to account for autocorrelation involved in repeated sampling of some wetlands over multiple years. We included elevation in all models as a "nuisance" covariate since it is not strictly a design feature but should have strong effects on species richness due to differences in growing season length and temperature at different elevations (Rahbek 1995). Next, we used the same model structure to test whether taxa richness increased with age of created wetlands age. To compare invertebrate community composition among wetland types, we used non-metric multi-dimensional scaling (NMDS) implemented in the R package vegan (Oksanen et al. 2017) based on the rank orders of taxa in our samples. There is no way to account for temporal autocorrelation in NMDS, so we used data from 2015, when most wetlands were sampled. We examined the specific differences in community composition between wetland types by comparing the occurrence of common taxa in each wetland type, defining "common" as those taxa occurring in at least 40 percent of wetlands in each type (natural, impacted, created).

Table 2: *Wetlands surveyed for invertebrates, by year***.**

Site	Type	Years surveyed
12DC	Created	2015
13AC	Created	2013, 2014, 2015
16BC	Created	2013, 2014, 2015
19AC	Created	2015
24CC	Created	2015
25AC	Created	2015
26BC	Created	2013, 2014, 2015
ML	Created	2014,2015
QU	Created	2013, 2014, 2015
SP	Created	2013, 2014, 2015
12CI	Impacted	2015
15AI	Impacted	2013, 2014, 2015
17AI	Impacted	2015
17BI	Impacted	2013, 2014, 2015
19BI	Impacted	2015
25BI	Impacted	2013, 2014, 2015
26AI	Impacted	2015
16CR	Natural	2013, 2014, 2015
17DR	Natural	2015
17ER	Natural	2013, 2014, 2015
21AR	Natural	2015
21BR	Natural	2015
21CR	Natural	2015
25CR	Natural	2013, 2014, 2015
HE	Natural	2013, 2014, 2015
MW	Natural	2013,2014
ND	Natural	2013,2014
OX	Natural	2013,2014
RW	Natural	2013, 2014, 2015
SD	Natural	2015

Objective 7: Bird species richness and composition

We recorded bird vocalizations using the same recording units described in Objective 3. ARUs were set to record for an entire hour starting at sunrise to capture bird calls. Bird recordings were processed in the RAVEN program. We subsampled bird call recordings, examining only recordings from 1-5 June in each year because most bird species are present and vocal during this time (Smith et al. 2013). To assess bird presence during each hour-long recording, we randomly selected 15 individual 1-minute long segments of that hour to listen to. A skilled listener identified vocalizations heard to bird species during each of these segments.

Analysis: Each year, we counted the number of species detected at each site over the 5-days of 1-hour recordings. We also counted the number of riparian "obligate" or "dependent" songbirds detected (Rich 2002). Riparian dependent songbirds are those that place 60 percent-90 percent of their nests in riparian vegetation or for which 60 percent-90 percent of their occurrence occurs in riparian vegetation during the breeding season. Obligate species place greater than 90 percent of their nests in riparian vegetation or for which >90 percent of their occurrence occurs in riparian vegetation during the breeding season (Rich 2002).

CHAPTER 5: FINDINGS AND DISCUSSION

Objective 1: Habitat characteristics

We assessed habitat characteristics for a subset of wetlands (10 natural [3 Blackrock, 7 Togwotee]; 7 impacted [all Togwotee], and 10 created [3 Blackrock, 7 Togwotee]) and used multiple metrics to assess potential differences among wetland types including size and depth, water chemistry, vegetation and the presence of fish (which can be detrimental to amphibian persistence of some amphibians (Hecnar and M'Closkey 1997).

Wetland size and depth: Natural and impacted wetlands were similar in total wetland area. The total area of natural wetlands ranged from 480 to 12,190 m^2 (median = 2724), and created wetlands ranged from 1,336 to 68,000 m^2 (median = 3721). On average, only 37.1 percent of total wetland area in created wetlands held standing water in early June, compared to 100 percent of natural wetlands. All natural and impacted wetlands were single water bodies, while created wetlands were composed of 1 to 16 separate water bodies. Created wetlands were significantly shallower than natural wetlands, while impacted wetlands did not differ from natural wetlands (Figure 3). For example, in 2015 and 2016, created wetlands were often completely dry by mid-July (2015: SP and 19AC; 2016: QU, 13AC, and 19AC). In contrast, no natural or impacted wetlands dried in either year. Natural sites lost water at approximately the same rate as created wetlands (Figure 3), suggesting that the natural wetlands had at least some deeper sections that did not dry. In 2016, both SP and ML gained water throughout the summer; SP is controlled by a ditch coming out of Blackrock creek, and the mitigation lake (ML) appeared to be draining water from QU. In both cases, these sites were relatively deep and cold compared to other natural and created sites.

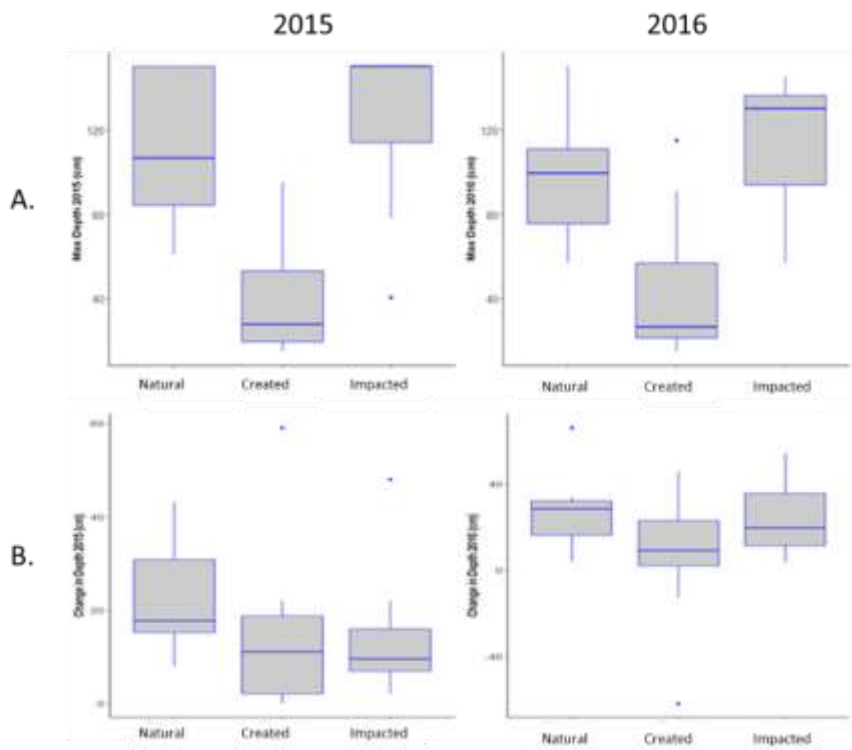


Figure 3*: Median, interquartile range, and range of A: Maximum depth (depths > 150 cm not measured); and B: dry down (maximum – minimum depth), of created, natural, and impacted wetlands.*

Water Chemistry: Mean pH and specific conductance were similar among natural, impacted, and created wetlands (Table 3). Created wetlands tended to have higher specific conductance, possibly as a result of shallower water depths and greater soil-to-water ratios, but all of the values are within normal ranges for wetlands in the GYE (Klaver et al. 2013). Because impacted wetlands were all adjacent to the highway, overall similarity among wetland types suggests de-icing chemicals used during winter are not having a persistent effect on pH or specific conductance.

Table 3: *Mean pH (SD = standard deviation) and mean specific conductance (µS/cm) of created, impacted, and natural wetlands by year.*

Year	Wetland Type	Mean pH (SD)	Mean Specific Conductance (µS/cm)
2015	created	8.46 (0.69)	225.41 (122.4)
	impacted	7.68 (1.08)	161.01 (120.04)
	natural	7.92 (0.54)	143.98 (86.35)
2016	created	8.62 (0.71)	303.77 (187.17)
	impacted	8.61 (0.58)	159.32 (121.86)
	natural	8.38 (0.33)	159.03 (84.22)

Vegetation: Mean percent cover of emergent vegetation (sedges, rushes, cattails) was lower in created wetlands than natural and impacted wetlands in 2015, but increased in 2016, likely reflecting the development and succession of vegetation as the wetlands aged. Mean percent cover of submersed and woody vegetation was lower in created wetlands than impacted and natural wetlands across years. The mean percent cover of free floating and rooted, floating leaved vegetation was low for all wetland types. A large proportion of the total area in many created wetlands did not hold water into summer (photo sites, appendices A and B) and so was dominated by terrestrial vegetation (i.e., forbs, weeds). Terrestrial vegetation was not found in natural or impacted wetlands.

Table 4: *Mean percent cover of vegetation types (standard deviation) in 2015 and 2016.*

Vegetation Type	Year	Created	Impacted	Natural
Emergent	2015	19.8 (20.56)	37.35 (31.91)	34.41 (27.14)
Emergent	2016	32.71 (28.09)	32.74 (29.02)	32.17 (27.58)
Free Floating	2015	0.34 (0.81)	0	1.47 (2.67)
Free Floating	2016	0.26 (0.57)	0.36 (0.94)	2.19 (4.16)
Rooted Floating Leaved	2015	0.3 (1.01)	1.07 (1.97)	1.5 (3.37)
Rooted Floating Leaved	2016	0.45 (1.51)	3.2 (8.15)	3.54 (6.8)
Submersed	2015	3.67 (9.28)	9.08 (18.42)	14.98 (20.64)
Submersed	2016	1.11 (1.76)	20.83 (20.67)	18.58 (18.93)
Terrestrial	2015	17.81 (15.51)	0	0
Terrestrial	2016	17.94 (14.88)	0	0
Woody	2015	1.41 (2.03)	14.18 (18.78)	4.69 (6.14)
Woody	2016	1.16 (0.95)	6.43 (8.52)	3.62 (2.97)

Photo points: Repeat photographs at established photo points provide a qualitative assessment of within- and between-year changes to wetlands and illustrate the dynamic nature of wetlands in this ecosystem. The Blackrock photos (Appendix A) highlight greater variation in hydroperiod in created wetlands compared to most natural wetlands. Similarly, the Togwotee Pass photos (Appendix B) show how the shallow, created wetlands dried much sooner than the impacted and natural wetlands.

Fish: We detected fish (*Onchorhynchus* spp) in three wetlands (two impacted wetlands near the top of Togwotee Pass) and at one natural wetland at Blackrock (Heron). These wetlands were all natural to begin with, were permanent, and were connected to flowing water. All four species of amphibians were detected in HE. We suspect that it is likely elevation, rather than fish, that is limiting amphibian presence at the top of Togwotee Pass. Tiger salamanders, adult amphibians, and predatory invertebrates are typically the dominant predators in this high elevation system and it is unlikely that fish are affecting the presence of amphibians in these wetlands, although tiger salamanders can be affected by fish presence (e.g., Tyler et al. 1998).

Objective 2: Amphibian demographics

Boreal Toads: We captured 3047 individual toads (2631 males, 239 females, 6 juveniles) during 127 focal night capture sessions (6 sites, 3 created and 3 natural, Table 1) from 2003 to 2016. Capture probability was higher at created wetlands (0.95 – 0.99) because aquatic vegetation was less established and the surrounding habitat less complex than at natural wetlands (0.18-0.60) such that amphibians were less able to hide and were more visible to workers.

Demographic parameter estimates: Toads inhabiting natural wetlands (on average) tended to have higher probabilities of survival than toads in created wetlands (0.17 to 0.65 natural versus 0.03-0.46 created) (Figure 4).

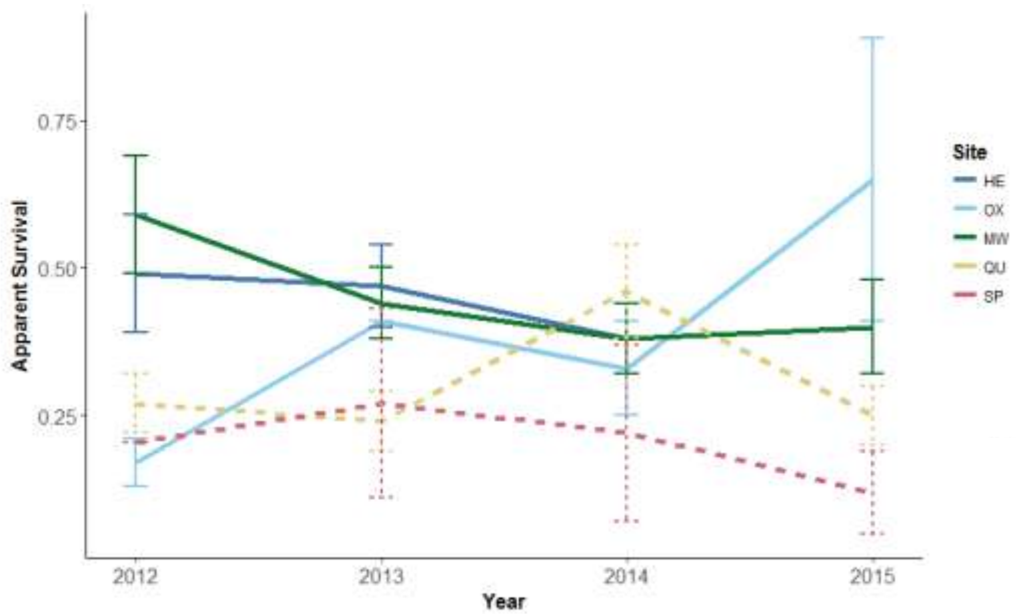


Figure 4: *Apparent survival estimates for boreal toads by site and year. Solid lines and cool colors represent natural wetlands, while dashed lines and warm colors represent created wetlands. Survival in OX was not estimable in 2013 and survival in SP was not estimable in 2012 (too few recaptures); we used the average value for survival from all other years for 2013. Error bars represent standard errors.*

Per capita recruitment tended to be higher in created sites (not in Swan Pond) possibly because of shallow and thus warm water and close proximity to other breeding sites (Figure 5). Recruitment at natural wetlands ranged from 0.22 – 0.87 at Oxbow, to 0.46 – 1.37 at Heron, to 0.42 – 1.65 at Midway, compared to created wetlands (0.13 – 2.74 at Quarry, 0.17 – 2.33 at Swan Pond, and 0.17-0.22 at Mitigation Lake). Quarry is a good illustration of this variability; this created site initially provided excellent habitat but with the construction of Mitigation Lake (ML) in 2013-2014, water levels dropped precipitously and in 2016 precluded most metamorphosis of amphibians that year at Quarry. The Oxbow was more variable than other natural wetlands likely because of the proximity to the river; toads often breed prior to peak flows, which can over-wash the levees, washing eggs downstream. Because boreal toads take three to four years to reach maturity, recruitment estimates reflect conditions three to four years previous rather than the year immediately preceding the estimate. For example, the impacts of the levee breach in 2011 are likely reflected in our inability to estimate recruitment in 2013 and 2014.

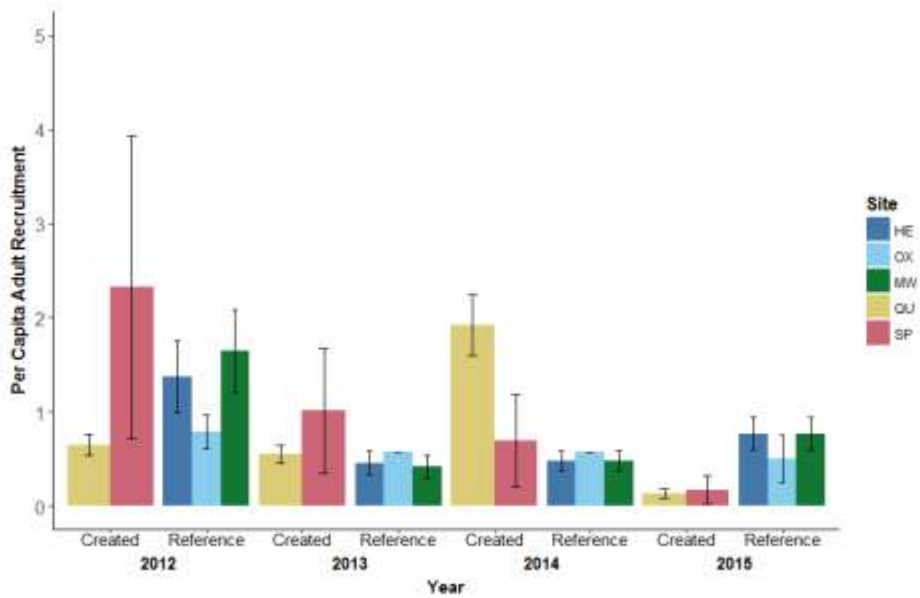


Figure 5: *Per-capita adult recruitment estimates for boreal toads by site and year. Cool colors represent natural wetlands, warm colors represent created wetlands. Error bars represent standard errors.*

In general the abundance of toads at natural and created wetlands varied by year and by the situation at each of the sites. Natural sites had a greater abundance of toads (4 – 226 individuals versus 3 – 115 individuals) (Figure 6) and the populations tended to have greater persistence (positive population growth rates in more years than negative) in natural versus created wetlands (Figure 7). Of particular interest is Quarry where initial estimates of toad demography were strong, but have fluctuated; most recent estimates of survival, abundance and recruitment rate are relatively low. There is a potential link between the early success of Quarry and the completion of the Mitigation Lake (ML). We suspect that the larger mitigation action is affecting water levels and hydroperiod at Quarry. Note that longer-term data (e.g., from Oxbow 2003 – 2015, Figure 8) can provide context to elucidate interdependencies among sites and impacts of environmental covariates on demographics. Such information from Quarry and ML would be useful in assessing long-term success of the mitigation effort at Blackrock.

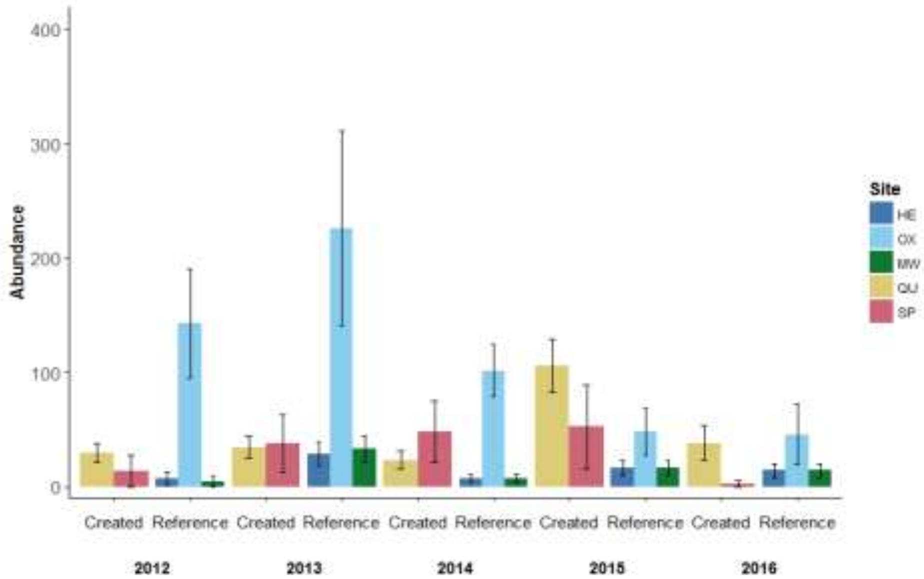


Figure 6: *Estimated abundance of boreal toads by site and year from 2012-2016. Cool colors represent natural wetlands, warm colors represent created wetlands. Error bars represent confidence intervals.*

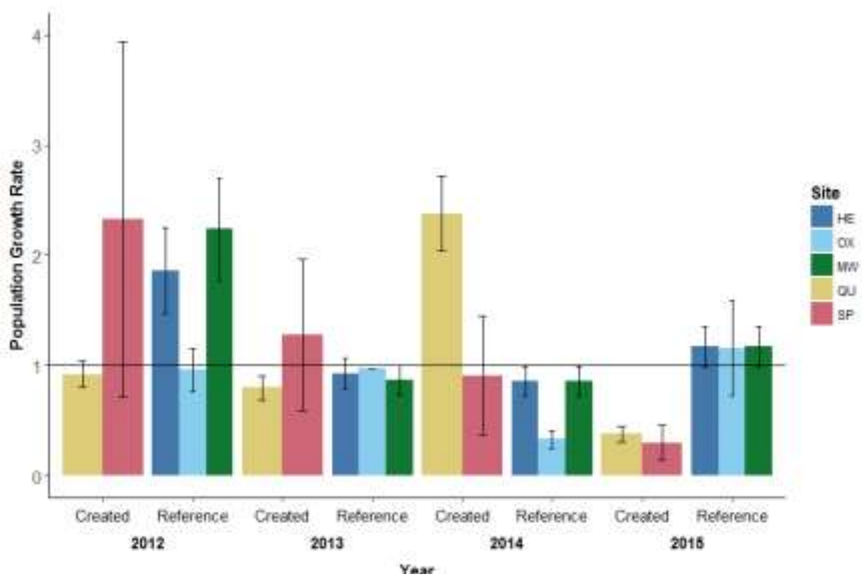


Figure 7: *Population growth rate estimates for boreal toads by site and year Cool colors represent natural wetlands, warm colors represent created wetlands. Error bars represent standard errors. The horizontal line represents a stable population (λ=1). Values below the line represent a declining population while values above the line represent an increasing population.*

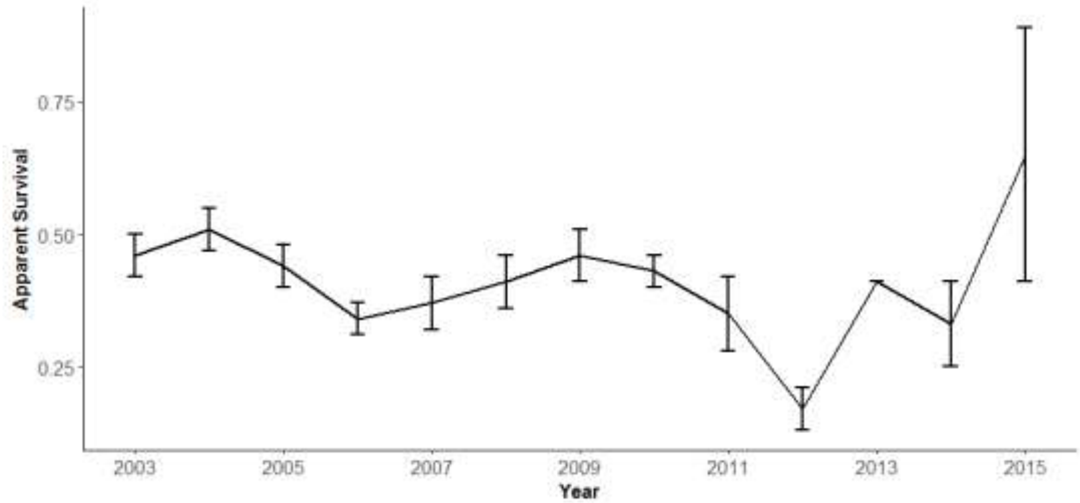


Figure 8A: *Demographic parameter estimates for boreal toads at Oxbow provide a longer-term perspective on variability in amphibian population demography at a natural site. Apparent survival. Error bars represent standard errors*

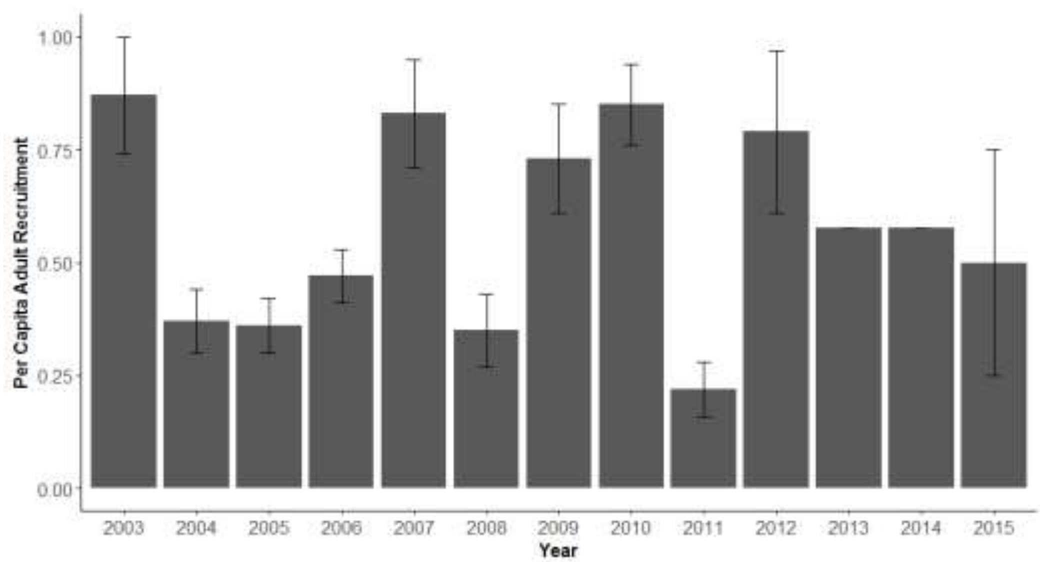


Figure 8B: *Demographic parameter estimates for boreal toads at Oxbow provide a longer-term perspective on variability in amphibian population demography at a natural site. Per-capita recruitment; recruitment not estimable in 2013 or 2014. Error bars represent standard errors.*

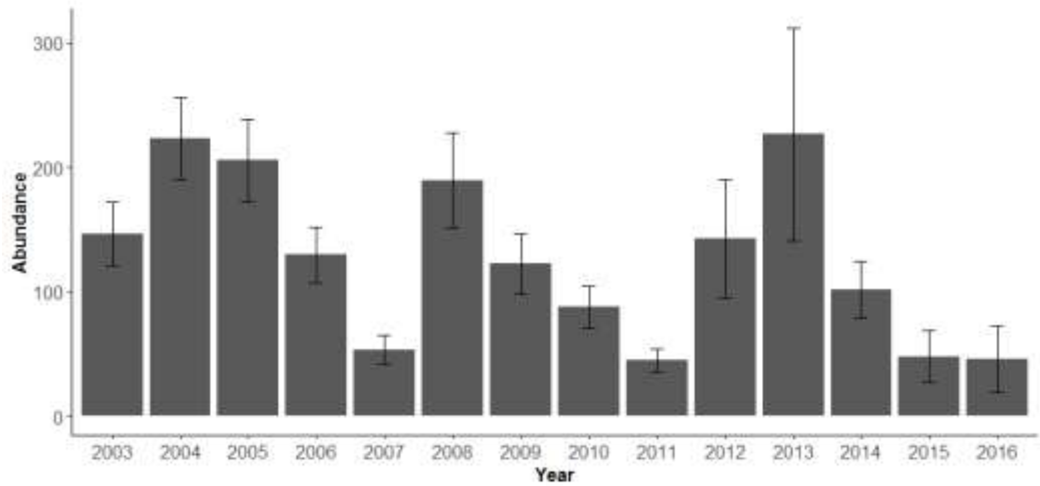


Figure 8C: *Demographic parameter estimates for boreal toads at Oxbow provide a longer-term perspective on variability in amphibian population demography at a natural site. Abundance. Error bars represent standard errors.*

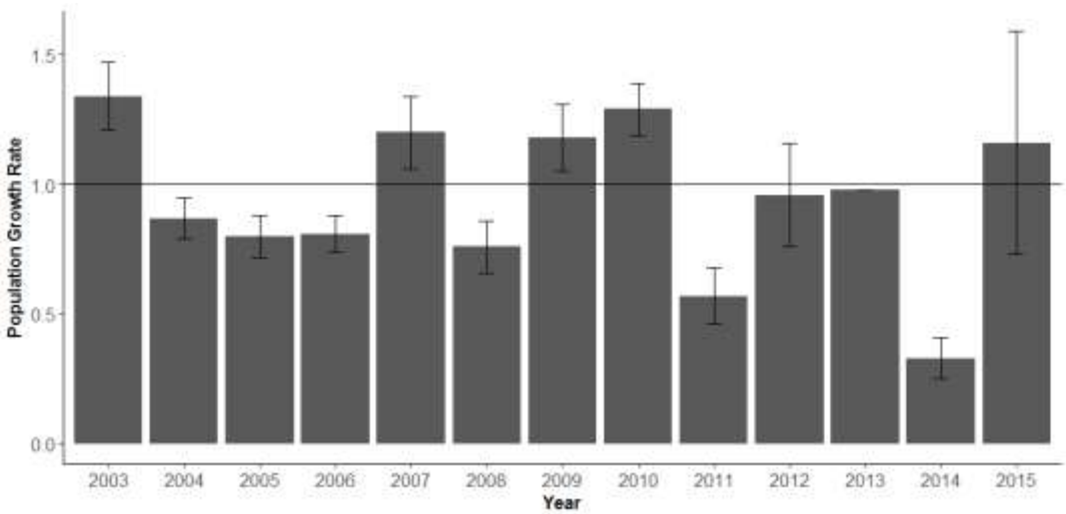


Figure 8D: *Demographic parameter estimates for boreal toads at Oxbow provide a longer-term perspective on variability in amphibian population demography at a natural site. Population growth rate.*

Survival at created versus natural sites. The model best supported by the data (Table 5) indicated a difference in the rate of survival between created and natural sites. Estimates of apparent survival for toads at natural sites ranged from 0.32-0.53 (Table 6), and are similar to estimates reported earlier from Blackrock (0.51-0.54, Muths et al. 2011). These estimates are also similar to the apparent survival estimate reported for individuals that tested Bd positive at the Blackrock Oxbow in our previous work (0.42, Pilliod et al. 2010). In contrast, estimates of apparent survival at created sites were higher (0.57-0.78) and were more similar to estimates from toad populations in the southern Rocky Mountains where disease was not present, and from individuals testing negative for disease at Blackrock (0.76, Pilliod et al. 2010). Despite the attractiveness of these results - suggesting that created sites might have less disease and facilitate higher survival in amphibians relative to natural sites, there are several lines of evidence that refute this: 1) confidence intervals for the estimates (created vs natural wetlands, Table 5) overlap in two of the three years; 2) prevalence of the pathogen Bd does not differ among wetland types (see below), suggesting that the similarity in survival estimates at natural sites to survival estimate for toads with disease is likely coincidental; and 3) in comparing survival between created and natural wetlands, two sites provided the bulk of the data. One natural site (Oxbow) was recovering from an extreme event that affected survival and recruitment; and one created site (Quarry), that provided ideal habitat, but proved unstable (i.e., the creation of mitigation lake (ML) affected water levels at Quarry).

Table 5: *Top models for apparent survival (phi) and capture probability (p) differences between created and natural wetlands (additional models that received no weight in model selection are not shown [see appendix C for full model set]).*

Model	AICc	Delta AICc	Wt
{Phi(site*t) p(site*t)}	1591.4	0	0.76
{Phi(site+t) p(site+t)}	1595.4	4.1	0.1
{Phi(site*t) p(site+t)}	1596.5	5.1	0.06
{Phi(site+t) p(site*t)}	1597.1	5.8	0.04
{Phi(site+t) p(site)}	1598.4	7	0.02
{Phi(site*t) p(site)}	1599.7	8.3	0.01

Table 6: *Model averaged estimates of apparent survival for natural (OX, HE, and MW) and created (QU, SP, and ML) wetlands. Error bars represent 95% confidence intervals.*

	Estimate	SE	LCI	UCI
Natural wetlands				
2012	0.53	0.13	0.28	0.76
2013	0.32	0.10	0.17	0.53
2014	0.43	0.10	0.26	0.63
Created wetlands				
2012	0.72	0.04	0.64	0.79
2013	0.78	0.04	0.69	0.86
2014	0.57	0.04	0.50	0.65

Chorus Frogs: Quarry was constructed in 2008. We observed that chorus frogs colonized Quarry soon after construction and rapidly increased in abundance, and began data collection (capture-recapture) in 2010. We captured 999 individual chorus frogs over 7 years, but recaptured only 131 (13%) of those individuals. Low recapture rate leads to low precision in estimates of survival, recruitment and abundance (Williams et al. 2002), thus we limit our discussion of these data. The low recapture rate for chorus frogs, despite significant effort, suggests a very large population, low yearly survival, or a combination of both of these characteristics. Chorus frogs tend to live about 5 years (Muths et al. 2016), suggesting that it is the size of the population, rather than low survival, that is driving the low recapture rate.

Average apparent survival ranged from 0.11 – 0.73, (mean = 0.32) (Figure 9), slightly lower than the only estimates available for survival in chorus frogs (range 0.67 – 0.79, Muths et al. 2016). The abundance and breeding success suggests that Quarry was providing adequate and likely preferred habitat for this amphibian soon after its creation.

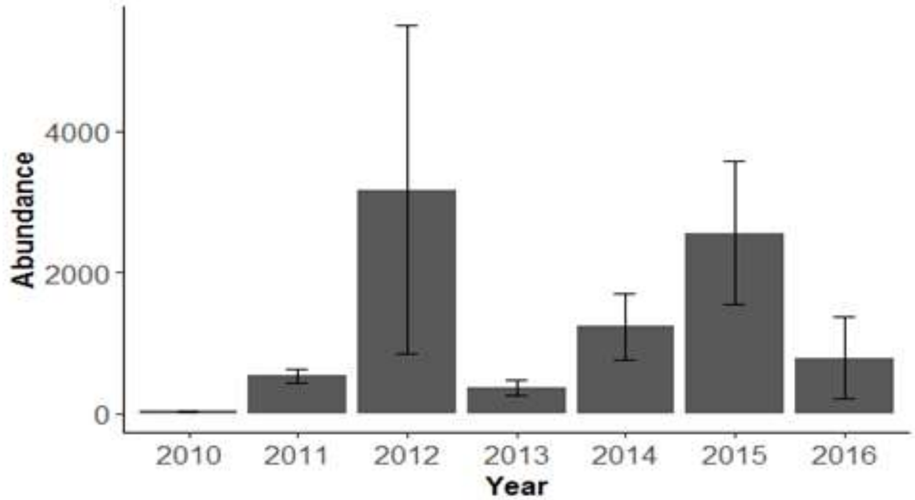


Figure 9A: *Abundance, recruitment, survival, and population growth rate estimates for boreal chorus frogs from QU. Error bars represent standard errors. Note: high abundance in 2012 is likely due to very low recapture rates and may reflect personnel issues that year.*

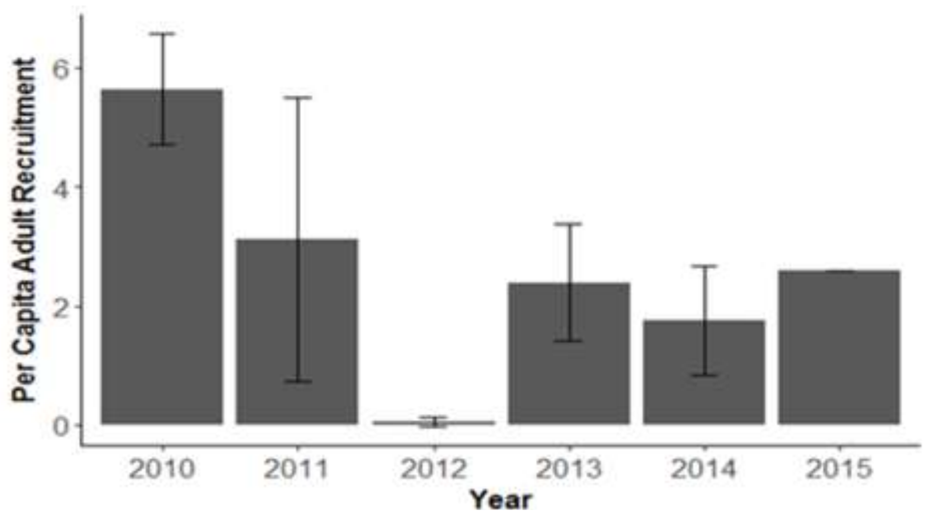


Figure 9B: *Per capita recruitment, survival for boreal chorus frogs from QU. Recruitment was not estimable in 2015 (too few recaptures) thus we used the average value for recruitment from all other years for 2015. Error bars represent standard errors.*

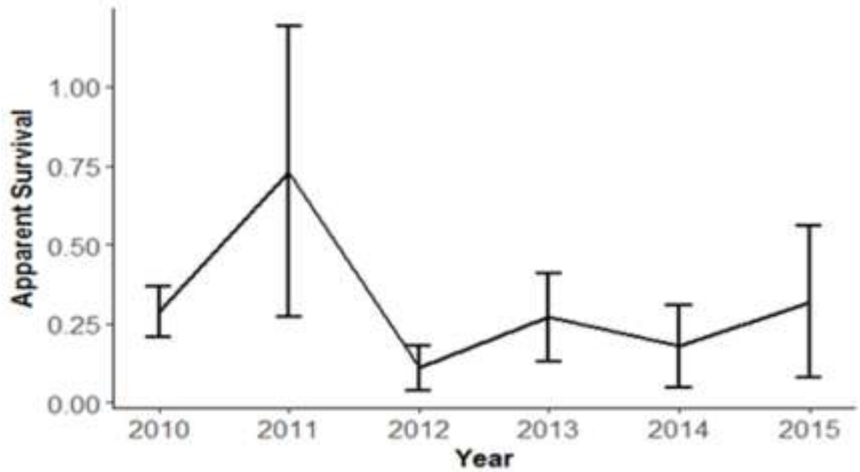


Figure 9C: *Apparent survival estimates for boreal chorus frogs from QU. Error bars represent standard errors.*

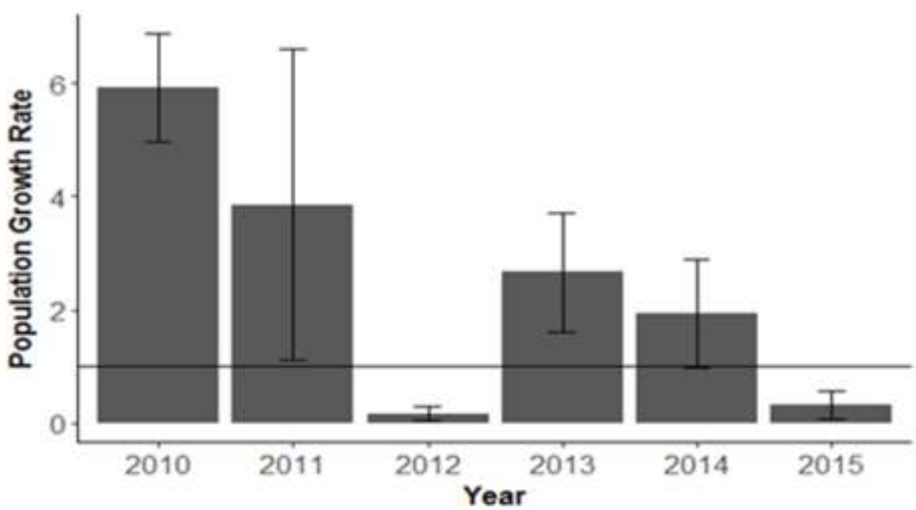


Figure 9D: *Population growth rate estimates for boreal chorus frogs from QU. Error bars represent standard errors.*

Columbia spotted frogs: We searched for Columbia spotted frog egg masses at 33 wetlands (10 created, 7 impacted, 16 natural) and found them in only 15 (1 created, 4 impacted, 10 natural) (Table 7). Egg mass counts ranged from 0 to 40 per site. The number of egg masses was similar among natural and impacted sites but was lower at the created site (i.e., Quarry; a maximum of 3 per year). The use of created wetlands by Columbia spotted frogs appears to be limited. Spotted frogs are one of the most highly aquatic amphibian species in the GYE and are most likely to breed in large, permanent wetlands with emergent vegetation (Hossack et al. 2015). It is plausible that we detected spotted frog reproduction (eggs) in only the oldest created wetland (Quarry) because Quarry had time to develop more aquatic vegetation that is crucial for spotted frog breeding (Pearl et al. 2007). Quarry is also deeper than most of the other constructed wetlands, especially those at Togwotee Pass. Impacted and natural wetlands had similar numbers of egg masses in most cases. The effects of road construction on impacted wetlands were typically < 25 percent of the bank area, suggesting that this level of disturbance had minimal effects on the use of that habitat by spotted frogs.

Table 7: *Number of Columbia spotted frog egg masses by wetland type from 2013 to 2016.*

		Eggmass Totals				
Site	Wetland Type	2013	2014	2015	2016	mean # of egg masses by site (standard deviation), all
	Created					0.17 (0.5)
12DC	Created	--	0	0	0	
13AC	Created	--	0	0	0	
16BC	Created	--	0	0	0	
19AC	Created	--	0	0	0	
24CC	Created	--	0	0	0	
25AC	Created	--	0	0	0	
26BC	Created	--	0	0	0	
ML	Created	--	0	0	0	
QU	Created	2	2	3	0	
SP	Created	0	0	0	0	
	Impacted					7.71 (11.2)
12CI	Impacted	--	0	0	0	
15AI	Impacted	--	3	21	24	
17AI	Impacted	--	40	24	23	
17BI	Impacted	--	3	0	0	
19BI	Impacted	--	12	7	5	
25BI	Impacted	--	0	0	0	
26AI	Impacted	--	0	0	0	
	Natural					6.48 (9.0)
16CR	Natural	--	2	0	0	
17DR	Natural	--	1	1	1	
17ER	Natural	--	18	14	9	
21AR	Natural	--	0	0	0	
21BR	Natural	--	0	0	0	
21CR	Natural	--	0	0	0	
25CR	Natural	--	0	0	0	
CH	Natural	0	6	10	1	
HE	Natural	27	25	39	30	
MA	Natural	0	0	0	0	
MW	Natural	1	4	3	2	
ND	Natural	12	14	19	3	
OX	Natural	0	0	0	0	
RP	Natural	1	9	10	6	
RW	Natural	7	3	19	4	
SD	Natural	32	12	37	9	

Objective 3: Amphibian chytrid fungus

We tested 596 boreal toads, 79 chorus frogs, 114 Columbia spotted frogs, and 33 tiger salamanders for the presence of Bd between 2012 and 2016 (Table 8). We detected Bd in all species, and at all wetlands sampled regardless of type (Appendix D). Naïve prevalence of Bd ranged from only 17 percent in tiger salamanders in natural wetlands to 78 percent in chorus frogs at Quarry, the only created wetland where we sampled chorus frogs. For boreal toads, estimated disease prevalence did not differ ($z = -0.57$, $p = 0.56$) between created wetlands (mean = 0.65, 95percent CI = 0.39–0.84) and natural wetlands (mean = 0.55, 95percent CI = 0.35–0.75). Across all species and years, naive prevalence of Bd was 56.82 percent at created wetlands and 58.52 percent at natural wetlands. These data indicate that Bd prevalence is high in this system, but also suggest that the risk of infection does not vary based on wetland type. These data also emphasize the need to determine how infection affects population dynamics (e.g., survival rates) of all local species.

Table 8: *Number of individuals tested and # positive for the pathogenic fungus Bd and naïve prevalence (number of individuals testing positive / number of individuals tested).*

Wetland Type	Species	# Individuals Tested	# Individuals positive for Bd	Naïve Prevalence
Created	Boreal Toad	260	135	0.52
	Boreal Chorus Frog	79	55	0.78
	Columbia Spotted Frog	10	7	0.70
	Barred Tiger Salamander	27	17	0.63
Natural	Boreal Toad	336	192	0.57
	Boreal Chorus Frog	--	--	--
	Columbia Spotted Frog	104	67	0.64
	Barred Tiger Salamander	6	1	0.17

Objective 4: Landscape occupancy of amphibians

Boreal toads: Because we only detected boreal toads in two wetlands at Togwotee Pass, we did not have enough data to estimate all of the parameters required for occupancy models. Both wetlands where we documented boreal toad reproduction were created wetlands, and in both cases toads colonized and began breeding the year after wetland construction. Boreal toads often respond positively to disturbances such as wildfire (Hossack et al. 2013) and pond construction (Pearl and Bowerman 2006), perhaps reflecting a preference for bare mineral soils, shallow water, and an open canopy.

Barred Tiger Salamanders: The top ranked model for tiger salamander detection showed high and constant detection across years, survey method, and wetland type (estimate = 0.88, se = 0.06). Similarly, the top ranked model for initial occupancy, colonization, and extinction probability did not vary by wetland type or year (Table 9). Estimated initial occupancy probability was 0.28 (se = 0.10), estimated colonization probability was 0.10 (se = 0.04), and estimated extinction probability was 0.52 (se= 0.12). This suggests that tiger salamanders may be using natural, impacted, and created wetlands at a similar, low level.

Table 9: *Comparison of models for estimating initial occupancy (psi), colonization (gam), extinction (eps), and detection (p) of barred tiger salamanders using AIC. Models with (WT) refer to wetland type, while (.) refers to a constant parameter across wetland type.*

Model	Number of Parameters	Delta AIC	Model AIC Weight
psi(.)gam(.)eps(.)p(.)	4	0.00	0.43
psi(.)gam(.)eps(WT)p(.)	6	1.58	0.29
psi(.)gam(WT)eps(.)p(.)	6	2.21	0.14
psi(WT)gam(.)eps(.)p(.)	6	2.53	0.12
psi(WT)gam(.)eps(WT)p(.)	8	4.11	0.06
psi(WT)gam(WT)eps(.)p(.)	8	4.76	0.04
psi(WT)gam(WT)eps(WT)p(.)	10	6.14	0.02

Columbia Spotted Frogs: The top ranked model for Columbia spotted frog detection probability showed differences in detection probability among wetland types. However, Columbia spotted frogs were only detected in natural and impacted wetlands so detection probability was not estimable for created wetlands. Therefore, we assumed constant detection across years, survey methods, and wetland type. The top-ranked model for Columbia spotted frogs supported differences in initial occupancy probability based on wetland type, but no differences in the probability of extinction or colonization. According to this model, the estimated probability of initial occupancy was highest in natural and impacted wetlands (estimate = 0.43, se = 0.19), followed by created wetlands (estimate = 0.0001) (Tables 10 and 11)

Table 10: *Model for initial occupancy (psi), colonization (gam), extinction (eps), and detection (p) for Columbia spotted frogs. Models are ranked using AIC, wt refers to wetland type, while (.) indicates that the parameter is constant.*

Model	Number of Parameters	Delta AIC	wt
psi(WT)gam(.)eps(.)p(.)	6	0.00	0.59
psi(.)gam(.)eps(.)p(.)	4	2.35	0.18
psi(WT)gam(.)eps(WT)p(.)	8	3.94	0.08
psi(.)gam(WT)eps(.)p(.)	6	4.08	0.07
psi(WT)gam(WT)eps(WT)p(.)	10	5.78	0.03
psi(.)gam(.)eps(WT)p(.)	6	5.89	0.03
psi(WT)gam(WT)eps(.)p(.)	8	9.85	0.00

Table 11: *Estimates of initial occupancy (psi) by wetland type from the top model for Columbia spotted frogs.*

Wetland Type	Predicted Psi	SE	lower CI	upper CI
Natural	0.43	0.19	0.14	0.77
Impacted	0.43	0.19	0.14	0.77
Created	0.00	0.00	0.00	1.00

Boreal chorus frogs: The model with the most support indicated that occupancy of chorus frogs was influenced by wetland type (Table 12) and was higher in natural and impacted wetlands relative to created wetlands (Table 13). Colonization (0.16, se = 0.06) and extinction (0.16, se = 0.06) rates were uniform across wetland type. Detection of chorus frogs in the occupancy models was high and constant across years, survey method and wetland type (0.89 [SE = 0.04]).

Table 12: *Models estimating initial occupancy (psi), colonization (gam), extinction (eps), and detection (p) of boreal chorus frogs using AIC. WT refers to wetland type, while (.) refers to a constant parameter.*

Model	Number of Parameters	Delta AIC	Model AIC Weight
psi(WT)gam(.)eps(.)p(.)	6	0	0.37
psi(.)gam(.)eps(.)p(.)	4	0.12	0.35
psi(WT)gam(.)eps(WT)p(.)	8	3.32	0.07
psi(WT)gam(WT)eps(.)p(.)	8	3.38	0.07
psi(.)gam(.)eps(WT)p(.)	6	3.48	0.07
psi(.)gam(WT)eps(.)p(.)	6	3.5	0.06
psi(WT)gam(WT)eps(WT)p(.)	10	6.65	0.01

__Table 13:__ Estimates of initial occupancy (psi) by wetland type from the top model for boreal chorus frogs.

Wetland Type	Predicted Psi	SE	lower CI	upper CI
Natural	0.57	0.19	0.23	0.86
Impacted	0.58	0.19	0.23	0.87
Created	0.14	0.13	0.02	0.57

Objective 5: Amphibian breeding phenology

Calling by chorus frogs began earliest at created sites, notably Quarry (as early as 17-April; Figure 10), likely because of the shallow water and warmer temperatures. Calling was most intense at Quarry and most variable at Swan Pond (both created sites) which is probably the most variable site in terms of depth.

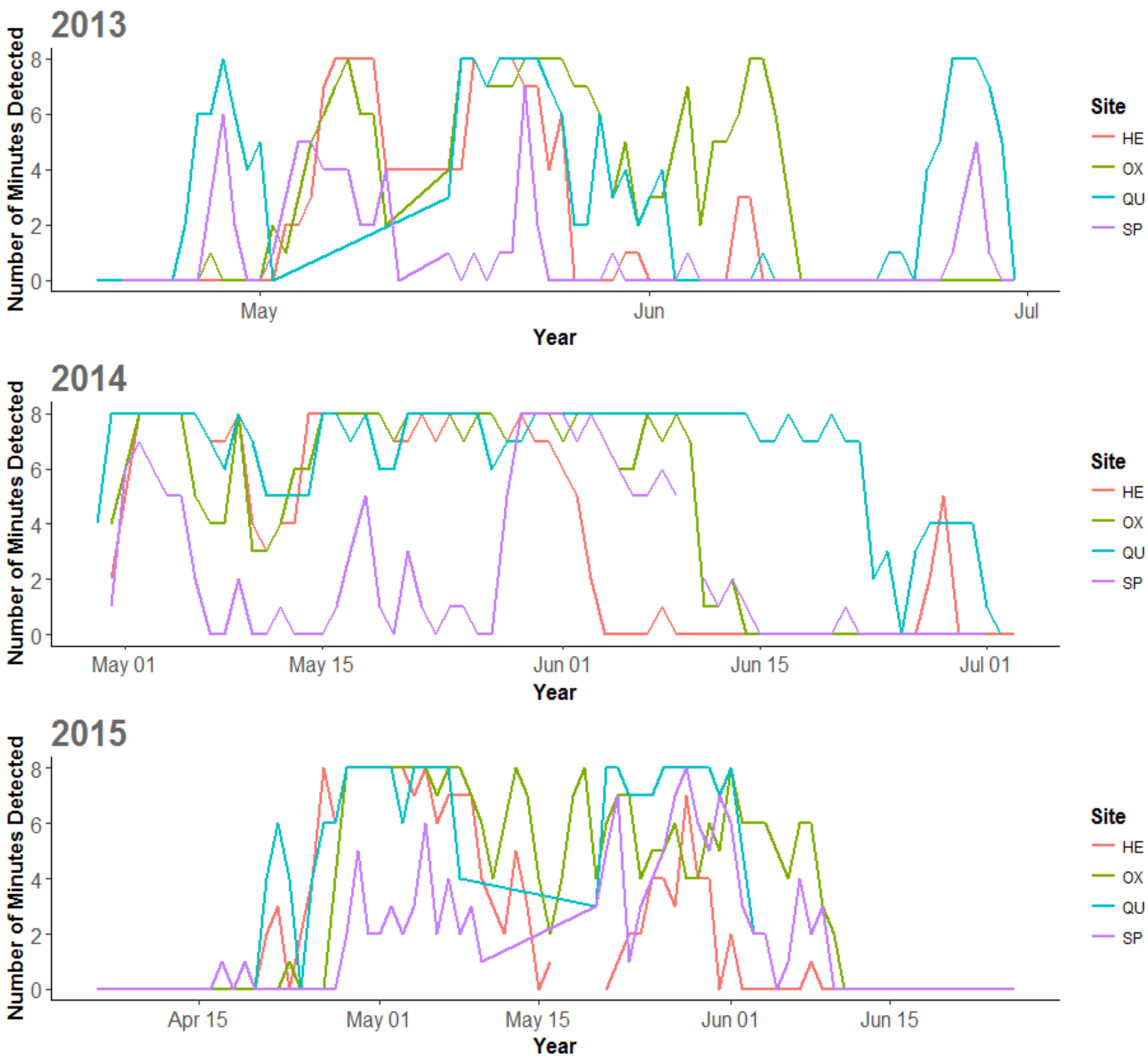


Figure 10: Number of minutes each night that chorus frogs were detected on ARUs at each wetland (ARUs recorded for 8 minutes). Gaps in lines indicate ARU malfunction.

Objective 6: Invertebrate species richness and composition

We identified 63 taxa of invertebrates from 13 orders in our wetland samples. Taxonomic richness was higher in natural (22.40 taxa) and impacted (16.06 taxa) wetlands than in created wetlands (15.77 taxa) (mixed effects model, Figure 11); and richness was higher at lower elevations (Figure 11). Within created wetlands, after accounting for elevation, there was no evidence that richness increased with wetland age (Table 14). However, the highest observed richness estimate, in 2013 and 2015 for any individual wetland, was at Quarry, the oldest created wetland.

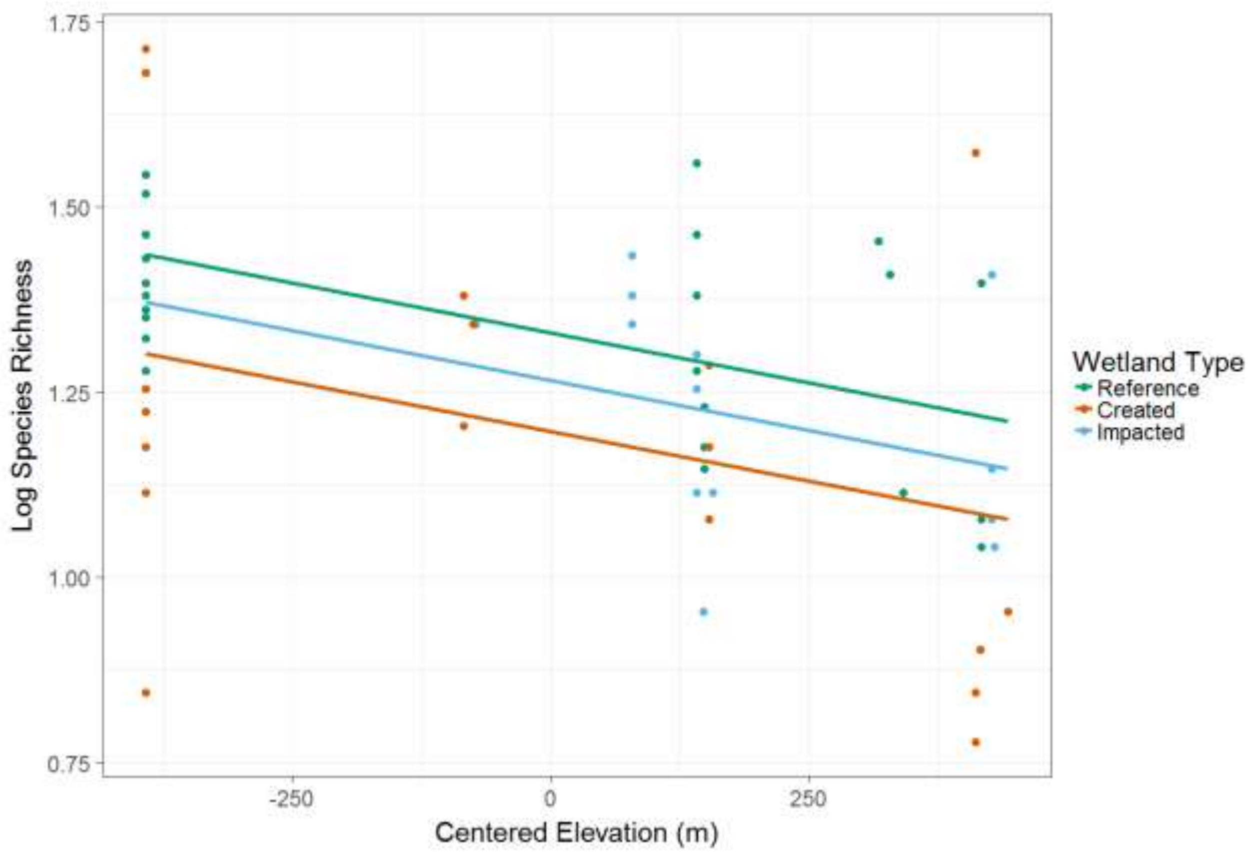


Figure 11. *Estimated log species richness of invertebrates in natural, impacted, and created wetlands across elevation. Elevation was centered at a mean of 0 to improve model fit (so 0 is approximately 2575 m and wetlands range from 2100 m – 3050 m).*

Table 14: *Coefficient estimates from model of log species richness by wetland age, after accounting for elevation for created wetlands only, with site as a random effect to account for repeated sampling of some sites over multiple years.*

	Value	Std.Error	DF	t-value	p-value
Intercept	1.22	0.11	10	11.12	
Elevation(centered)	-0.12	0.06	8	-1.92	0.09
Wetland Age	-0.01	0.02	10	-0.26	0.80

Consistent with lower richness, communities in created wetlands clustered separately from communities in natural and impacted wetlands in our NMDS plot (Figure 12). This indicates that invertebrate communities in created wetlands were compositionally different from those in natural wetlands, while those in impacted wetlands were similar. Within wetland types, natural wetlands showed the least variability in community composition, with much larger 95 percent confidence ellipses around created and impacted wetlands. The only group of invertebrates that was more common in created wetlands than natural or impacted wetlands was the family Notonectidae (backswimmers, order Hemiptera). In contrast, there were five groups of common invertebrates in natural and impacted wetlands that were very rare or absent from created wetlands (Table 15). This study demonstrates that invertebrate biodiversity is both reduced and altered in created wetlands relative to natural and impacted sites in this study area. Species richness was lowest in created wetlands but the age of those sites did not explain these differences, suggesting that there are fundamental differences in habitat between created and natural wetlands that persist several years after creation.

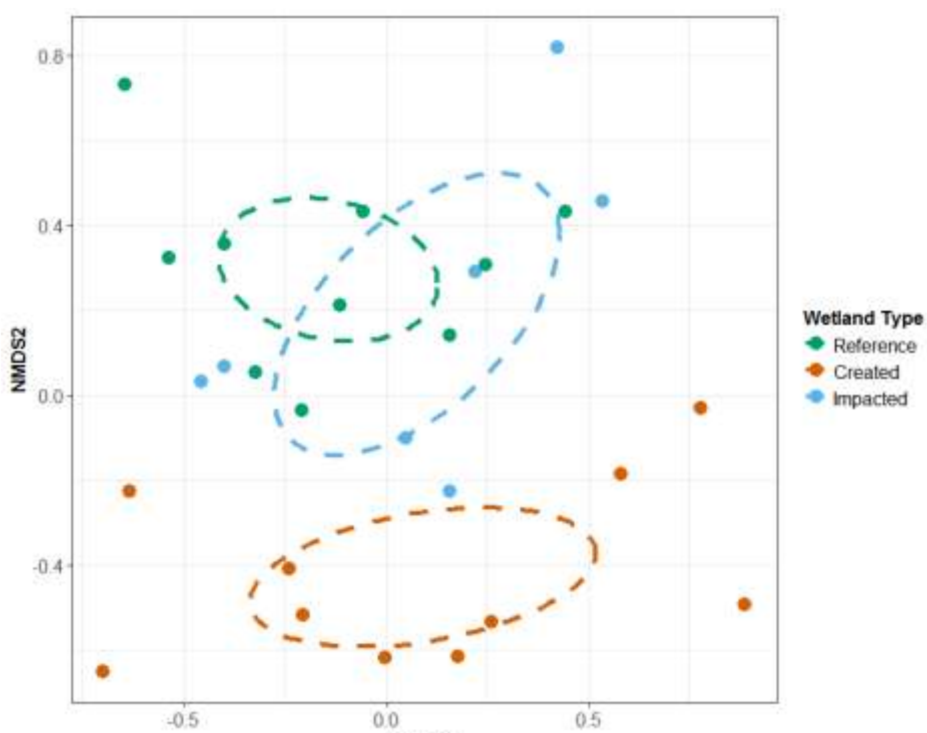


Figure 12: *Non-metric multidimensional scaling (NMDS) ordination of invertebrate community composition/richness/something in created (orange), natural (green), and impacted (blue) wetlands (2015 only). Each point represents the community composition of invertebrates in a single wetland, where points that are closer together in ordination space have more similar community composition than points that are farther away from each other, thus, the axes are unitless. Ellipses represent 95% confidence intervals around the mean axis score for each group.*

Table 15: *Common macroinvertebrate taxa (found in >40% of wetlands) that are shared between all wetland types or common only in created or natural/impacted wetlands. 2015 only.*

Common in all wetland types	Common in created wetlands	Common in Natural /impacted wetlands
Lymnaea spp.	Notonectidae	Pisidium spp.
Ceratopogonidae		Chaoboridae
Dixidae		Lestidae
Callibaetis spp.		Limnephilus spp.
Corixidae		Oligochaeta
Glossiphonidae		

Objective 7: Bird species richness and composition

When we included all species detected (Figure 13), OX (mean=33.33 species) and QU (mean = 32.33 species) had the highest species richness of birds across years, followed by HE (mean=27.33 species) and SP (mean=19.66 species). When we reduced the dataset to include only riparian obligate and dependent songbirds OX and HE had the highest mean species richness across years (mean = 7.66 and 6.33, respectively), followed by QU and SP (mean = 5.33 and 4.66, respectively). The lower species richness in QU was heavily influenced by the data from 2014 when very few species were detected (unknown reasons). At SP the lower species richness was driven by data from 2015 when SP was almost completely dry for the whole season, likely reducing the number of birds that visited the SP site.

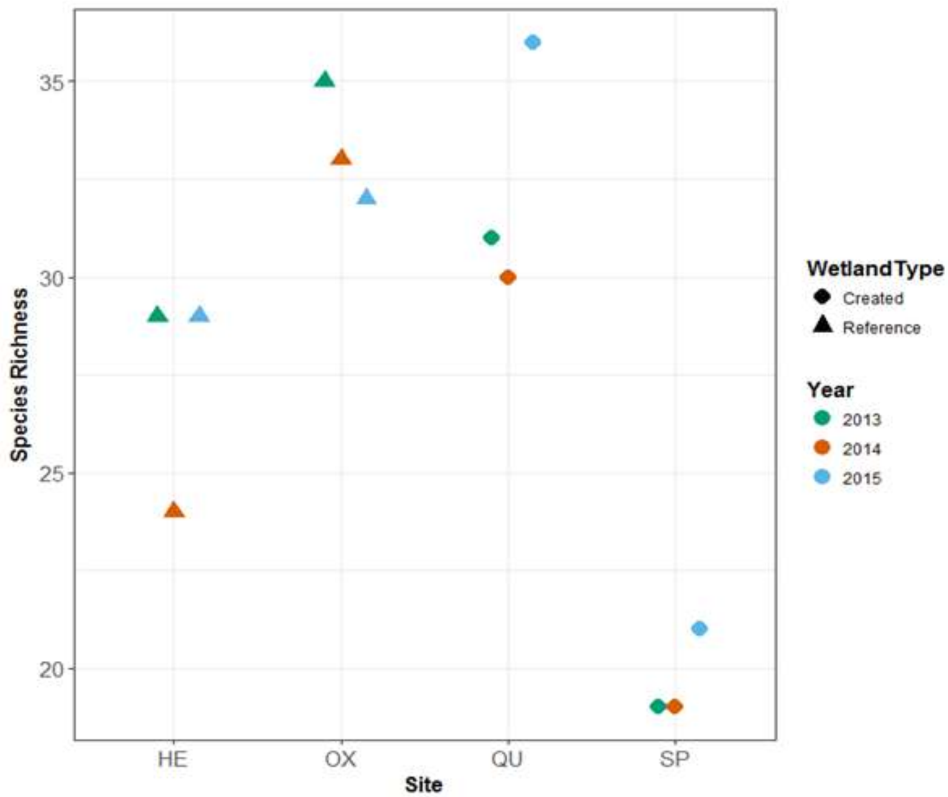


Figure 13A: *Number of bird species detected at each focal wetland in each year.*

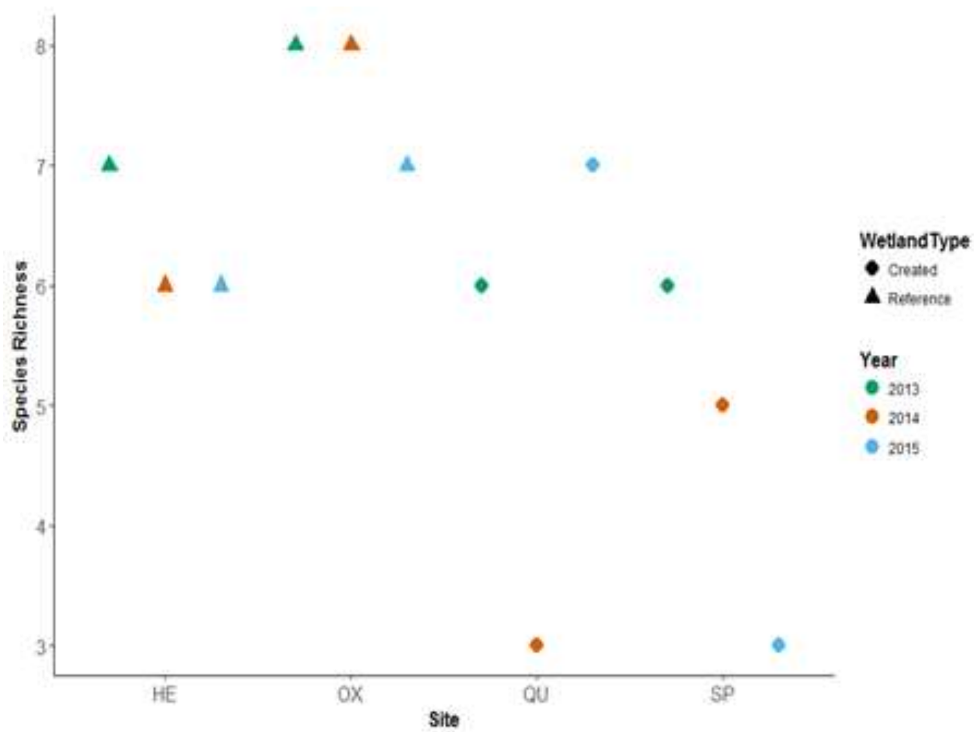


Figure 13B: *Total number of riparian-obligate and riparian-dependent songbirds detected at each focal site in each year.*

We found notable differences in which species occurred at each wetland (Table 16?). For example, species associated with tall willows, such as the willow flycatcher and Wilson's warbler, were detected exclusively at HE and OX (natural wetlands with lots of willows). Lincoln's sparrows and yellow warblers were detected at all wetlands in all years, indicating that they may be habitat generalists. ARUs also recorded calls from birds that were not necessarily calling from the target wetland and thus results should be viewed with caution. For example, Blackrock Creek runs behind SP and has abundant cottonwood trees and willows – some riparian specialist bird species that were detected by the ARU at SP may have been calling from Blackrock Creek rather than SP. Riparian-obligate and riparian-dependent songbirds likely respond strongly to the development of vertical habitat (i.e., willows, Baril et al. 2011) as it provides structure and cover for nesting. Thus, birds may take longer to colonize newly created wetlands than amphibians and invertebrates.

Table 16: *Riparian-obligate and dependent songbird species detected in each wetland each year. Xs represent positive detections, 0s represent non-detections.*

Site	HE	HE	HE	OX	OX	OX	QU	QU	QU	SP	SP	SP
Year	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
Belted kingfisher	X	0	0	0	0	X	0	0	0	X	X	0
Black-capped chickadee	X	0	X	0	X	0	0	0	0	X	X	0
Black-headed grosbeak	X	X	X	X	0	0	0	0	0	0	0	0
Bullock's oriole	0	0	0	0	0	0	0	0	0	X	0	0
Cedar waxwing	0	X	0	0	0	X	X	0	0	0	0	0
Common yellowthroat	0	0	X	X	X	X	0	0	0	0	0	0
Gray catbird	0	0	0	0	X	0	0	0	0	0	0	0
Lincoln's sparrow	X	X	X	X	X	X	X	0	X	X	X	X
Red-winged blackbird	0	0	0	X	X	X	X	X	X	0	0	0
Song sparrow	X	X	X	X	X	0	0	0	X	X	X	0
Warbling vireo	0	0	0	0	0	0	X	X	X	0	0	X
Western wood-pewee	0	0	0	0	0	0	0	0	X	0	0	0
Willow flycatcher	X	0	0	X	X	X	0	0	0	0	0	0
Wilson's warbler	0	X	0	X	0	0	0	0	0	0	0	0
Yellow-headed blackbird	0	0	0	0	0	0	X	0	X	0	0	0
Yellow warbler	X	X	X	X	X	X	X	X	X	X	X	X

CHAPTER 6: IMPLEMENTATION AND SUGGESTIONS

CONCLUSIONS

This dataset from natural, impacted, and created wetlands at Blackrock Ranger Station and along the Highway 26/26/287 reconstruction corridor provided several important insights into the efficacy of wetland mitigation for providing quality replacement habitat for wildlife. While our efforts focused primarily on amphibians, we also assessed how disease prevalence and community structure of invertebrates and songbirds are likely to be affected by wetland mitigation. This project was initially funded to evaluate the success of the Phase I wetland mitigation site (Quarry), but the construction of Phase II and III mitigation wetlands both at Blackrock Ranger Station and along the highway corridor afforded us the opportunity to expand our efforts significantly. The Blackrock project has been an excellent opportunity for collaboration among the U.S. Geological Survey, WYDOT, the U.S. Forest Service, and the University of Montana.

There are several lines of evidence pointing towards the success of the Phase I mitigation site, Quarry relative both to nearby natural wetlands and most other created wetlands. Quarry is the only created wetland where we documented reproduction by all four amphibian species (in 2013, 2014, and 2015). Quarry has supported a large population of boreal toads and boreal chorus frogs since our demographic monitoring began in 2010, with vital rates including recruitment and survival in the range of nearby natural wetlands. Additionally, in 2014 and 2015, Quarry had the highest observed richness of invertebrate taxa out of any wetland, regardless of wetland type. Similarly, bird species richness was similar to, or higher than, two nearby natural wetlands. We attribute this success to the intermediate-permanent hydroperiod, a variety of depths (warm shallows for breeding and deeper spots to buffer against complete drying), abundant aquatic vegetation, and proximity to nearby natural wetlands which can act as source populations of amphibians and invertebrates. While wetland age plays a role in success (Quarry was constructed in 2008), amphibians began reproducing in Quarry soon after its construction (our monitoring began in 2010). We found no relationship between wetland age and invertebrate species richness, suggesting that design features such as depth, size, and vegetation may be more important than wetland age in determining the richness and composition of species in created wetlands. While willows have successfully established along one side of Quarry, it is primarily dominated by emergent vegetation including sedges and rushes. Our study suggests that this type of wetland (i.e., Quarry) represents an appropriate "endpoint" indicating successful mitigation for the conservation of amphibians, invertebrates and likely birds.

The 2014 construction of the Phase II mitigation wetland, "ML", adjacent to Quarry, appears to have altered the hydrology of the immediate area, such that the long-term success of the mitigation efforts (for our target species) is difficult to predict. The depth of the ML has varied considerably since its construction; the entire wetland flooded in 2014, was almost completely dry in 2015, and inundated again in 2016 (Appendix A). Quarry dried up completely in 2016 by the beginning of June, after amphibian breeding, but before tadpole metamorphosis, potentially because of the proximity and likely connection to the ML. These observations highlight the importance of understanding the hydrology prior to and after wetland construction and illustrate the potential for constructed mitigation wetlands to act as ecological traps, where amphibians are attracted to and breed at sites, but experience complete reproductive failure when wetlands dry prior to metamorphosis.

At Togwotee Pass, we saw mixed success of wetland construction at providing adequate replacement habitat for amphibians and invertebrates, with overall lower species richness as elevation increased. At the top of the pass, the persistence of snow and cold temperatures until late in the summer slowed establishment of vegetation and likely limited colonization by aquatic organisms including amphibians and invertebrates. Additionally, the majority of the created wetlands at Togwotee pass were too shallow to retain water long enough for successful amphibian reproduction. Even so, the only two wetlands were we detected boreal toads at Togwotee pass were created wetlands.

One important finding from this research was that impacted wetlands did not differ significantly from natural wetlands in physical habitat characteristics, amphibian occupancy, invertebrate taxa richness, or invertebrate community composition. This suggests that natural wetlands can be quite resilient to some disturbance and if the impact is minimal (i.e., <25percent of the perimeter), wetlands retain their functionality.

Most studies examining amphibian and invertebrate response to wetland mitigation have been conducted in warm, temperate climates (Balcombe, Anderson, Fortney, & Kordek, 2005; Batzer, Taylor, DeBiase, Brantley, & Schultheis, 2015; Ruhí, Boix, Sala, Gascón, & Quintana, 2009), where aquatic organisms are not limited to short, ice-free seasons for dispersal and establishment in newly created wetlands. In contrast, the GYE is characterized by long winters with significant snowfall and short, cool summers, so wetlands are only ice free for a few months out of the year. This research is valuable as a case study of the effects of wetland construction on aquatic organisms in an arid climate at northern latitudes.

MANAGEMENT SUGGESTIONS:

1) Created wetlands are more successful if they maintain a minimum hydroperiod corresponding to the life history requirements of target organisms (e.g., all four species of amphibians in this region breed during early spring and require standing water until at least mid-July for larvae to metamorphose). If wetlands dry prior to metamorphosis, they have the potential to act as ecological traps where amphibians are attracted to and breed but experience lower survival or recruitment than in nearby natural wetlands. Small, isolated wetlands are particularly vulnerable to premature drying resulting from climate change (Matthews, 2010). This vulnerability reinforces the importance of designing mitigation wetlands that are resilient to climatic fluctuations so they can provide quality habitat for amphibians and other wetland-dependent or –associated species.

2) Open, less shrubby wetlands are critical wildlife habitat and may be an appropriate endpoint for wetland mitigation. For example, at Togwotee Pass, boreal toads colonized more created wetlands-within a short time of their creation-than impacted and natural wetlands, possibly because toads prefer sites with warm, shallow water and bare mineral soil. Not all target organisms may respond that quickly or prefer such habitat (e.g., songbirds likely have the opposite response, as they rely on vertical habitat structure) suggesting that there is a need to

create mitigation wetlands with a broad range of habitat characteristics, rather than very specific end points that are focused on primarily on vegetation and large animal species. Our results illustrate the notion that “successful” mitigation can be achieved at a variety of endpoints and that some endpoints may occur quite soon after mitigation is begun.

Figure 14: *Photos of wetland drying prior to amphibian metamorphosis from ML (left) and QU (right) in 2016 illustrating the potential for temporary wetlands to act as population sinks or ecological traps if they dry before amphibian larvae are able to metamorphose. Photo credit: L. Swartz.*

CHAPTER 7: OUTREACH AND EDUCATION

Montana Chapter of the Wildlife Society March 2017, Helena, MT. Swartz, L.K., Hossack, B.R. W.H. Lowe. Amphibian and Invertebrate Community Responses to Wetland Mitigation in the Greater Yellowstone Ecosystem.

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APPENDIX A. PHOTOPOINTS - BLACKROCK WETLANDS
(Original photos: L. Swartz)

Created Wetlands:

Quarry (QU)

Mitigation Lake (ML) looking south

Mitigation Lake (ML) looking north

Swan Pond (SP)

Natural Wetlands:

Chick (CH)

Heron (HE)

Midway (MW)

North Dike (ND)

Oxbow (OX)

Roundworm (RW)

South Dike (SD)

Photo point locations: Blackrock (Coordinates in WGS84 Datum):

Site	Wetland Type	Latitude	Longitude	Compass Bearing
QU	Created	43.83303	-110.354452	241
ML	Created	43.831606	-110.355237	see photos
SP	Created	43.829627	-110.355992	91
CH	Natural	43.843841	-110.327414	320
HE	Natural	43.84474	-110.328246	60
MW	Natural	43.8347	-110.351943	175
ND	Natural	43.839345	-110.339315	10
OX	Natural	43.834251	-110.34695	10
RW	Natural	43.841453	-110.336539	310
SD	Natural	43.839345	-110.339316	200

APPENDIX B: PHOTOPOINTS - TOGWOTEE PASS WETLANDS
(Original photos: L. Swartz)

Created Wetlands:

12DC

13AC

16BC

19AC – Note photo point different in 2014 and 2015

24CC

25AC

26BC

Impacted Wetlands:

12CI

15AI

17AI

17BI

19BI

25BI

26AI – Note photo point changed in 2014

Natural Wetlands:

16CR

17DR

17ER

21AR

21BR

21CR

25CR

Photo point locations: Togwotee Pass (coordinates in WGS84 Datum):

Site	Wetland Type	Easting	Northing	Compass Bearing
12DC	Created	558322	4851425	165
13AC	Created	559090	4851295	106
16BC	Created	565025	4851977	308
19AC	Created	568242	4849429	279
24CC	Created	574993	4845292	313
26AC	Created	575042	4844978	249
26BC	Created	575867	4843728	101
14CI	Impacted	560605	4851560	156
15AI	Impacted	563291	4851497	352
17AI	Impacted	565695	4851329	160
17B1	Impacted	565731	4851295	181
19BI	Impacted	568314	4849341	206
25BI	Impacted	575232	4844456	102
26AI	Impacted	575788	4844063	260
16CR	Natural	564954	4851883	219
17ER	Natural	566030	4850975	131
17DR	Natural	566007	4851007	323
21AR	Natural	571937	4847161	91
21BR	Natural	571811	4847148	332
21CR	Natural	571880	4846844	97
25CR	Natural	575555	4844168	261

APPENDIX C: FULL MODEL SET FOR CJS MODEL (boreal toads)

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance	-2log(L)
{Phi(site*t) p(site*t)}	1591.4	0.0	0.76	1.00	14	324.7	1563.0
{Phi(site+t) p(site+t)}	1595.4	4.1	0.10	0.13	9	338.9	1577.3
{Phi(site*t) p(site+t)}	1596.5	5.1	0.06	0.08	12	333.9	1572.3
{Phi(site+t) p(site*t)}	1597.1	5.8	0.04	0.06	12	334.5	1572.9
{Phi(site+t) p(site)}	1598.4	7.0	0.02	0.03	7	345.9	1584.3
{Phi(site*t) p(site)}	1599.7	8.3	0.01	0.02	10	341.1	1579.5
{Phi(site) p(site+t)}	1609.2	17.8	0.00	0.00	7	356.7	1595.1
{Phi(site) p(site*t)}	1609.7	18.3	0.00	0.00	10	351.1	1589.5
{Phi(site) p(site)}	1615.2	23.8	0.00	0.00	4	368.8	1607.2
{Phi(t) p(site)}	1618.4	27.0	0.00	0.00	6	368.0	1606.3
{Phi(t) p(site+t)}	1619.0	27.7	0.00	0.00	8	364.5	1602.9
{Phi(t) p(site*t)}	1621.6	30.2	0.00	0.00	11	361.0	1599.4
{Phi(.) p(site)}	1637.9	46.5	0.00	0.00	3	393.5	1631.9
{Phi(.) p(site+t)}	1638.9	47.5	0.00	0.00	6	388.5	1626.8
{Phi(.) p(site*t)}	1639.8	48.4	0.00	0.00	9	383.3	1621.7
{Phi(site*t) p(.)}	1712.9	121.6	0.00	0.00	9	456.4	1694.8
{Phi(site*t) p(t)}	1715.9	124.5	0.00	0.00	11	455.3	1693.6
{Phi(site+t) p(t)}	1720.6	129.3	0.00	0.00	8	466.1	1704.5
{Phi(site+t) p(.)}	1722.4	131.0	0.00	0.00	6	471.9	1710.3
{Phi(site) p(t)}	1723.9	132.6	0.00	0.00	6	473.5	1711.9
{Phi(site) p(.)}	1736.5	145.1	0.00	0.00	3	492.1	1730.5
{Phi(t) p(.)}	1978.2	386.8	0.00	0.00	5	729.8	1968.2
{Phi(t) p(t)}	1980.2	388.8	0.00	0.00	7	727.7	1966.1
{Phi(.) p(t)}	1983.3	391.9	0.00	0.00	5	734.8	1973.2
{Phi(.) p(.)}	1997.3	406.0	0.00	0.00	2	754.9	1993.3

APPENDIX D: Disease prevalence (#that tested positive/#tested); ANBO = boreal toad, AMMA = tiger salamander, PSMA = chorus frog, RALU = Columbia spotted frog.

Wetland Type	Site	Species	Year	# Tested	# Positive	# Negative	Prevalence
Created	ML	AMMA	2016	5	5	0	1
		ANBO	2014	1	0	1	0
			2015	16	16	0	1
			2016	17	17	0	1
	QU	AMMA	2014	6	2	4	0.33
			2015	10	6	4	0.6
		ANBO	2012	40	9	31	0.23
			2013	40	6	34	0.15
			2014	23	16	7	0.7
			2015	20	9	11	0.45
			2016	20	5	15	0.25
		PSMA	2012	19	12	7	0.63
			2014	20	17	3	0.85
			2015	20	13	7	0.65
			2016	20	20	0	1
		RALU	2014	6	6	0	1
			2015	2	0	2	0
			2016	2	0	2	0
	SP	AMMA	2014	2	2	0	1
			2016	4	2	2	0.5
		ANBO	2012	7	2	5	0.29
			2013	19	4	15	0.21
			2014	23	23	0	1
			2015	19	11	8	0.58
			2016	14	13	1	0.93
Natural	CH	RALU	2015	2	2	0	1
	HE	AMMA	2016	2	1	1	0.5
		ANBO	2012	19	8	11	0.42
			2013	30	13	17	0.43
			2014	25	13	0	0.52
			2015	30	20	11	0.67
			2016	20	16	4	0.8
		RALU	2014	25	24	1	0.96
			2015	10	4	6	0.4
			2016	12	11	1	0.92
	MA	ANBO	2012	16	6	10	0.38
	MW	ANBO	2012	1	1	0	1
			2013	24	5	19	0.21
			2015	20	20	0	1
			2016	20	18	2	0.9
		RALU	2015	2	2	0	1
	ND	RALU	2015	3	2	1	0.67
	OX	ANBO	2012	25	4	21	0.16
			2013	32	12	20	0.38
			2014	30	27	3	0.9
			2015	20	15	5	0.75
			2016	20	5	15	0.25
		RALU	2012	1	0	1	0
			2014	3	3	0	1
			2015	1	0	1	0
			2016	1	0	1	0
	RW	AMMA	2016	4	0	4	0
		RALU	2015	10	10	0	1
			2016	12	0	12	0
	SD	RALU	2015	10	9	1	0.9
			2016	11	0	11	0