A population viability analysis of the Oregon chub (*Oregonichthys crameri*)

in the Willamette Valley, Oregon

by

Erin Peterson

A PROJECT

Submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Fisheries and Wildlife Science (Honors Associate)

Presented May 12, 2014
Commencement June 2014

AN ABSTRACT OF THE THESIS OF

Erin Peterson for the degree of Honors Baccalaureate of Science in Fisheries and Wildlife Science presented on May 12, 2014. Title: A population viability analysis of the Oregon chub (*Oregonichthys crameri*) in the Willamette Valley, Oregon.

Abstract approved: ____

Selina Heppell

The Oregon chub (*Oregonichthys crameri*) is a small minnow (Family: Cyprinidae) endemic to Oregon's Willamette Valley. In 1993, the Oregon chub was listed as endangered because of habitat loss and predation and competition by nonnative fishes. Conservation efforts by the Oregon Department of Fish and Wildlife (ODFW) and other agencies have led the Oregon chub to become the first fish ever proposed for delisting due to recovery. The goal of this project was to analyze population parameters from 18 sites containing Oregon chub and determine how factors such as the presence of nonnative species and the supplementation of other chub might affect them. I used regression to determine overall trends for each population and a population viability analysis to evaluate quasi-extinction risk for each population. Results indicate that over long time periods, the supplementation of chub can reduce extinction risk, while the presence of nonnative fishes may cause populations to drop below critical thresholds for population size. The outcome of this project is important because it supports current management practices by showing that continued monitoring is needed to maintain the progress that has been made towards the recovery of the Oregon chub.

Key Words:
Oregon chub, population viability analysis, extinction risk

Corresponding e-mail address:
petersonerin@hotmail.com

A population viability analysis of the Oregon chub (*Oregonichthys crameri*)

in the Willamette Valley, Oregon

by

Erin Peterson

A PROJECT

Submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Fisheries and Wildlife Science (Honors Associate)

Presented May 12, 2014
Commencement June 2014

Honors Baccalaureate of Science in Fisheries and Wildlife Science project of Erin Peterson presented on May 12, 2014.

APPROVED:

Selina Heppell; Mentor, representing Fisheries and Wildlife Science

Douglas Markle; Committee Member, representing Fisheries and Wildlife Science

Paul Scheerer; Committee Member, representing the Oregon Department of Fish and Wildlife

Toni Doolen; Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Erin Peterson, Author

ACKNOWLEDGEMENTS

I would like to thank my mentor, Selina Heppell, and my committee members, Doug Markle and Paul Scheerer for all of their patience and support through the last 2+ years of writing this thesis. Also, thank you to my friends and family members for providing moral support and a listening ear whenever I needed it.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

A POPULATION VIABILITY ANALYSIS OF THE OREGON CHUB (*OREGONICHTHYS CRAMERI*) IN THE WILLAMETTE VALLEY, OREGON

Introduction

The global human population reached seven billion people in the year 2011 (Biella 2011). Humans, like most organisms, require food, clean water, and space in which to live. However, with each new person added to the planet there are fewer resources available per capita. This requires more land to be converted into agriculture and housing in order to support the growing number of humans. Habitat loss due to human influences has affected almost every biome in the world, and it is a particular problem in freshwater ecosystems.

Freshwater habitats provide food, clean water, transportation, and income to a large portion of the world population (Vie et al. 2009). For these reasons, humans often settle near and modify freshwater ecosystems. Many freshwater taxa—including fishes, mollusks, amphibians, and dragonflies, among others—have become extirpated or have gone extinct in recent years, or are threatened or endangered by such things as water pollution, over-harvest, the introduction of nonnative species, habitat modification, and global climate change (Vie et al. 2009).

One of the greatest challenges facing the conservation of freshwater taxa is that the conservation status of most species has not been evaluated at all, therefore nothing is known about extinction risk (Vie et al. 2009). McElhany et al. (2000) provide a set of guidelines for evaluating population viability of Pacific salmon. Population status is critically important for these species because of their conservation status. The parameters suggested for consideration include abundance, population growth rate, the spatial structure of the population, and the diversity within the population (McElhany et al. 2000). These guidelines can be applied to other species as well.

In Oregon, one freshwater fish species of particular concern is the Oregon chub (*Oregonichthys crameri*), a member of the minnow family (Cyprinidae). Oregon chub have been intensely monitored by the Oregon Department of Fish and Wildlife (ODFW) due to concerns regarding their restricted distribution and increasing threats from nonnative fishes in recent decades. In 1993, the Oregon chub was ESA listed as endangered, and in 2010 it was downlisted to threatened status due to the establishment of new populations through introductions and the discovery of new, previously unknown populations (USFWS 2010). The management efforts of ODFW led to the proposed delisting of the Oregon chub in 2014.

The purpose of this project is to develop a population viability analysis (PVA) that will model the trends of individual populations of chub that have been monitored for at least 10 years. A population viability analysis is a process that uses models generated from data in order to predict extinction risk and persistence of populations of organisms (Mills 2007). In this analysis, population trends and extinction risk were evaluated similar to McClure et al. (2003), using the risk of "quasi-extinction" (population decline to a threshold) as a metric to compare the status of introduced vs. naturally occurring populations and the potential impacts of nonnative predators. The ODFW provided twenty years of population data for Oregon chub from sites all across the Willamette Valley. Specific site information such as whether or not the population was naturally occurring or resulted from an introduction, and whether or not nonnative species were present was also included. These qualitative data were used to generate hypotheses about population growth trends.

Oregon Chub Biology and Conservation

The Oregon chub (*Oregonichthys crameri*) is a small minnow (Family: Cyprinidae) endemic to the Oregon's Willamette River basin (Bond 1966, USFWS 2010). It prefers slow-moving, off-channel habitats (Scheerer and McDonald 2003). However, the installation of dams and introduction of nonnative fishes such as bass and other centrarchids have caused a drastic reduction in access to the preferred habitat and overall population numbers for the Oregon chub (Scheerer 2002). The Oregon chub was listed as endangered in 1993, and downlisted to threatened in 2010. The US Fish and Wildlife Service (USFWS) 1998 Recovery Plan lists the following criteria for delisting this species:

1. Establish and manage 20 populations of at least 500 adults each;
2. All of these populations must exhibit a stable or increasing trend for 7 years;
3. At least 4 populations must be located in each of the 3 subbasins (Mainstem Willamette River, Middle Fork Willamette River, and Santiam River). For the purposes of this project, a fourth subbasin has been included, which is the McKenzie River. The McKenzie River is included in the Mainstem Willamette Recovery Area, but the ODFW recognizes it as a distinct subbasin. At the time of listing, there were no known populations of Oregon chub in the McKenzie River subbasin.

These guidelines were still in place in 2014, when the Oregon chub became the first fish proposed for delisting due to recovery.

Hypotheses

The ODFW included descriptive habitat information for each of the eighty-six populations of Oregon chub that it has been monitoring, some for the as many as twenty years. This information includes whether or not a population was introduced, and whether or not nonnative species were present in the censused area. All non-naturally occurring populations in this study are "introduced" sites that ODFW started by transferring Oregon chub from nearby locations. Sites for introduction were purposefully chosen in areas where nonnative species were absent (P. Scheerer, Oregon Department of Fish and Wildlife, personal communication).

I hypothesize that if an introduction is successful, these populations of Oregon chub will show higher population growth rates than naturally occurring populations. Likewise, if the presence of nonnative species affects population growth trends, then populations in locations where nonnative species are not present will show higher population trends than those where they are present.

Methods

Criteria for selecting populations and running sum

Eighteen of these eighty-six sites censused by ODFW were chosen for the examination of population trends and extinction risk: two from the Santiam River subbasin, three from the Mainstem Willamette and its tributaries, three from the McKenzie River subbasin, and ten from the Middle Fork Willamette subbasin (Table 1). These sites were chosen based on the following criteria:

1. All population estimates were from mark-recapture surveys, not the raw numbers of fish captured. It is important that the same method was used across all years in order to ensure consistency. In addition, mark-recapture estimates are not strongly affected by catch per unit effort; and
2. Population estimates were available for at least ten consecutive years, so that a three-year running sum would have at least eight consecutive years of data;

The mark-recapture estimates provided by the ODFW included precision estimates for each sampling occasion (APPENDIX A), and these mark-recapture estimates were the data used for population sizes at all eighteen sites. These data were all converted into three year running sums because although the methods used for data collection every year were consistent, natural variability sometimes caused large shifts in population size in consecutive years. For instance, the population at Dexter Reservoir Alcove was estimated to be 390 individuals in 2003. In 2004, however, the population estimate dropped to only 70 individuals, but then rebounded to 600 individuals in 2005. This change was not due to supplementation on the part of ODFW, nor was it due to a change in survey methods, because mark-recapture had been used every year at this site since 1995. Extreme fluctuations in population size were not unique to one site, and some sites even experienced multiple shifts over the last two decades of monitoring. Large increases or decreases in population abundance are interesting and important data, but over a short time period these sudden swings can yield inaccurate representations of the population trajectory. One method for dealing with unstable population sizes that may not reflect true dynamics is to convert yearly population estimates into a running sum. Running sums add together consecutive years of data which can then be used to replace the population estimate of a single year. The advantages of a running sum are to reduce variability and obtain a count, trend and variance that are most representative of the population (Holmes 2001).

A three-year running sum (3 YRS) was chosen for the Oregon chub in this study. Holmes (2001) recommends choosing a running sum based on the generation time of the organism in question, and three years is a reasonable estimate for the lifespan of a typical Oregon chub (Scheerer and McDonald 2003). Summing the population estimates over this timespan accounts for the fact that each fish is present in the population for its entire life, not just the years in which it was captured. The 3 YRS sums the data from years n, n+1, and n+2, and uses the sum as the population estimate in year n. In this way the variability in the time series is reduced, since the 3 YRS mimics the population trajectory without being heavily influenced by year-to-year variation (Figure 1). However, this method only accounts for the year-to-year variation in estimates and not the uncertainty associated with each annual estimate. To quantify this uncertainty it would be necessary to examine the 95% confidence interval and the distribution around each estimate.

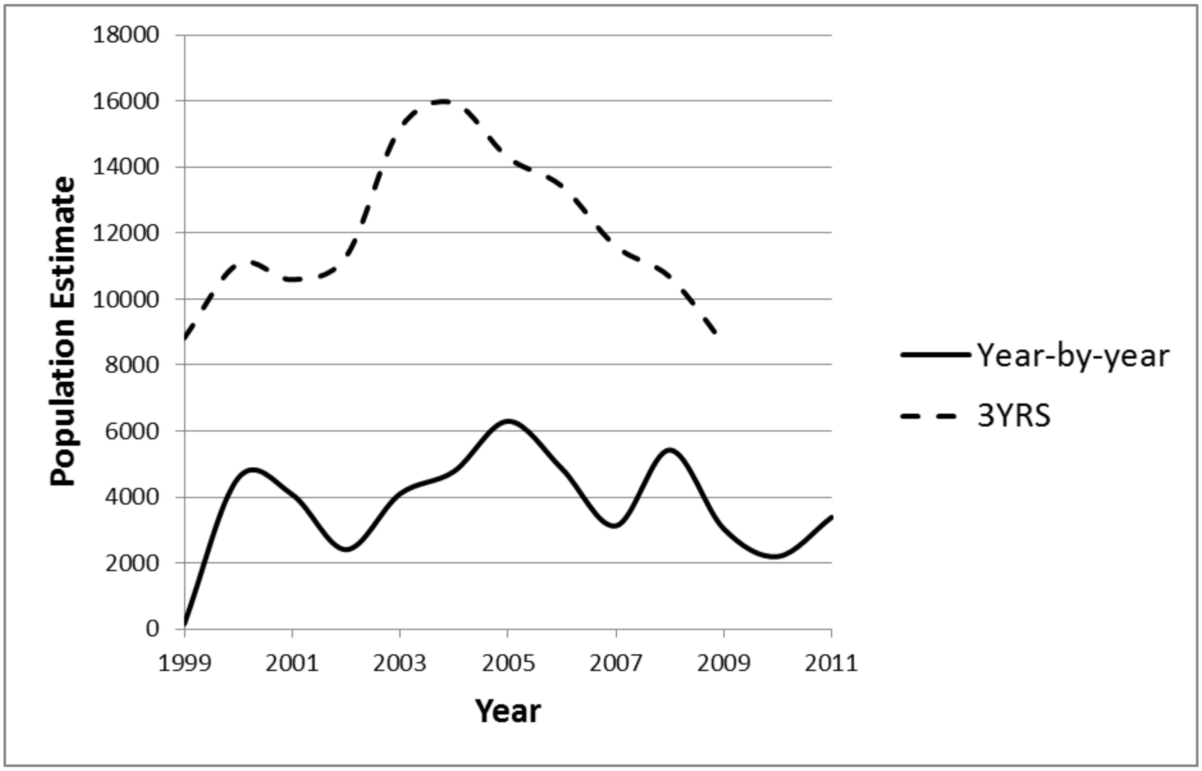


Figure 1. Time series from Wicopee Pond (Middle Fork Willamette). The solid line represents a mark-recapture estimate on a year-by-year basis, while the dashed line is the same data converted into a three-year running-sum. The 3 YRS mirrors the trend of the year-by-year line, but the variance is less.

Table 1. Monitoring time and descriptive site information for eighteen populations of Oregon chub (*Oregonichthys crameri*) in four Willamette Valley subbasins. Years of supplementation for the introduced sites refers to the number of years in which Oregon chub were added to these populations.

Population (Years Monitored)	Total Years Monitored	Population Estimate in 2011	Introduced (Years of supplementation)	Nonnatives present
Santiam				
Geren Island North Channel (1996-2011)	16	3030	No	Yes
Foster Pullout Pond (1999-2011)	13	2360	Yes (6)	No
Mainstem Willamette and Tributaries				
Dunn Wetland (1997-2011)	15	47350	Yes (1)	No
Finley Gray Creek Swamp (1993-2011)	19	2150	No	Yes
Finley Display Pond (1998-2011)	14	487	Yes (7)	No
McKenzie				
Shetzline Pond (2002-2011)	10	5750	No	No
Big Island (2002-2011)	10	400	No	Yes
Russell Pond (2001-2011)	11	340	Yes (2)	No
Middle Fork Willamette				
Fall Creek Spillway Ponds (1996-2011)	16	6690	Yes (1)	No
Wicopee Pond (1999-2011)	13	3390	Yes (1)	No
Hospital Pond (1997-2011)	15	2860	No	No
East Fork Minnow Creek Pond (1993-2011)	19	2170	No	No
Buckhead Creek (1999-2011)	13	1900	No	No
Shady Dell Pond (1993-2011)	19	1760	No	No
Elijah Bristow Berry Slough (1997-2011)	15	1040	No	No
Dexter Reservoir RV Alcove - DEX3 (1997-2011)	15	940	No	Yes
Elijah Bristow Northeast Slough (1999-2011)	13	670	No	Yes
Dexter Reservoir Alcove - PIT1 (1995-2011)	17	350	No	Yes

Evaluating trends and extinction risk

The analysis included measuring the finite rate of population growth, the instantaneous rate of growth, and the variance around these trends. Regression models provided equations to predict future population trends and also aided in the construction of quasi-extinction threshold plots, which model the extinction risk of a population at set generation times.

Regression analysis

Regression

The exponential trend of each population was estimated using simple regression (Table 2). The raw population estimates were natural log-transformed to smooth out variability in the estimates (Beauchamp and Olson 1973), and to ensure that values would be normally distributed. A linear regression was performed on the transformed data vs. year, and the slope obtained from the output was the trend for the population. A negative slope indicates a decreasing trend, and a positive slope indicates an increasing trend.

The data collected for this study spans a period of 8-19 years, which is a relatively short timeframe for this type of study. Therefore, a 95% confidence interval was consulted in order to estimate uncertainty for each population trend. The 95% confidence interval (CI) is created from the regression analysis, and it is the interval within which the true population mean can be found 95% of the time, if the simulation is run many times (Mills 2007). A confidence interval in which both ends of the interval are negative indicates that the population trend is most likely negative as well. Likewise, a positive confidence interval is indicative of a positive population trend. Confidence intervals in which the lower bound is negative and the upper bound is positive are inconclusive because the interval includes zero, meaning that there is a possibility that there is no trend in the data at all. The 95% CIs for abundance trends obtained for each of the populations in this study give an indication of significance of the calculated trends in population growth over the study period (Table 2).

Annual changes in population size

The regression slopes provided the first metric to compare population trends, but did not provide information on year-to-year variance that is needed for extinction risk calculations. Lambda (λ) is the ratio of population size in the next time period (N_{t+1}) to the current population size (N_t), where N is either the annual fish population estimate or the running sum total for the population each year. The equation for calculating lambda is as follows:

$$\lambda = N_{t+1}/N_t \quad \text{[Eq.1]}$$

A lambda value of 1 denotes a population whose overall numbers are not changing. A value of greater than one—such as λ=1.05—indicates that the population at time N_{t+1} has experienced an increase from time N_t, in this case a 5% increase from the previous time period. Likewise, a population that has decreased from time N_t to time N_{t+1} will have a lambda value of less than one. For instance, λ=0.95 means that the population at time N_{t+1} is 5% smaller than it was at time N_t, or only 95% of its original size. A population with a lambda greater than one has experienced “positive growth” and a population with lambda less than one has experienced “negative growth” even though the value of lambda itself will always be greater than zero.

Average values for lambda for each population were obtained by graphing the natural logarithm of the population versus year, and fitting a straight line to the points. The equation for this line is of the form y = mx + b, where m is the slope and b is the intercept. Lambda was calculated as e^m (Figure 2). Lambda is important to this analysis because it is used for developing quasi-extinction thresholds, which will be discussed in the next section.

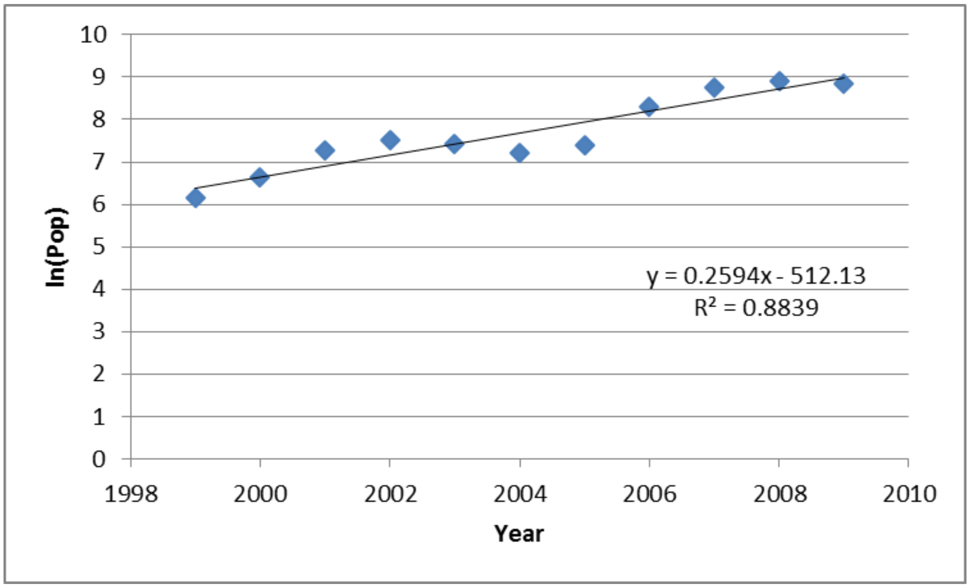


Figure 2. Natural log transformed population estimates for Foster Pullout Pond. A trendline fitted to the data has a slope of 0.2594. Calculating $e^{0.2594}$ yields a value of 1.2962, which corresponds to an annual growth rate of 29.62%.

PVA

The population viability analysis is an analysis of extinction risk. This analysis relies on data obtained from a simple census and can be applied in cases where there is not enough detailed data to create complicated life-history models (Holmes 2004). This is particularly useful for approximating stochastic trajectories for complex populations (Lande and Orzack 1988) and for comparing the chances of long-term decline across multiple populations, because each population can be evaluated individually over a long time series. In the case of the Oregon chub, the PVA was appropriate because the data for the analysis came from mark-recapture estimates, and populations could be evaluated individually or as metapopulations.

The approach used in this study incorporates only two parameters: mu (μ) and variance (σ^2). These parameters are known as the infinitesimal mean and infinitesimal variance, respectively, and are used to represent annual change and the variance associated with that change (Dennis et al. 1991). Mu and variance for each of the eighteen populations are directly related to calculating extinction risk for that population because the trajectory of the population (μ) and the variation around that trajectory (σ^2).

Mu

Mu (μ [pronounced "mew"]) is the average of the natural log of the annual λ values. This average gives an instantaneous rate of increase with normally distributed variance. Mu is akin to the slope of the regression line, but is based on year-to-year change in the estimate of N instead of a best fit line through the data. Mu is the average of $\ln(N_{t+1}/N_t)$, and therefore can be calculated only on three or more years of data, since obtaining one lambda value requires two years of data (N_t and N_{t+1}). The equation for mu looks like this:

$$\mu = \text{mean}[\ln[N_{t+1}/N_t]] \quad \text{[Eq. 2]}.$$

Unlike λ, μ can have a negative value. Due to the laws of natural logs, populations are stable when $\mu=0$ ($\lambda=1$). When μ is less than zero the population is decreasing and when it is greater than zero the population is increasing (McClure et al. 2003).

Variance

Variance (σ^2) accounts for the fact that natural variation occurs from year to year in the estimates of population growth (Gotelli 2008). For this study it is a measure of the variance in the natural log of lambda for each population (Table 2). Below is the equation for variance:

$$\sigma^2 = \text{variance}[\ln[N_{t+1}/N_t]] \text{ [Eq. 3].}$$

Table 2. Values for equations 1-3 for eighteen populations of Oregon chub in four Willamette Valley subbasins on a three-year-running sum basis. Slopes and 95% confidence intervals (CI) were obtained from regression analyses. Introduction sites are *italicized*, and sites containing nonnative fishes are underlined. Sites that are neither italicized nor underlined are reference sites (naturally-occurring Oregon chub populations with no nonnative fishes). P-values denote whether the slope of the regression line is significantly different from zero.

Population	μ	σ^2	λ	Slope	p-value (*Significant*)	95% CI
Santiam						
Geren Island North Channel (1996-2011)	-0.090319	0.3965458	0.93146	-0.07097	0.162	(-0.17472, 0.032775)
Foster Pullout Pond (1999-2011)	0.270236	0.1230468	1.2962	0.259385	*<0.001*	(0.18851, 0.33026)
Mainstem Willamette and Tributaries						
Dunn Wetland (1997-2011)	0.2440141	0.1497537	1.1907	0.174464	*<0.001*	(0.089881, 0.259048)
Finley Gray Creek Swamp (1993-2011)	0.0916797	0.0696678	1.0921	0.088125	*<0.001*	(0.041799, 0.134451)
Finley Display Pond (1998-2011)	-0.034771	0.1903541	0.95887	-0.04226	0.447	(-0.16115, 0.076634)
McKenzie						
Shetzline Pond (2002-2011)	0.1796374	0.826076	0.986098	-0.0136	0.919	(-0.32901, 0.301807)
Big Island (2002-2011)	0.0264274	0.1346078	1.03324	0.032683	0.627	(-0.12346, 0.188824)
Russell Pond (2001-2011)	0.1416522	0.0221586	1.1556	0.144572	*<0.001*	(0.114229, 0.174915)
Middle Fork Willamette						
Fall Creek Spillway Ponds (1996-2011)	0.1341627	0.1607348	1.02963	0.02916	0.451	(-0.05244, 0.110763)
Wicopee Pond (1999-2011)	-0.002178	0.0263129	1.0027	0.002749	0.896	(-0.04366, 0.049156)
Hospital Pond (1997-2011)	-0.052248	0.0363041	0.96271	-0.0378	*0.050*	(-0.07551, -0.00009)
East Fork Minnow Creek Pond (1993-2011)	-0.080261	0.0163733	0.91668	-0.08693	*<0.001*	(-0.10254, -0.07132)
Buckhead Creek (1999-2011)	-0.070488	0.0243925	0.90847	-0.0963	*<0.001*	(-0.12406, -0.06853)
Shady Dell Pond (1993-2011)	-0.023884	0.0549196	1.0099	0.009779	0.508	(-0.02096, 0.040519)
Elijah Bristow Berry Slough (1997-2011)	0.0111999	0.0554869	1.0541	0.052697	*0.009*	(0.015642, 0.089752)
Dexter Reservoir RV Alcove – DEX3 (1997-2011)	0.0683698	0.1165712	1.1129	0.106982	*0.002*	(0.049621, 0.164342)
Elijah Bristow Northeast Slough (1999-2011)	-0.056339	0.0993096	0.89763	-0.10759	*0.008*	(-0.17911, -0.03606)
Dexter Reservoir Alcove - PIT1 (1995-2011)	0.0651891	0.1159693	1.0309	0.030437	0.274	(-0.02717, 0.088046)

Extinction Risk

The probability of population extinction sometime in the future depends on the trend, variance, current population size, and a pre-defined parameter called the quasi-extinction threshold (QET). The QET is a future population size that acts as a floor for the population—below this number, a population may be considered extinct. The floor could be set to 1 fish, or 150 fish, or any other number of individuals, depending on the structure of the population and the life history of the organism in question. The QET should be based on ecological or genetic information to represent a population size below which the population would be unlikely to recover.

A QET plot is created using a stochastic simulation that incorporates mu and variance, producing a distribution of all possible future outcomes for a population based on those parameters. For this project, one hundred stochastic simulations were created for each population using mu, variance, and the starting population size based on a three-year running-sum. The computer model projected population trends one hundred years into the future for each of the one hundred runs by drawing random annual growth rates from the distribution defined by mu and σ^2. For the purpose of this project, the QET was set as a 90% reduction from the 2011 population estimate based on a three-year running-sum. Every year of the simulation, the model recorded the percentage of populations that had dropped below the QET. This percentage was plotted to give an overall risk of extinction for the population in the future (Figure 3). The proportion of populations extinct at nine years (three generation times), fifteen years (five generation times), thirty years (ten generation times), and one hundred years were all recorded .

The 90% reduction in population size was chosen based on criteria set out by the International Union for Conservation of Nature (IUCN). The IUCN maintains a “Red List” of vulnerable, threatened, and endangered species of the world. Qualification for a given category generally depends on a certain percent reduction in population size over a given period of time, and the criteria for inclusion in the Critically Endangered category included a 90% reduction in population over ten years (IUCN 2000).

The rationale for using a QET at all is that a population can be considered extinct long before the number of individuals reaches zero. Negative density dependence (depensation) can occur when populations are at low densities; instead of growing to reach carrying capacity, they may decline because of the inability to reproduce. This phenomenon is also known as the Allee effect, and it leads to extinction for the population in question. Because of this, populations can be threatened with extinction even when there are hundreds or even thousands of individuals still living. Certain populations of animals, such as colony breeding birds, may decide not to mate if colony sizes do not reach a critical level. Large territorial mammals or sessile aquatic invertebrates may encounter potential mates (or the gametes of potential mates) so infrequently at low densities that reproduction becomes impossible. The Allee effect is heavily studied in invertebrates, but Gascoigne et al. (2009) argue that it undoubtedly applies in vertebrate populations as well. While the threshold for depensation has not been determined for Oregon chub, a 90% reduction in population size may be low enough to trigger an Allee effect in some populations.

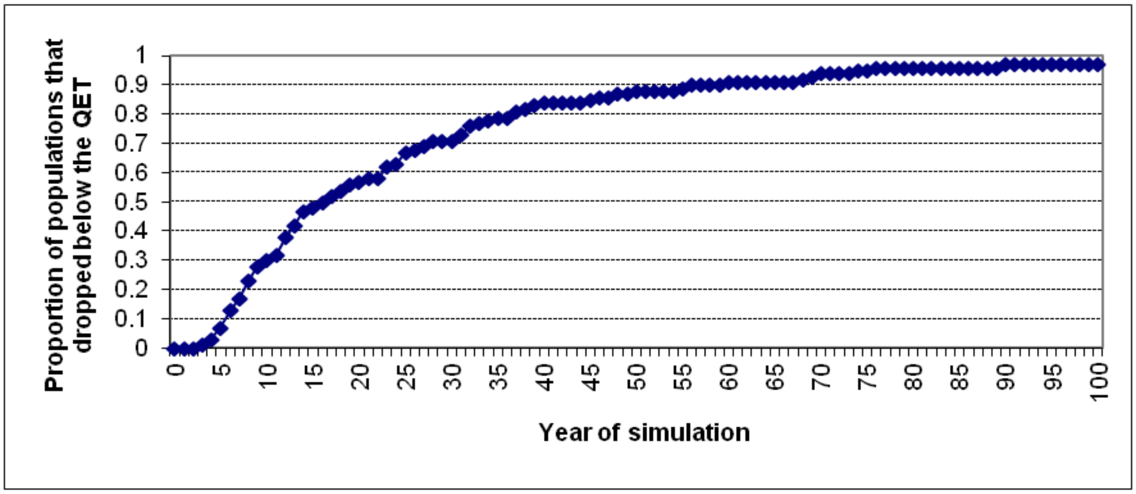


Figure 3. An example of a quasi-extinction threshold plot. In this case, QET is set at 50 individuals. Within the next 3-5 years, assuming mu and variance stay the same, the population has a 0% chance of dropping below 50 individuals, but that risk climbs to almost 100% in 80 years.

It is important to note that these population viability analysis models are simulations, and therefore the results of the simulation can change every time the model is run. A population that is projected to have an 80% risk of extinction in one simulation may have a 90% probability of dropping below QET in another. The simulation assumes that μ and σ^2 will remain constant throughout the timeframe of the simulation, which is not necessarily the case. For this reason, QET graphs should be used as an index for comparing populations instead of as a prediction for a single population.

Effect of Subbasin

Population trends were also modelled at the level of subbasin in order to determine the effect of geography on the chub. Quasi-extinction plots for the four subbasins present in this study—the Santiam, the Mainstem Willamette and Tributaries, the McKenzie, and the Middle Fork Willamette—were created by summing the population estimates for all populations in those subbasins and calculating μ and σ^2 for each subbasin, then running the viability analysis on 3 year-running sum population estimates through 100 stochastic simulations for 100 years. Quasi extinction threshold was set at 90% reduction in the 2011 pooled population estimate for each sub-basin. Within each subbasin, the analysis was restricted to years in which all populations were represented by data.

Results

For the purpose of testing the hypotheses laid out in the **Hypotheses** section, populations were divided into three groups to evaluate the effect of nonnative species and population origin (natural vs. introduced) on population growth rate. The first group was comprised of the six introduced populations, which are collectively called the "introduced" sites. The second group was comprised of six populations naturally occurring populations where nonnative fish species were present. These are referred to as "nonnative" sites. The third group was comprised of six naturally-occurring populations and did not contain nonnative fish species ("reference" sites). The trends of the reference populations were compared to the trends of the introduced and nonnative populations to determine the influence of these factors of population growth rates and extinction risk.

Effect of population origin on population trends and viability

Slopes (from Table 2) for the introduced and reference populations were compared to determine if introduced populations had a different growth rate than the natural reference populations (Figure 4). There is convincing evidence that introduced populations have an average slope greater than that of the reference populations (estimated difference: 0.1234, two sample t-test, p=0.052). With 95% confidence, this difference is between -0.0016 and 0.2484. There is a very slim chance that there is no trend at all or that the trend is opposite.

There were very pronounced differences in extinction risk for introduced and reference populations. Five of six introduced populations had a less than 10% risk of reaching QET within 100 years, and of those five, three had a 0% chance (Table 3). However, four of six reference sites had a 60% or greater probability of dropping below the QET within the same time period, and none had a risk of less than 20%. Two reference populations had a 100% of reaching QET within 100 years (APPENDIX B, Table 3).

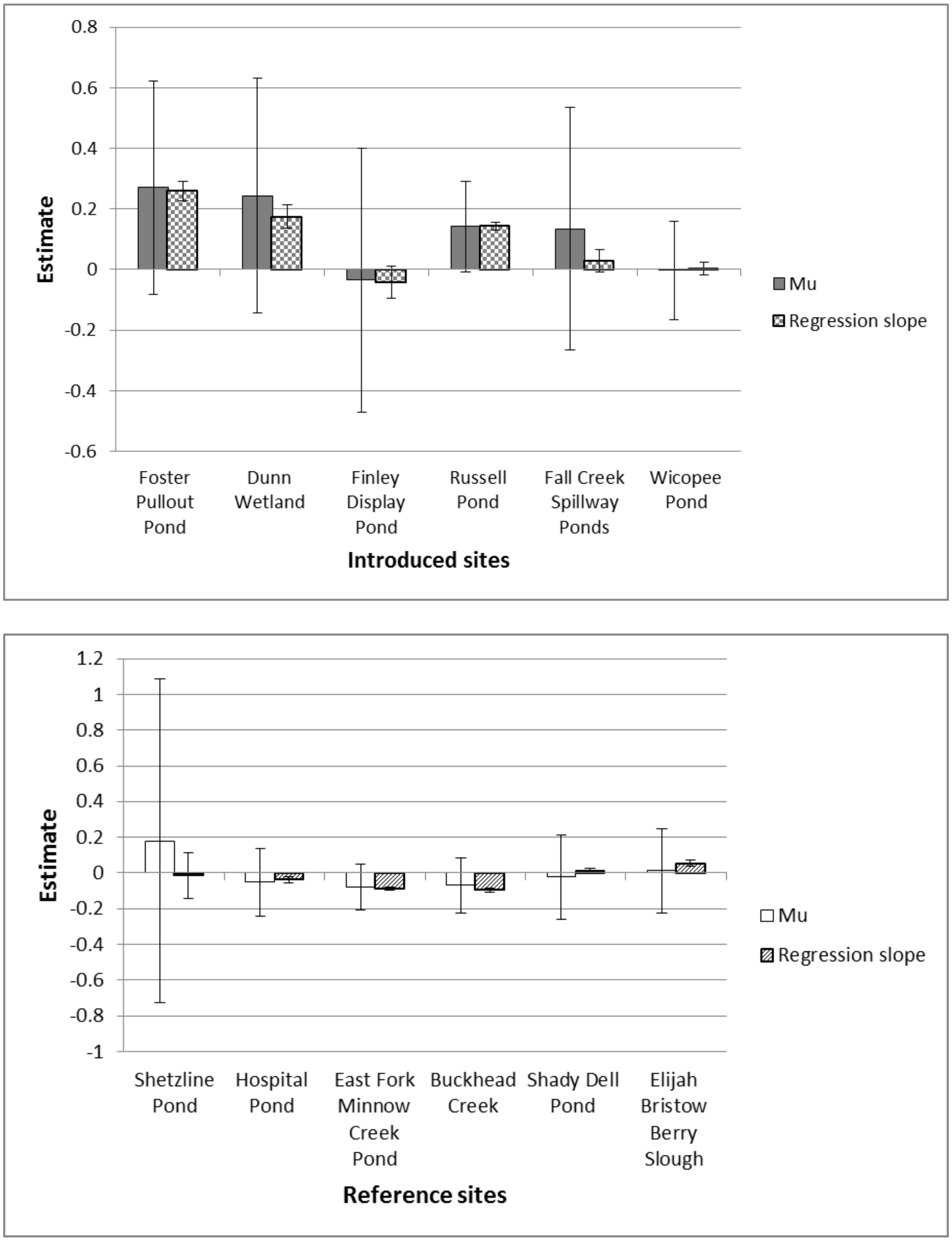


Figure 4. Instantaneous growth rate (μ) and regression slopes for introduced sites (top) and reference sites (bottom). Error bars represent standard deviation. Both μ and slope were obtained from the three-year running-sum.

Effect of nonnative species on population trends and viability

Despite the fact that nonnative fishes pose such a threat to Oregon chub, there is no evidence that their presence has influenced the growth rates of the populations in this study, based on a test of the slopes of the nonnative group versus the slopes of the reference group (two sample t-test, p=0.348 [Figure 5]). Extinction risk among sites containing nonnative fishes was also more variable than the risk for the introduced sites. Two of the nonnative sites had a 90% or greater risk of reaching QET within 100 years. However, three of them showed less than a 10% chance of reaching QET in the same time period. These values were lower than those obtained for the reference sites (refer to previous section and Table 3).

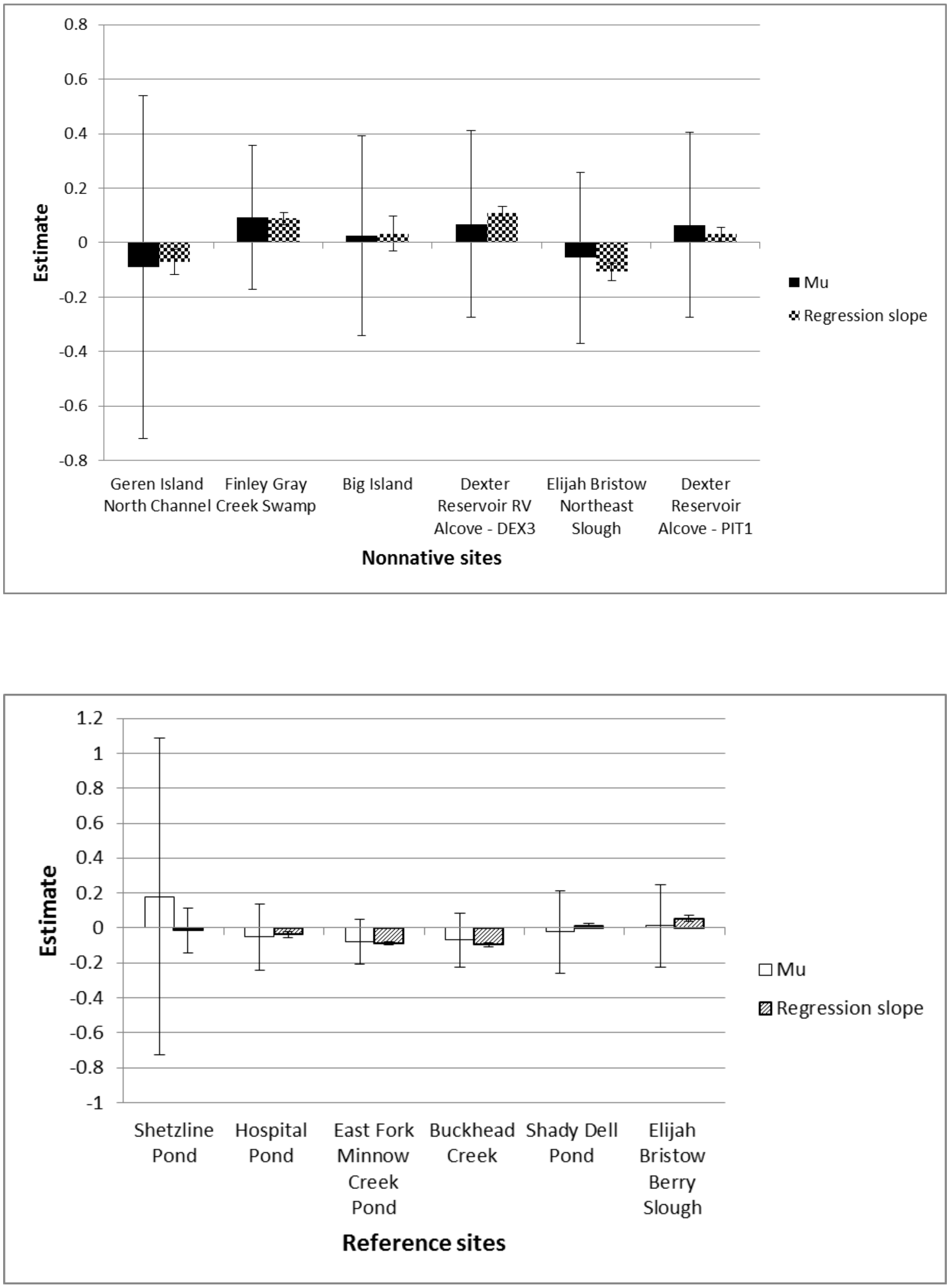


Figure 5. Instantaneous growth rate (μ) and regression slopes for sites with nonnative predators (top) and reference sites (bottom). Error bars represent standard deviation. Both μ and slope were obtained from the three-year running sum.

Table 3. Extinction risk after nine years (3 generations), fifteen years (five generations), thirty years (10 generations), and one hundred years for eighteen populations of Oregon chub in four Willamette Valley subbasins on a three-year-running sum basis. Introduction sites are *italicized*, and sites containing nonnative fishes are underlined. Sites that are neither italicized nor underlined are reference sites (naturally-occurring populations of Oregon chub with no nonnative fishes).

Population	Year 9 (3 gens.)	Year 15 (5 gens)	Year 30 (10 gens)	Year 100
Santiam				
Geren Island North Channel (1996-2011)	0.27	0.43	0.71	0.98
Foster Pullout Pond (1999-2011)	0	0	0	0
Mainstem Willamette and Tributaries				
Dunn Wetland (1997-2011)	0	0	0	0
Finley Gray Creek Swamp (1993-2011)	0	0	0	0
Finley Display Pond (1998-2011)	0.09	0.19	0.44	0.86
McKenzie				
Shetzline Pond (2002-2011)	0.15	0.16	0.20	0.24
Big Island (2002-2011)	0	0.06	0.20	0.28
Russell Pond (2001-2011)	0	0	0	0
Middle Fork Willamette				
Fall Creek Spillway Ponds (1996-2011)	0.01	0.02	0.02	0.02
Wicopee Pond (1999-2011)	0	0	0	0.09
Hospital Pond (1997-2011)	0	0.01	0.32	0.94
East Fork Minnow Creek Pond (1993-2011)	0	0.01	0.67	1
Buckhead Creek (1999-2011)	0	0.01	0.58	1
Shady Dell Pond (1993-2011)	0	0.02	0.15	0.63
Elijah Bristow Berry Slough (1997-2011)	0	0.01	0.04	0.21
Dexter Reservoir RV Alcove - DEX3 (1997-2011)	0	0.02	0.04	0.06
Elijah Bristow Northeast Slough (1999-2011)	0.03	0.16	0.46	0.95
Dexter Reservoir Alcove - PIT1 (1995-2011)	0	0.02	0.05	0.08

Population viability by subbasin

I pooled data by sub-basin for all of the eighteen populations chosen for analysis, restricting the analysis to years in which all populations had census data available. The QET plots show that three of the four sub-basins (the Santiam, the Mainstem Willamette and Tributaries, and the McKenzie) have no risk of dropping below the QET (90% reduction in current estimated population size, pooled by sub-basin) within the next century. However, the Middle Fork Willamette sub-basin has approximately a 75% risk of reaching the QET within 100 years (Figure 6).

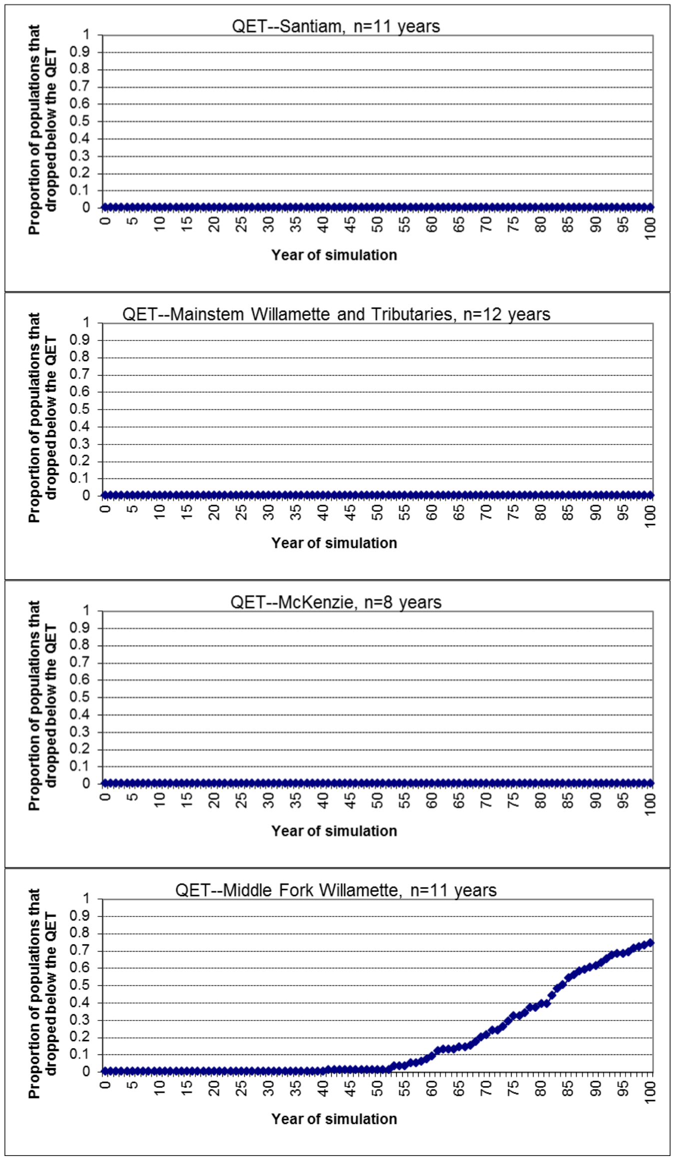


Figure 6. QET plots by subbasin using the eighteen populations chosen for population viability analysis. The Middle Fork Willamette subbasin is the only subbasin that faces the risk of dropping below the quasi-extinction threshold (90% reduction from the 2011 population estimate, based on a three year running sum) within 100 years. Data for sites within each subbasin (Table 1) were pooled and the number of years (n) of census data used in the analysis was restricted to years in which all populations had available data.

Discussion

Oregon chub live in an environment heavily impacted by human development and land use. Several factors—such as alteration of hydrologic regimes and the introduction of nonnative species—pose threats to the Oregon chub. Populations of Oregon chub have benefitted greatly from active management by ODFW, but there may still be management actions needed to maintain the tremendous gains that have been made for this species.

The effects of introductions and nonnative fishes on population growth and viability were variable. Introductions have a very clear benefit to chub recovery—those populations have higher growth rates and lower extinction risks when compared to reference populations. In the short term, there did not appear to be a difference in the slopes of nonnative and reference populations, but models of future extinction risk showed that populations where nonnative fish are present have a higher likelihood of dropping below QET when compared to the reference populations.

The results of this study suggest that introduced populations have a reduced risk of extinction in the future. Many reference sites are likely to fall below QET in several generations. Therefore, it appears that the ODFW's management practices have contributed significantly to the stability of the species. As for the nonnative sites, high variance (σ^2) around population trends accounts for some of the variability in extinction risk. The ODFW provided precision estimates for population sizes (APPENDIX A), but natural variation always exists.

The trends of the subbasin as a whole were also considered. Three of the four subbasins showed no risk of dropping below QET; the Middle Fork Willamette subbasin was the only subbasin that had a chance of dropping below QET. The sample sizes for this metapopulation analysis were small and skewed; three of the subbasins contained three or fewer populations. The most influential source of bias in this study is the small sample size. Only six populations were chosen for each category, so it is possible that the projections were skewed by unusual trends occurring at only one site. Introduced sites also lacked other fish species besides Oregon chub. Therefore, population growth rates at these locations were not influenced by the presence of other species. This could influence the positive growth trends reported in most introduced sites.

In addition to the small sample sizes, a couple of caveats must be considered and taken into account when interpreting the results of this study. The first of these caveats is the way in which the nonnative sites were designated. A site was described as containing nonnative species regardless of the abundance of nonnative species—for instance, a site where one bluegill was found and a site where there were 1,000 bass would both be considered nonnative sites. Future studies might consider running separate analyses for sites based on the relative abundance of nonnative species. This approach would more accurately describe the effect of nonnative fishes. Secondly, it must be assumed that the introduced sites in this study have become stable and self-sustaining in order for those sites to contribute to the downlisting and delisting criteria of the Oregon chub. This is a reasonable assumption to make because the introduced sites were only supplemented until the starting population reached 500 individuals—after this goal was reached, ODFW ceased adding fish to the population. By the time this study was conducted, most of the introduced sites had been established long enough to show reliable population trends.

Another consideration that can be made in future studies is to set the QET at a numerical threshold instead of a percentage drop in population size. Either method can be justified. In this study, the QET was set at a 90% reduction in population size because these criteria are consistent with extinction risk calculation methods used by the IUCN. However, after a 90% reduction in size, a population with a starting estimate of 8,000 individuals is still ten times larger than a population that began with 800 individuals and underwent the same reduction, and yet according to this method both populations are functionally extinct. For this reason it might make sense to set QET at a common level for both populations—for instance, set QET equal to 500 individuals. This method allows for better comparison between populations, but it is not relative to each individual population.

Conclusion

A population viability analysis was applied to survey data from the Oregon Department of Fish and Wildlife and used to determine the growth rates of eighteen populations of Oregon chub in the Willamette Valley. Six of these sites were introduction sites, six were naturally occurring sites which contained nonnative fish species, and the remaining six were naturally occurring reference sites that did not contain nonnatives. The growth rates of the populations in these three groups were compared, and there appears to be no significant difference between rates in the short term. However, models of future extinction risk suggest that there may be a very strong negative effect of nonnative species and a positive effect of introducing chub on a longer timescale.

Management actions by ODFW have been successful in saving the Oregon chub from extirpation. In 2014, the Oregon chub became the first fish on the Endangered Species List to be proposed for delisting due to recovery. Future management will ensure that the gains made for this species are maintained.

Literature Cited

Beauchamp, J.J., and J.S. Olson. 1973. Corrections for bias in regression estimates after logarithmic transformation. Ecology 54:1403-1407.

Biella, D. 2011. Human population reaches seven billion—how did this happen and can it go on? Scientific America. 28 October 2011.

Bond, C.E. 1966. Endangered plants and animals of Oregon: Fishes. Volume 1. Agricultural Experiment Station, Oregon State University, Corvallis, Oregon.

Dennis, B., P.L. Munholland, and J.M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115-143.

Gascoigne, J., L. Berec, S.Gregory, and F. Courchamp. 2009. Dangerously few liaisons: A review of mate-finding Allee effects. Population Ecology 51:355-372.

Gotelli, N.J. 2008. A primer of ecology. Fourth edition. Sinauer Associates, Sunderland, Massachusetts.

Holmes, E.E. 2001. Estimating risks in declining populations with poor data. Proceedings of the National Academy of Sciences 98: 5072-5077.

Holmes, E.E. 2004. Beyond theory to application and evaluation: Diffusion approximation for population viability analysis. Ecological Applications 14.4: 1272-1293.

International Union for Conservation of Nature [IUCN]. 2000. IUCN Red List Categories and Criteria. Version 3.1, second edition. IUCN Species Survival Commission, Gland, Switzerland.

Knight, R.R., and L.L. Eberhardt. 1985. Population dynamics of Yellowstone grizzly bears. Ecology 66:323-334.

Lande, R., and S.H. Orzack. 1988. Extinction dynamics of age-structured populations in a fluctuating environment. Proceedings of the National Academy of Sciences of the United State of America 85:7418-421.

McClure, M.M, E.E. Holmes, B.L Sanderson, and C.E. Jordan. 2003. A large-scale, multispecies status assessment: Anadromous salmonids in the Columbia River Basin. Ecological Applications 13:964-989.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42, 156p.

Mills, L.S. 2007. Conservation of wildlife populations: Demography, genetics, and management. Blackwell, Oxford.

Scheerer, P.D. 2002. Implications of floodplain isolation and connectivity on the conservation of an endangered minnow, Oregon chub, in the Willamette River, Oregon. Transactions of the American Fisheries Society 131:1070-1080.

Scheerer, P.D., and P.J. McDonald. 2003. Age, growth, and timing of spawning of an endangered minnow, the Oregon chub (*Oregonichthys crameri*), in the Willamette Basin, Oregon. Northwestern Naturalist 84:68-79.

United State Fish and Wildlife Service [USFWS]. 1998. Recovery plan for the Oregon chub (*Oregonichthys crameri*).
---- 2010. Endangered and threatened wildlife and plants; reclassification of the Oregon chub from endangered to threatened. Federal Register.

University of Idaho. 2012. WLF 448: Fish and Wildlife Population Ecology 2011: Lab 5, exponential population growth. <http://www.cnr.uidaho.edu>. Accessed 2 Nov 2012.

Vie, J., C. Hilton-Taylor, and S.N. Stuart, editors. 2009. Wildlife in a changing world: An analysis of the 2008 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland

Appendix A: ODFW Precision Estimates

Santiam

Geren Island North Channel (Nonnative)			
Year	Pop. Estimate	Lower CI	Upper CI
1996	8340	5480	16100
1997	8700	7420	10440
1998	1830	1170	4350
1999	860	580	1580
2000	360	210	1230
2001	760	480	1440
2002	740	530	1270
2003	1590	1260	2140
2004	2290	1740	3360
2005	2630	2160	3200
2006	1021	695	1491
2007	512	360	725
2008	207	117	354
2009	560	378	824
2010	2230	1960	2540
2011	3030	2710	3380

Foster Pullout Pond (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
2000	80	40	320
2001	210	130	700
2002	320	200	780
2003	640	370	930
2004	570	370	840
2005	200	130	320
2006	465	378	570
2007	981	862	1116
2008	2636	2393	2903
2009	2643	2421	2886
2010	2010	1680	2400
2011	2360	2150	2580

Mainstem Willamette and Tributaries

Dunn Wetland (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
1998	460	290	1000
1999	4860	3070	11690
2000	14090	11500	18210
2001	26280	22560	31480
2002	19270	16050	24120
2003	28740	23570	36800
2004	25810	19910	33420
2005	28290	22960	34840
2006	21531	17832	25988
2007	34530	28920	41225
2008	46332	39814	53909
2009	34300	28350	41930
2010	28510	22280	36490
2011	47350	40220	55830

Finley Gray Creek Swamp (Nonnative)			
Year	Pop. Estimate	Lower CI	Upper CI
1993	370	310	480
1994	600	460	860
1995	460	340	710
1996	470	340	740
1997	520	420	680
1998	620	460	930
1999	510	270	1320
2000	730	540	1150
2001	630	470	930
2002	290	180	770
2003	230	120	930
2004	520	380	840
2005	240	160	350
2006	1389	1059	1820
2007	1399	1118	1751
2008	2141	1673	2738
2009	1700	1403	2049
2010	2350	1890	2920
2011	2150	1840	2510

Finley Display Pond (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
1999	360	240	790
2000	1750	1060	5050
2001	670	510	960
2002	500	410	660
2003	130	100	210
2004	70	50	130
2005	240	160	340
2006	242	186	316
2007	227	186	278
2008	832	700	988
2009	323	269	386
2010	500	430	580
2011	420	360	500

McKenzie

Shetzline Pond (Reference)			
Year	Pop. Estimate	Lower CI	Upper CI
2002	120	80	240
2003	650	510	930
2004	1050	780	1590
2005	730	490	1100
2006	319	249	606
2007	207	139	307
2008	130	70	232
2009	297	216	407
2010	350	240	490
2011	5750	5150	6440

Big Island (Nonnative)			
Year	Pop. Estimate	Lower CI	Upper CI
2002	940	790	1180
2003	620	490	860
2004	310	220	550
2005	430	280	660
2006	380	230	610
2007	190	140	270
2008	200	130	300
2009	608	422	870
2010	1240	930	1650
2011	400	310	500

Russell Pond (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
2002	470	330	490
2003	450	360	600
2004	720	560	1010
2005	810	700	950
2006	997	794	1251
2007	1397	1003	1940
2008	651	483	876
2009	1288	1037	1598
2010	2780	2060	3740
2011	340	270	420

<u>Middle Fork Willamette</u>

Fall Creek Spillway Ponds (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
1997	480	400	590
1998	1420	960	2660
1999	6310	5460	7450
2000	5030	4060	6620
2001	7770	6480	9690
2002	6370	5320	7930
2003	5620	4380	7840
2004	5850	4770	7170
2005	6250	5190	7520
2006	3246	2814	3744
2007	2742	2433	3091
2008	3052	2784	3346
2009	2925	2667	3241
2010	4110	3420	4930
2011	6690	5790	7730

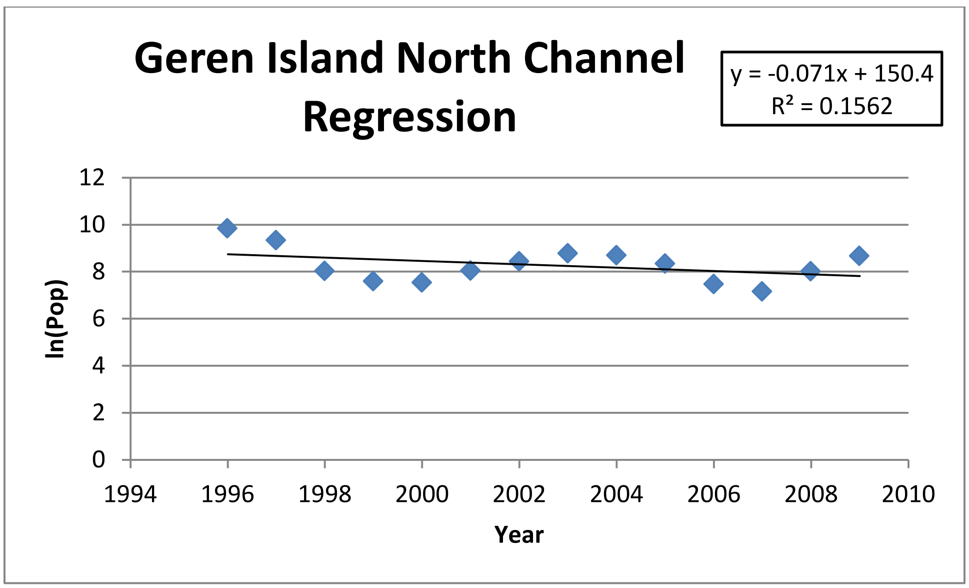
Wicopee Pond (Introduced)			
Year	Pop. Estimate	Lower CI	Upper CI
1999	160	110	310
2000	4580	3600	6290
2001	4080	3370	5150
2002	2410	1540	5550
2003	4100	3630	4720
2004	4780	3890	5870
2005	6300	5440	7290
2006	4856	3941	5980
2007	3130	2585	3788
2008	5431	4275	6894
2009	3042	2039	4508
2010	2200	1745	2780
2011	3390	2750	4190

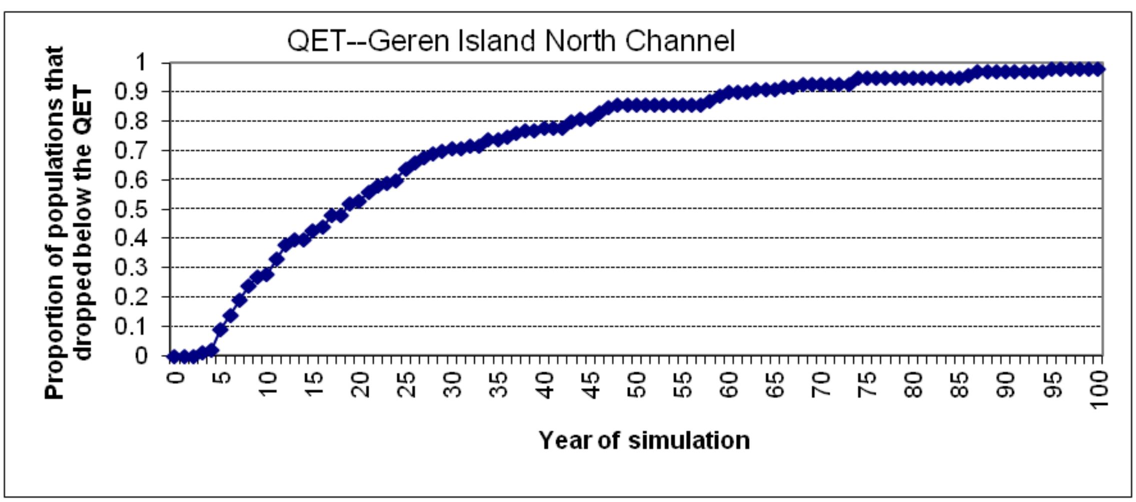
Hospital Pond (Reference)			
Year	Pop. Estimate	Lower CI	Upper CI
1997	3160	2480	4370
1998	3030	2050	5780
1999	3020	2330	4290
2000	2980	2050	5410
2001	2700	1830	5140
2002	2130	1680	2910
2003	1600	1060	3240
2004	4940	4230	5950
2005	5040	4050	6270
2006	2042	1436	2891
2007	1524	1114	2080
2008	3682	2970	4563
2009	730	526	1009
2010	1330	1080	1650
2011	2860	2490	3270

Appendix B: Regression and QET graphs by population

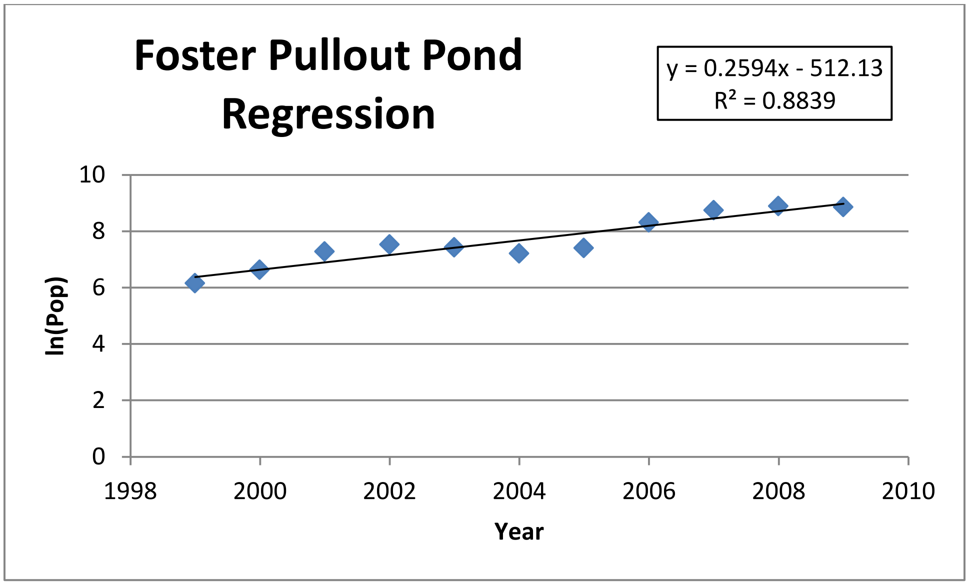
Santiam—Following are the regression plots and QET plots for populations in the **Santiam** subbasin. Regression plots show the overall trend of the population, and QET plots show the probability of the population experiencing a 90% reduction within the next 100 years. Population sizes were based on a three-year running-sum.

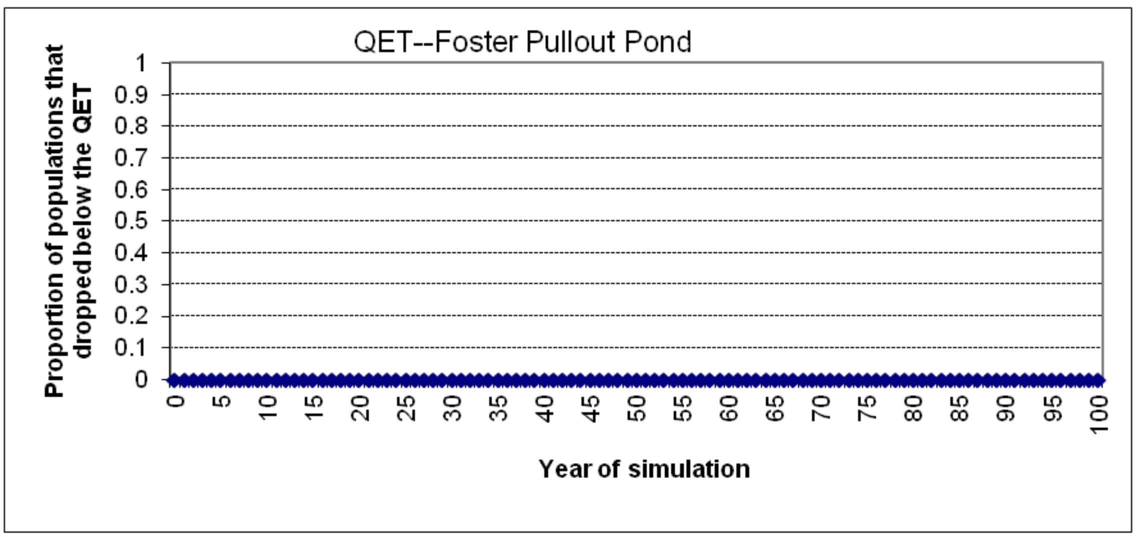
1. Geren Island North Channel (Nonnative)





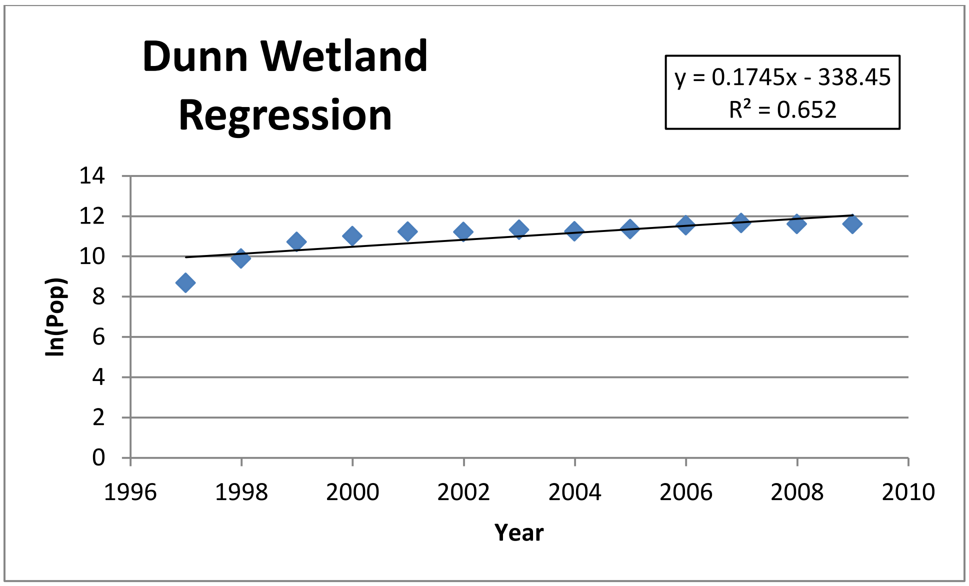
2. Foster Pullout Pond (Introduced)

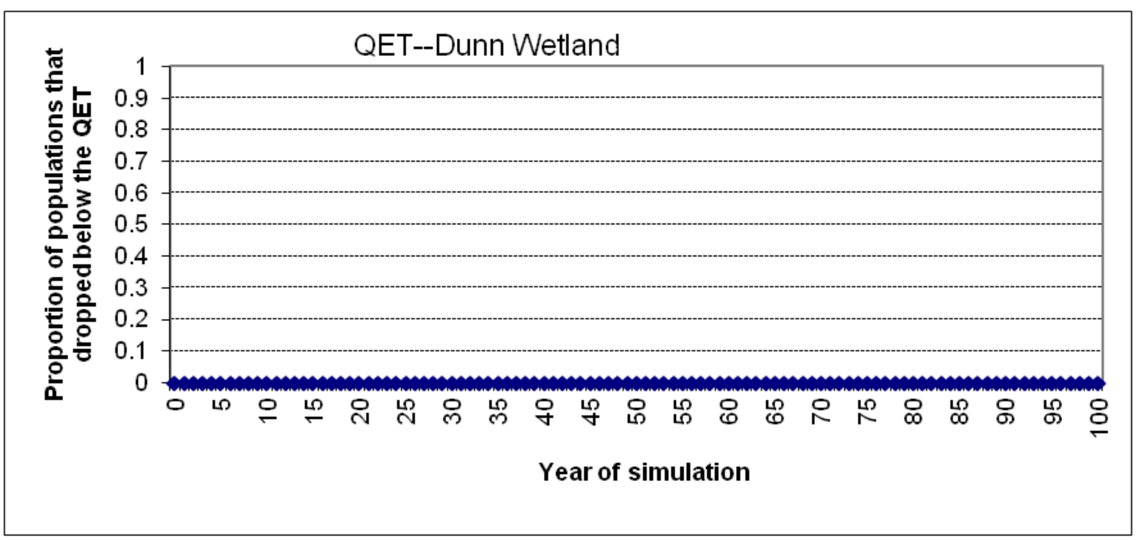




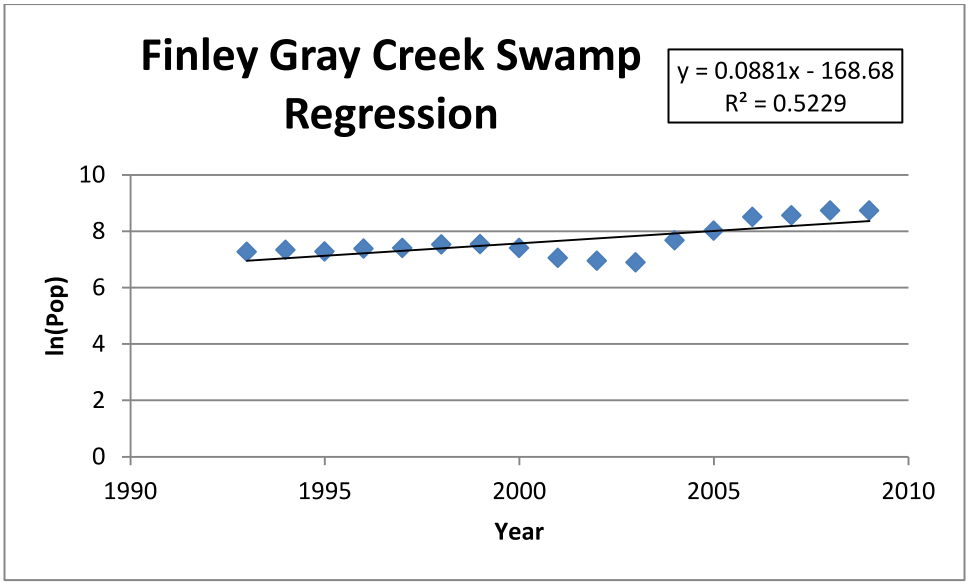
Mainstem Willamette and Tributaries—Following are the regression plots and QET plots for populations in the **Mainstem Willamette and Tributaries** subbasin. Regression plots show the overall trend of the population, and QET plots show the probability of the population experiencing a 90% reduction within the next 100 years. Population sizes were based on a three-year running-sum.

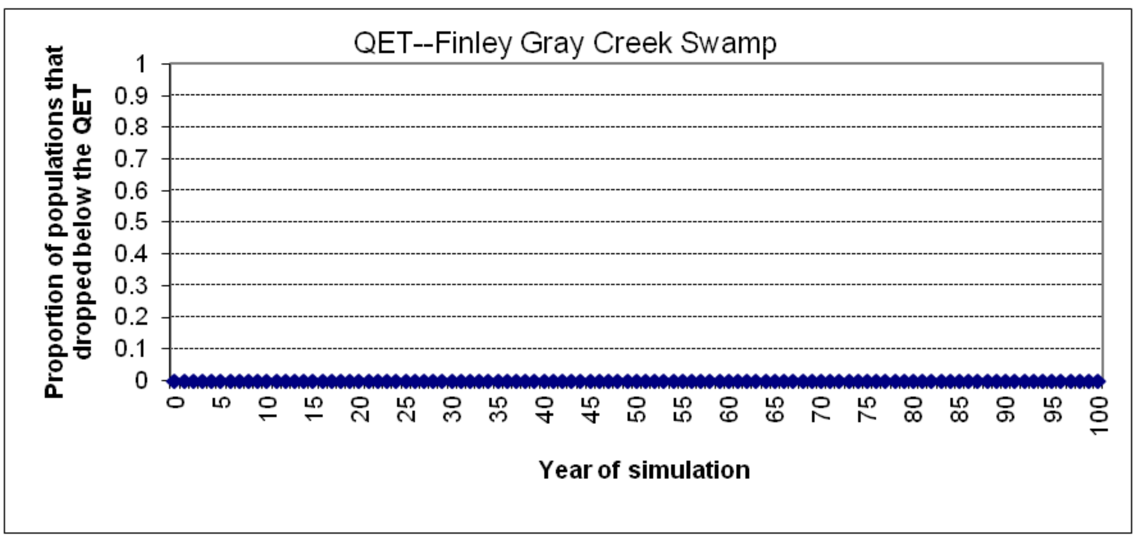
1. Dunn Wetland (Introduced)



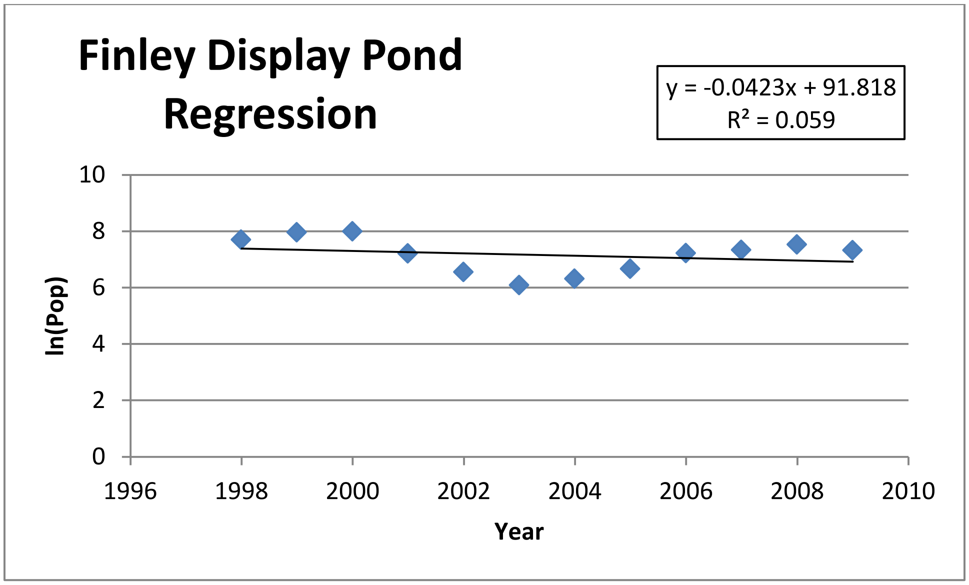


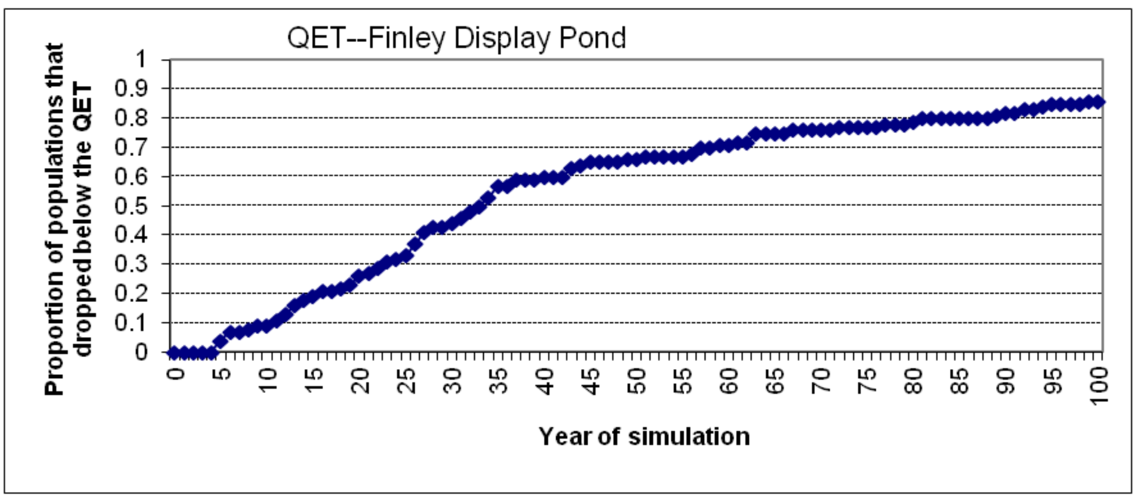
2. Finley Gray Creek Swamp (Nonnative)





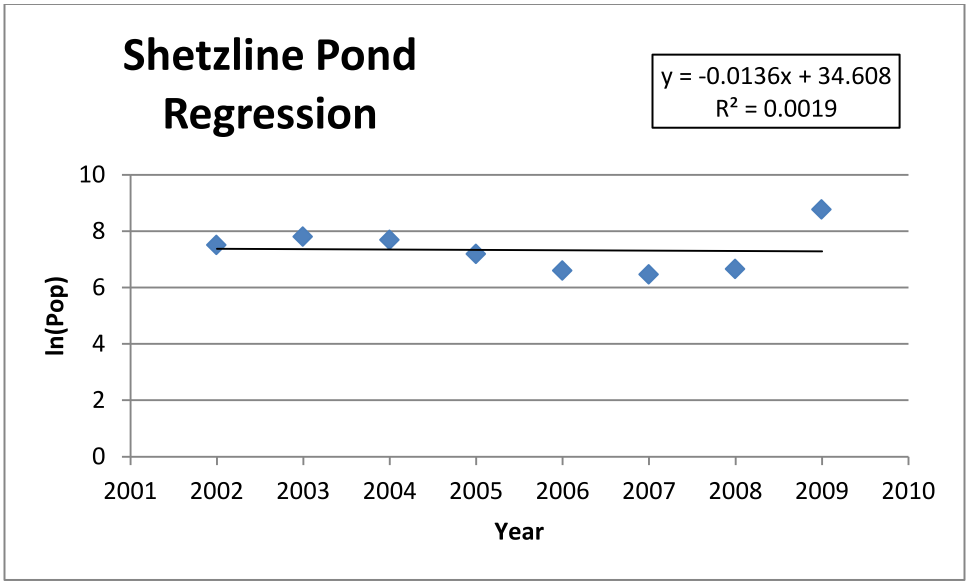
3. Finley Display Pond (Introduced)

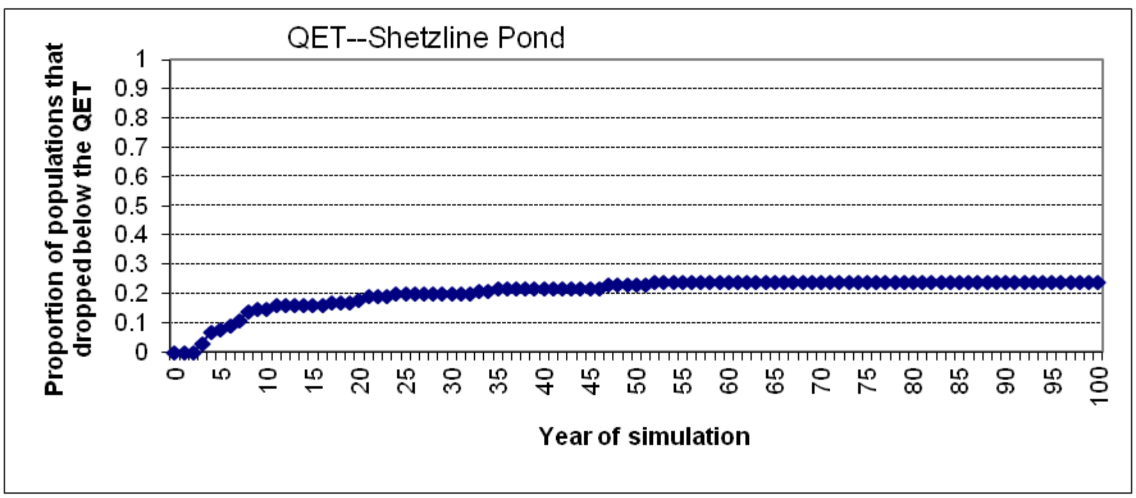




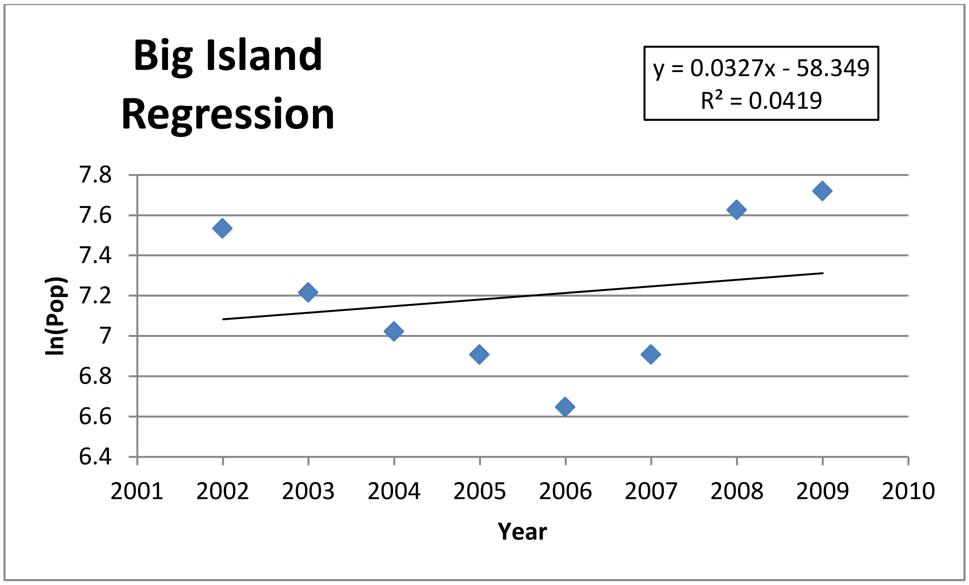
McKenzie—Following are the regression plots and QET plots for populations in the **McKenzie** subbasin. Regression plots show the overall trend of the population, and QET plots show the probability of the population experiencing a 90% reduction within the next 100 years. Population sizes were based on a three-year running-sum.

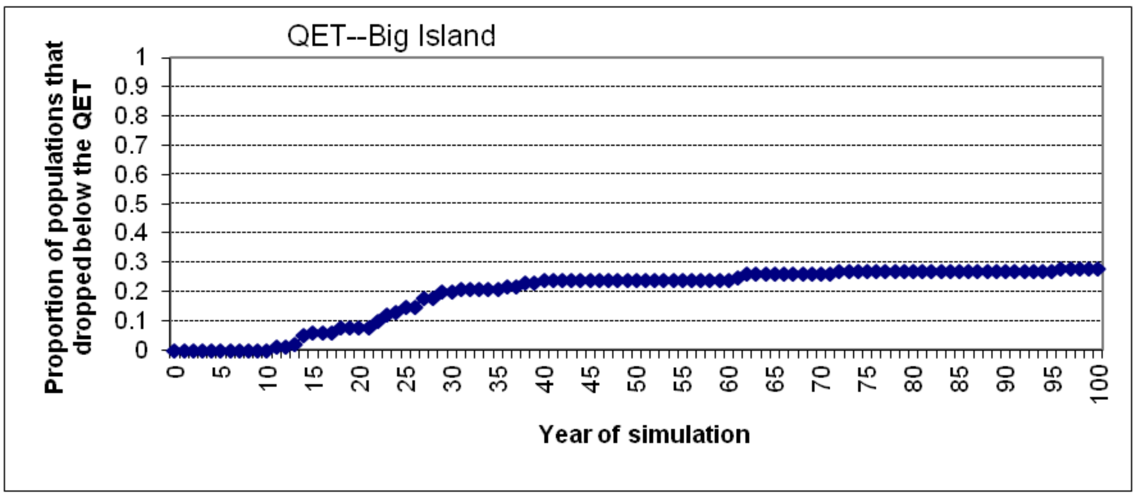
1. Shetzline Pond (Reference)



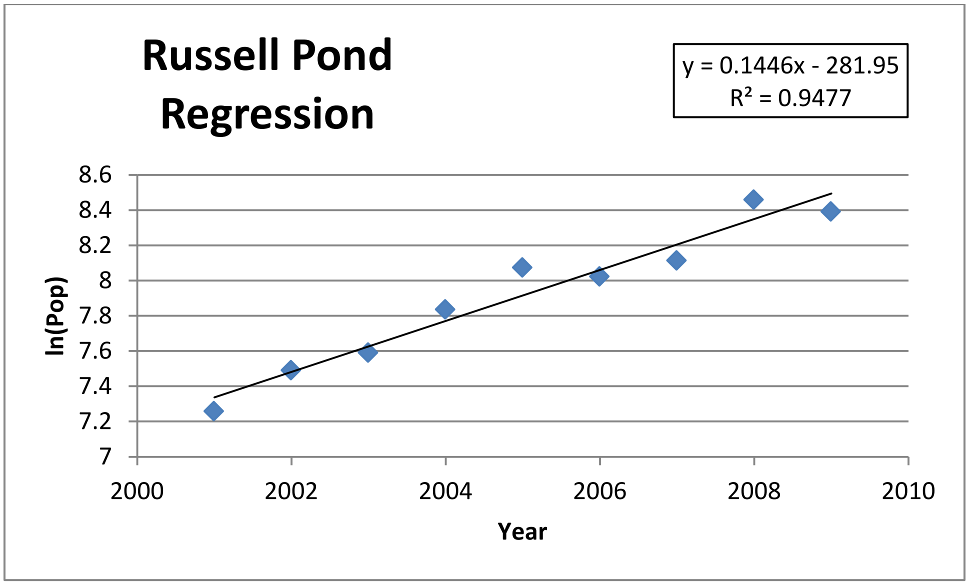


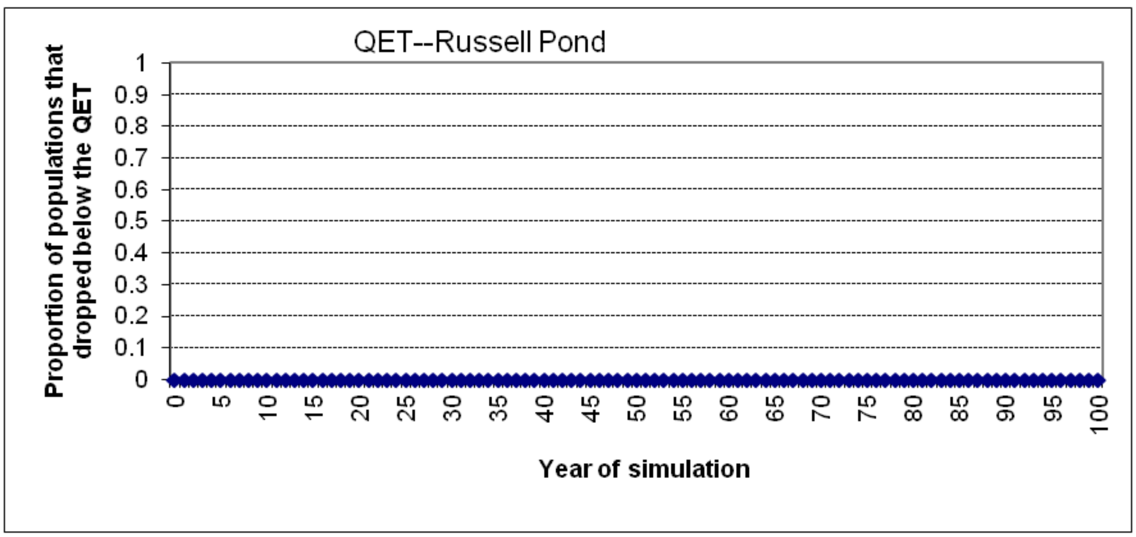
2. Big Island (Nonnative)





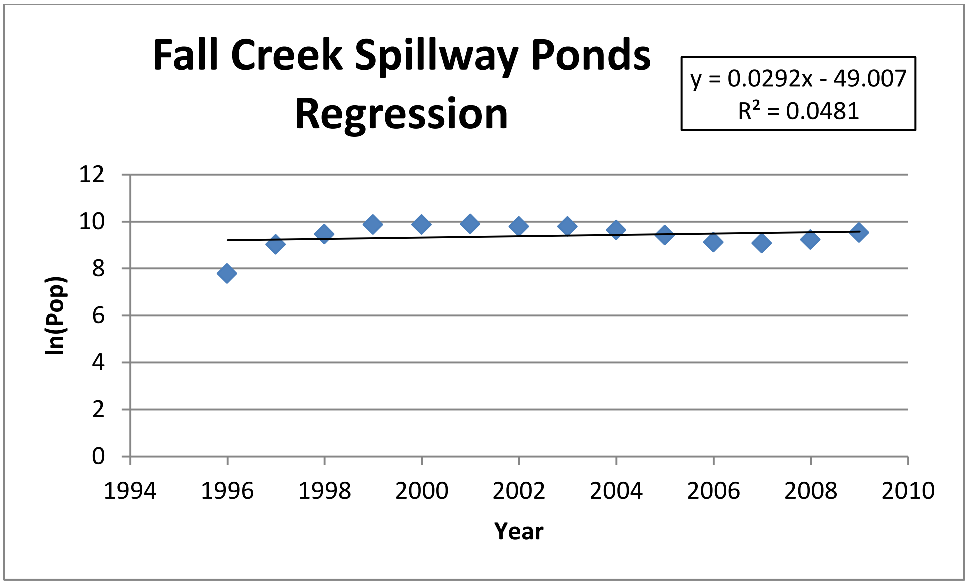
3. Russell Pond (Introduced)

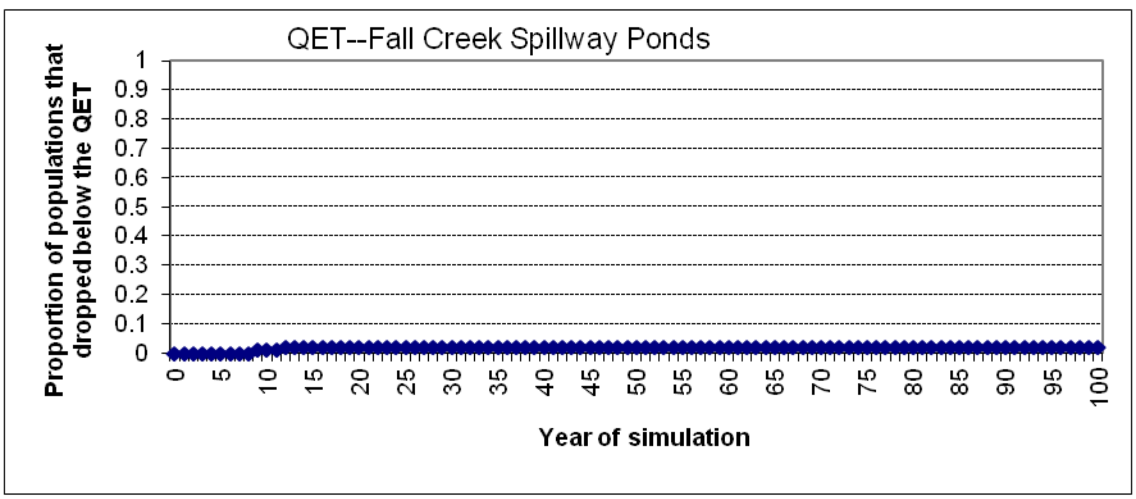




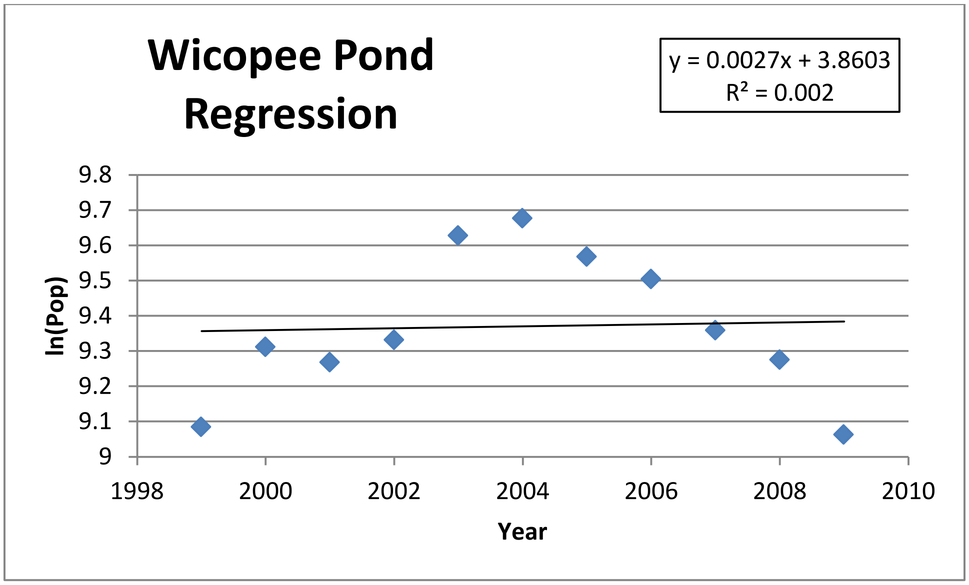
Middle Fork Willamette—Following are the regression plots and QET plots for populations in the **Middle Fork Willamette** subbasin. Regression plots show the overall trend of the population, and QET plots show the probability of the population experiencing a 90% reduction within the next 100 years. Population sizes were based on a three-year running-sum.

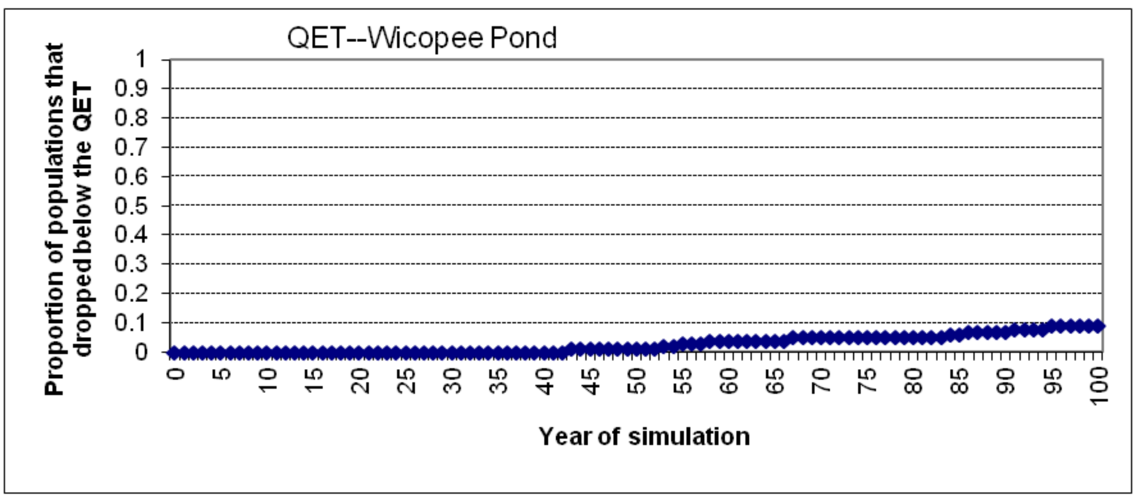
1. Fall Creek Spillway Ponds (Introduced)



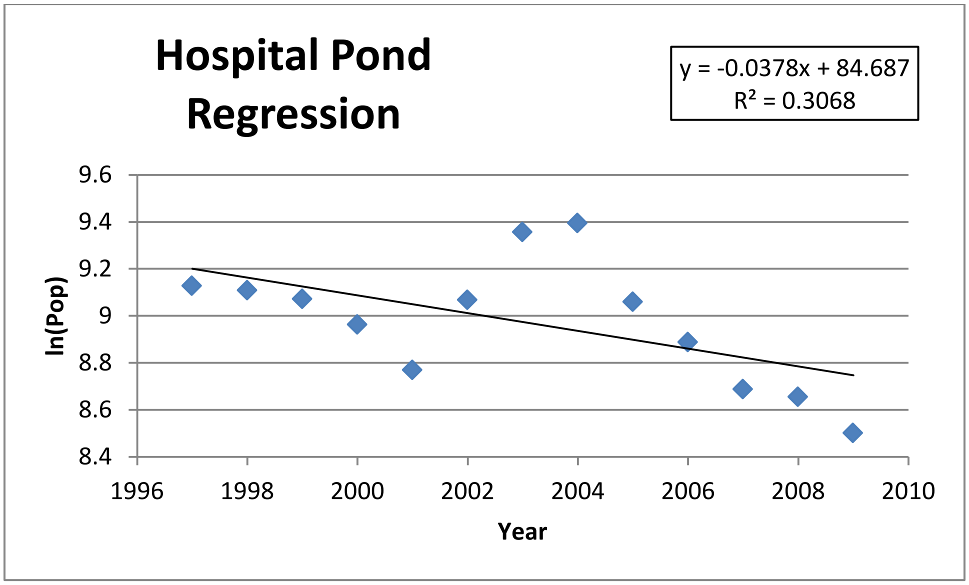


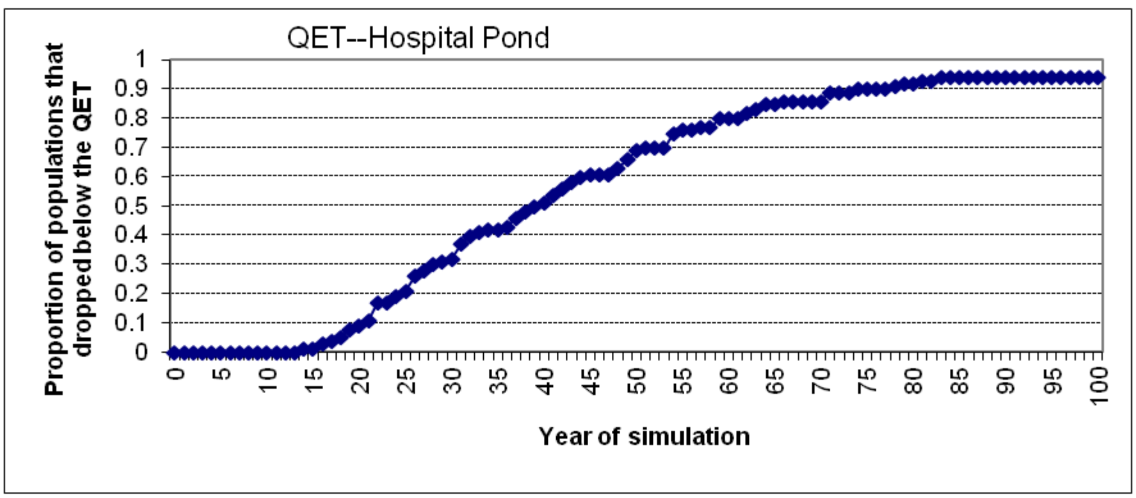
2. Wicopee Pond (Introduced)



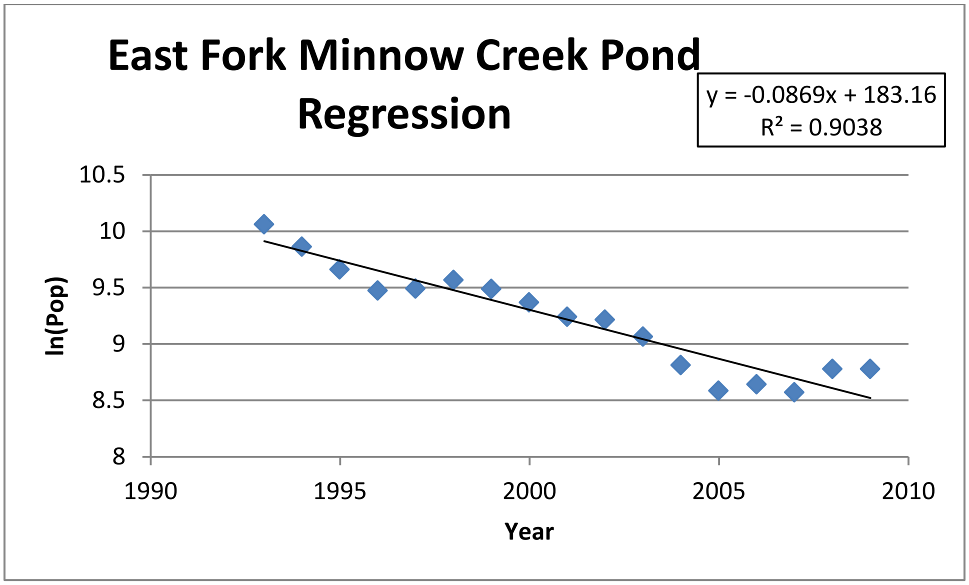


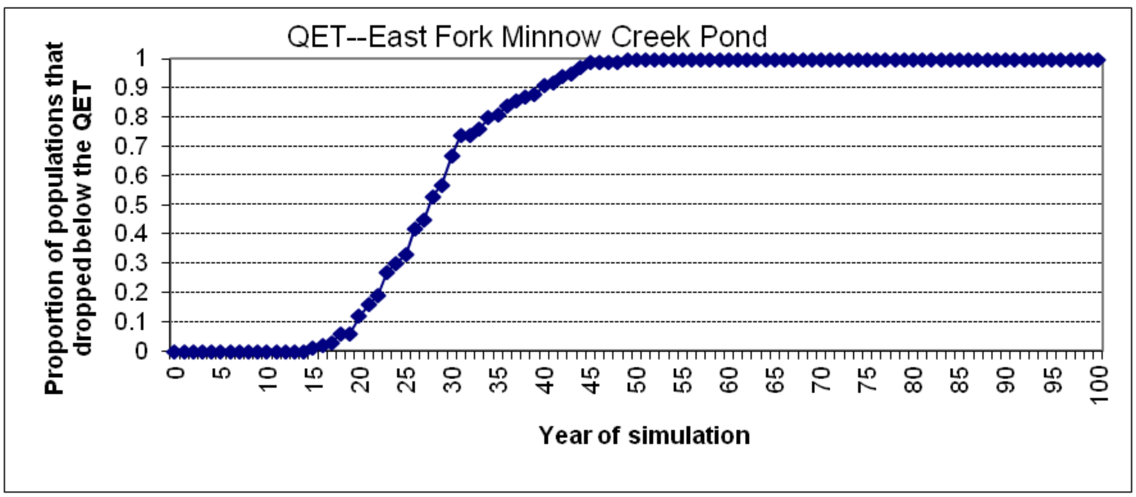
3. Hospital Pond (Reference)



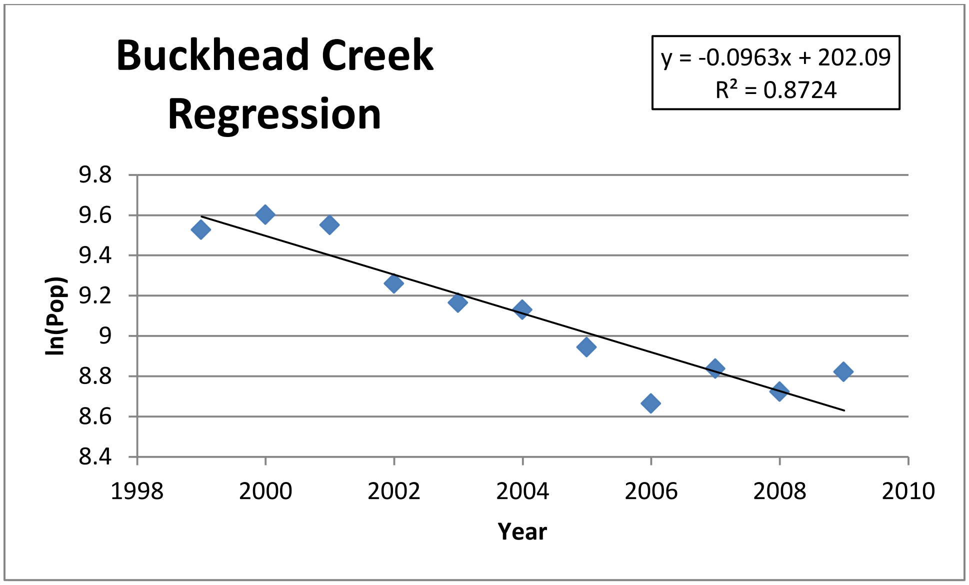


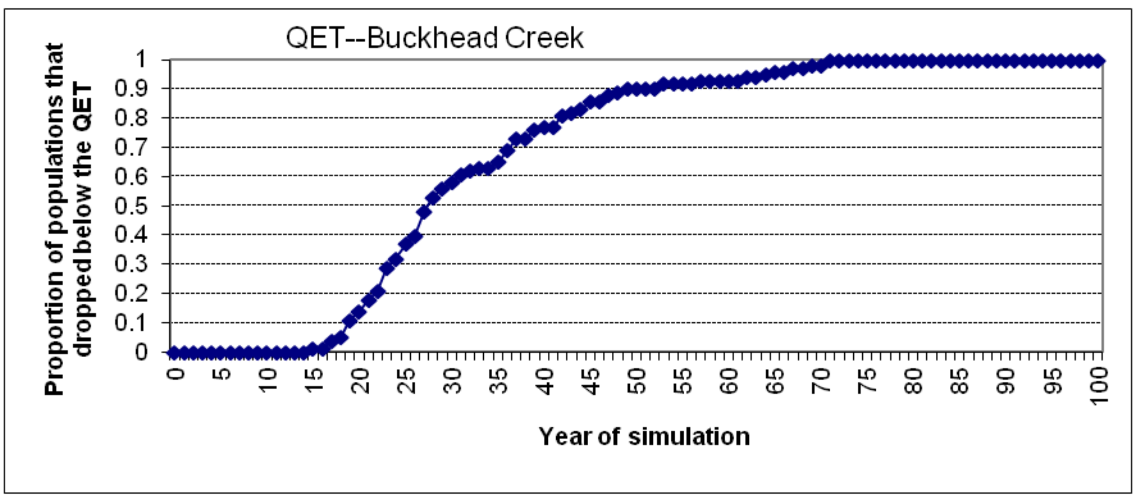
4. East Fork Minnow Creek Pond (Reference)



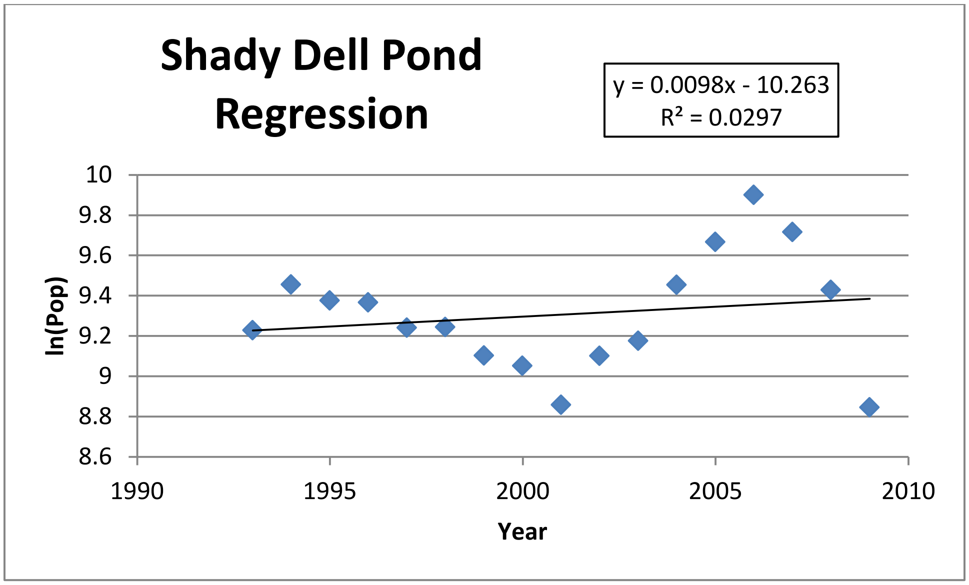


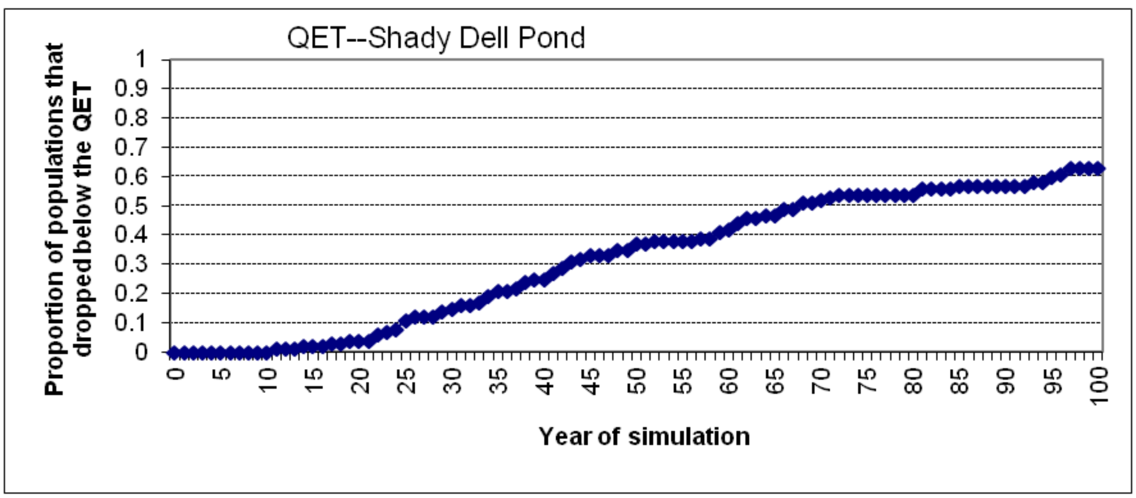
5. Buckhead Creek (Reference)



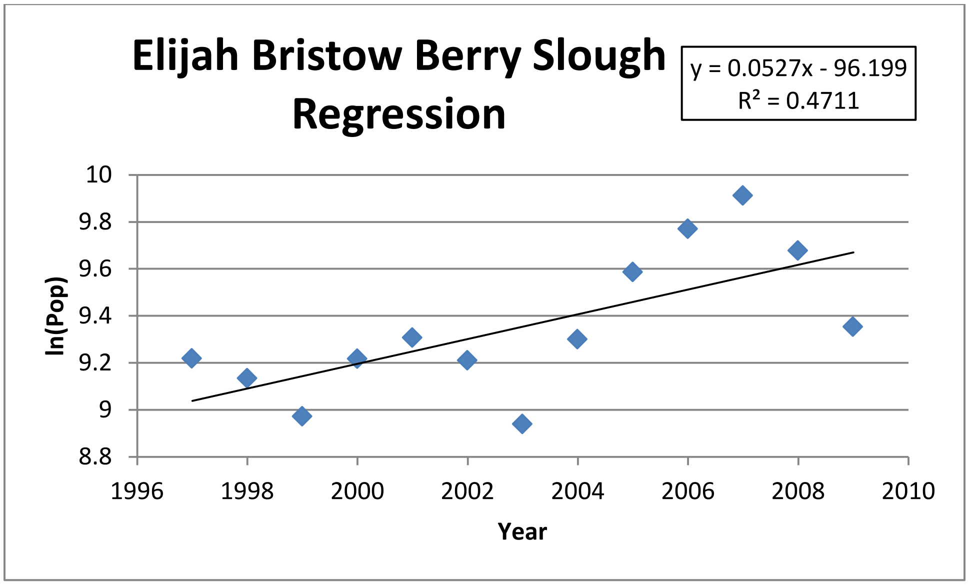


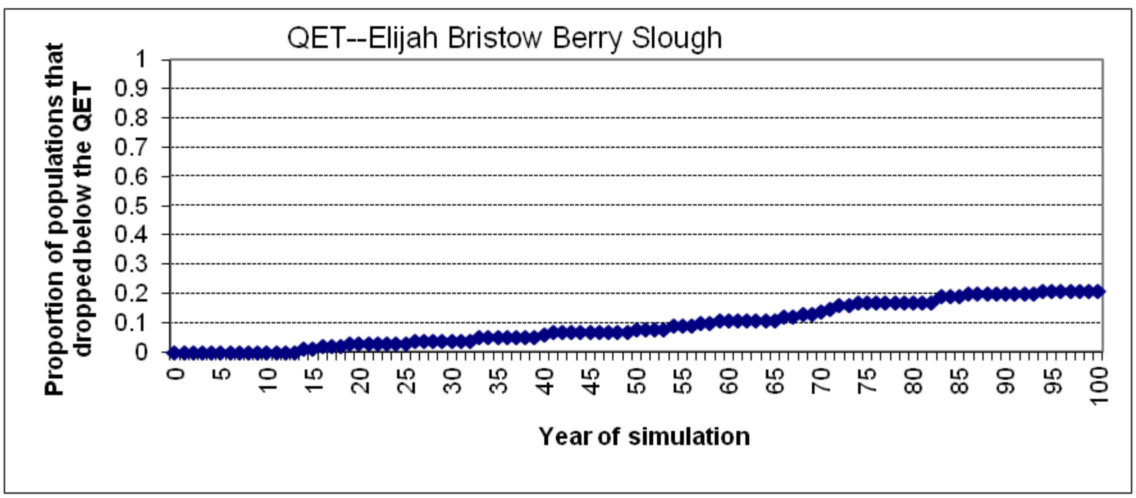
6. Shady Dell Pond (Reference)



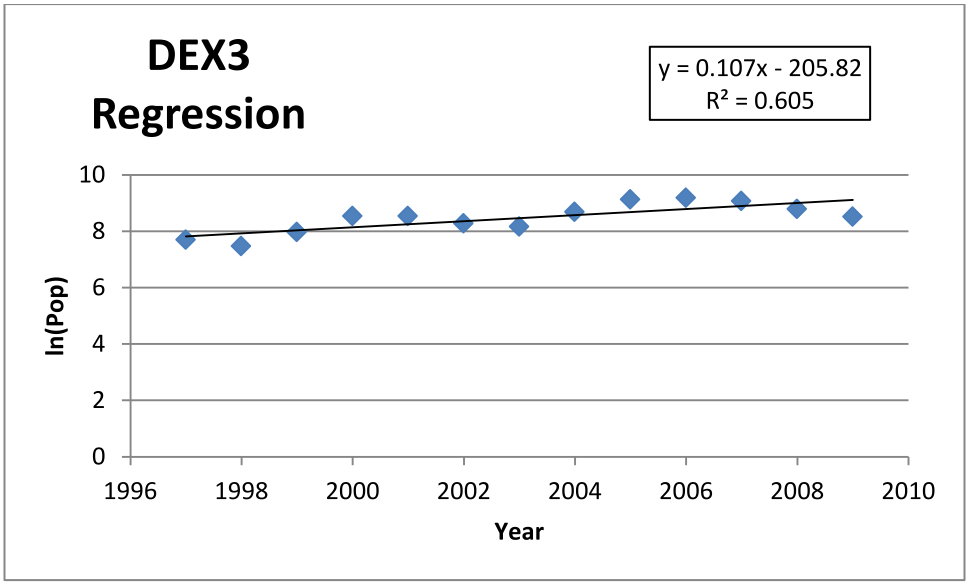


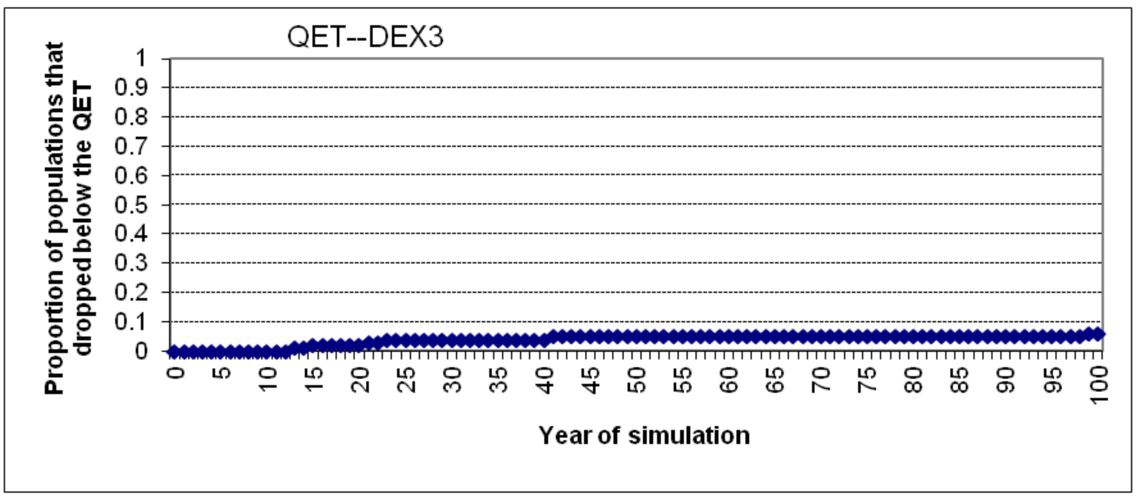
7. Elijah Bristow Berry Slough (Reference)



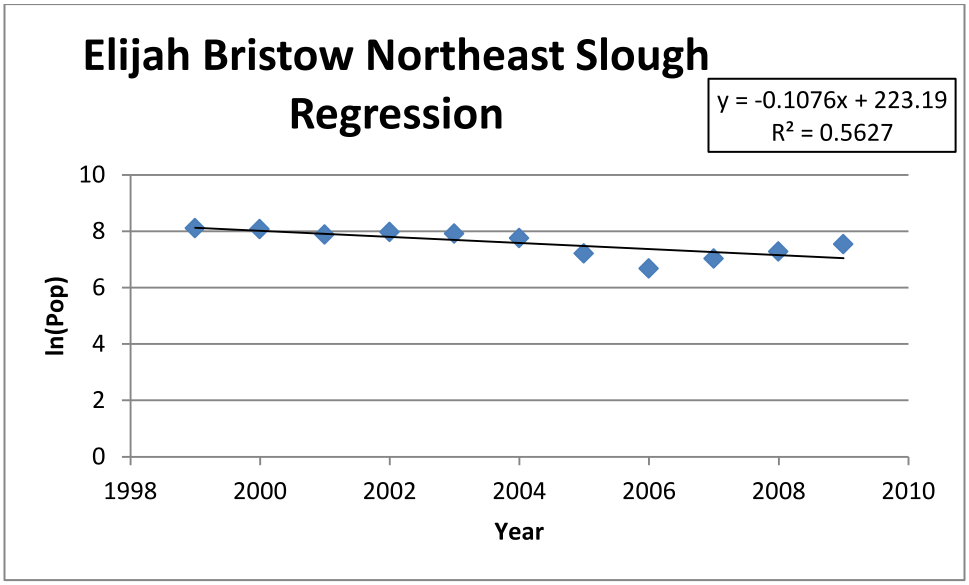


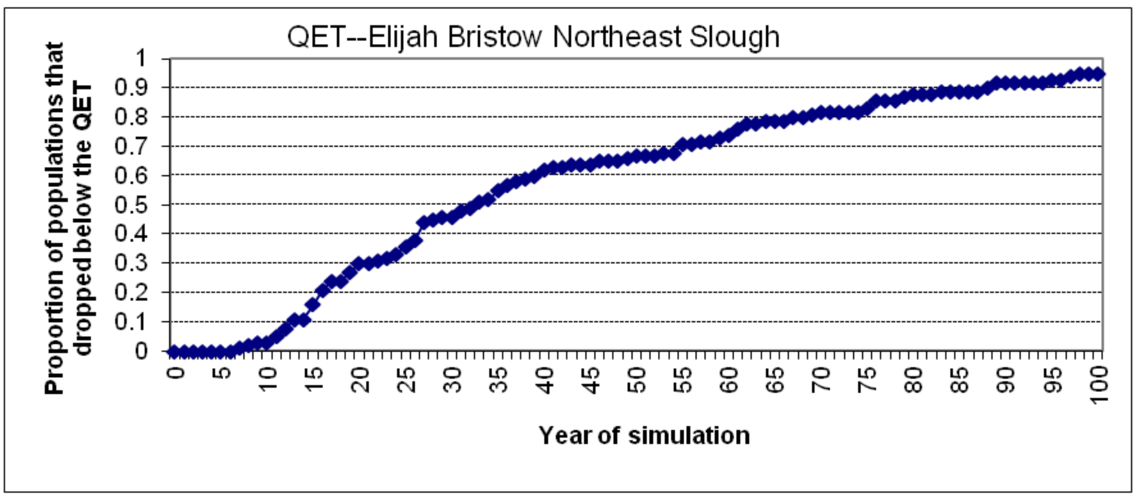
8. Dexter RV Alcove (DEX3) (Nonnative)



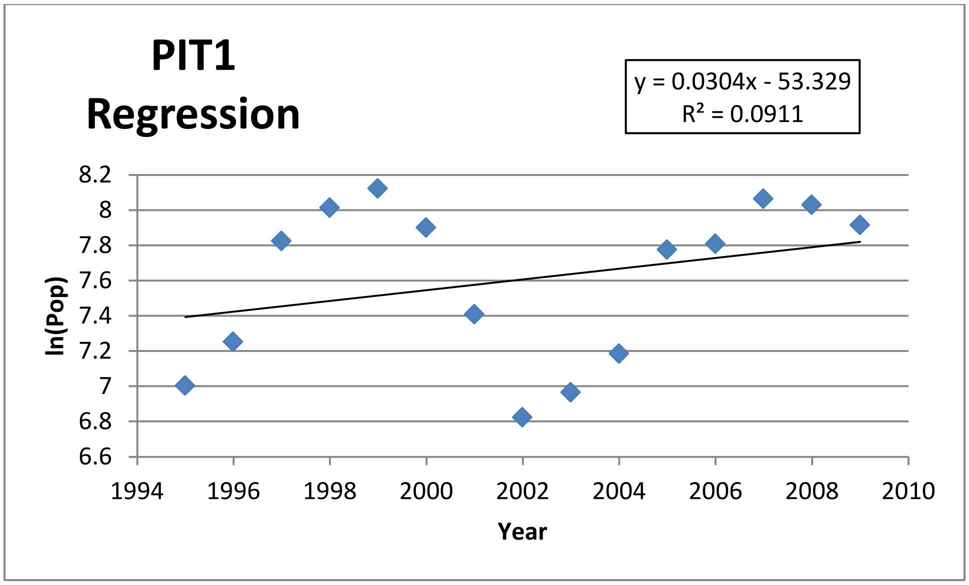


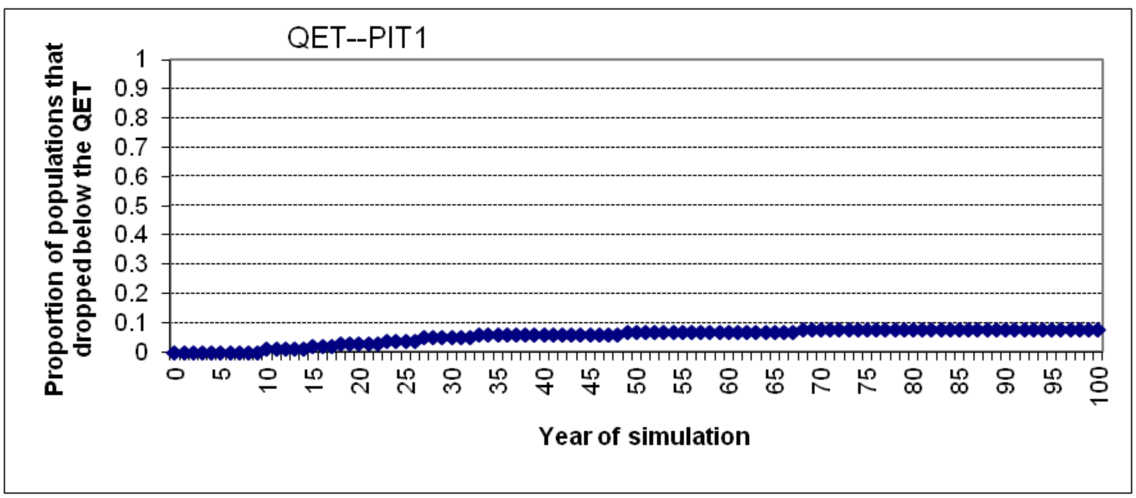
9. Elijah Bristow Northeast Slough (Nonnative)





10. Dexter Reservoir Alcove (PIT1) (Nonnative)





.