THE BANFF SPRINGS SNAIL

UPDATED POPULATION VIABILITY ANALYSIS BASED ON UP TO 12 YEARS OF POPULATION ABUNDANCE DATA IN THE THERMAL SPRINGS OF BANFF NATIONAL PARK AB, CANADA

Photo/ image: Mark & Leslie Degner

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Summary

This report presents the results of an updated population viability analysis (PVA) for Banff Springs Snail (*Physella johnsoni*) populations in the thermal springs of Banff National Park. A previous population viability and recovery scenario analysis was conducted in 2003 based on population counts of up to 7 years since 1996. Since then population abundance data over 5 more years have been collected for the existing 5 populations and populations were re-established at the Kidney and Upper Middle springs. These efforts result in 12 years of continuous abundance data for 5 populations and 4 or 5 years of continuous abundance data for the 2 newly re-established populations. Without further quantitative analysis, the collected data indicate a zero percent extinction risk over 12 years and an overall population growth across all 5 and/or 7 populations. The annual average abundance over all 5 existing populations grew from 3116 in 1996 to 9237 in 2007. Adding abundances of the 2 newly re-established populations raises the annual average for 2007 to 16351. Hence, about 54% of the observed growth in overall, annual average population abundance is attributed to the successful re-establishment of 2 populations into the Kidney and Upper Middle springs. These data present an encouraging account that a combination of habitat protection and carefully planned re-establishment scenarios helped to significantly increase population abundances with likely positive effects on population viability of the Banff Springs Snail over the last decade.

Nevertheless, a number of single populations of the Banff Springs Snail were extirpated in the past and most populations experience abundance fluctuations across 2 orders of magnitude within a single year. Also, the thermal springs on Sulphur Mountain must be considered as isolated from each other with respect to their function as habitat for the Banff Springs Snail. Active or passive dispersal of snails among the thermal springs is very unlikely excluding any potential re-colonization of extirpated populations. In addition, the frequency of drying of the thermal springs has recently accelerated under climate change. Therefore, the viability over a time period of 100 years is not necessarily guaranteed or cannot be assumed based on the past 12 years of observed encouraging population growth.

This updated PVA tries to quantify the extinction risk of each and all populations combined by means of simulating observed population abundances under consideration of stochastic variability and carrying capacities of each spring. Demographic parameters for each population model were derived from abundance fluctuations alone while aiming to reproduce the observed abundance trajectories as closely as possible. Some assumptions of the previous PVA were revised and adjusted based on new insights of the extended data sets resulting in a modification of the structure (i.e. number of stage classes and time steps of simulation) of the population models. The results suggest no extinction risk over 100 years for all populations combined. Extirpation risks of single populations range from almost zero to about 8 percent over 100 years with generally lower risks over shorter periods of time.

The results also revealed insights into potential minimal viable population sizes (MVP) and population size thresholds below which the extirpation risk would rise above 10 percent. One important finding is that MVP could not be determined for most populations. This means that population size cannot entirely mitigate the risk of extirpation, which is primarily a result of stochasticity rather than of population size. In other words, the inherent extirpation risk of the Banff Springs Snail populations cannot be mitigated by increased population sizes. The extinction risk is not a result of low population sizes, but mostly driven by the stochastic fluctuations in population abundances, i.e. a large reproductive potential (fecundity) combined with a large mortality potential (low annual survival rates). For some populations and shorter time periods (<= 50 years) in general, population size thresholds for a 10 percent extinction risk could be determined. These population thresholds were consistently lower than the observed annual minimum abundances over the last 12 years.

In summary, this updated PVA benefited from extended time series of abundance data allowing consideration of potential carrying capacities of single springs in the population models. Revised population models produced abundance trajectories very similar to observed abundances and suggest an overall lower extirpation or extinction risk than previously assumed.

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Notice

The results provided in this report are subject to an unknown degree of uncertainty. There is still substantial uncertainty in the knowledge of demographic data, such as fecundity, survival or dispersal distances. This uncertainty and its propagation over time is partly considered in the demographic and environmental stochasticity of the population model. Due to the stochastic nature of the population models, simulation runs were replicated up to 10000 times and results are averages out of those replicate simulation runs. Absolute numbers should be interpreted with caution. Instead trends and differences between different simulation runs (scenarios) are generally more trustworthy. All information used in this work have been verified as well as substituted from the scientific, peer-reviewed literature. The work therefore represents our best possible educated “guess” based on our current knowledge of the biology, life history and habitat requirements for this species.

1 Banff Springs Snail *(Physella johnsoni)*

1.1 Demography

There are currently 7 populations of the Banff Springs Snail in ~~the~~ Banff National Park. Despite long-term observations of population abundances, little is known about the demographic characteristics of the Banff Springs Snail. Continuous abundance data have been collected for 5 populations over 12 years and for 2 re-established populations over 4 and 5 years (Lepitzki 2007a).

Snails are believed to live about one year. It is assumed that adults reproduce only once but continuously after reaching adult-hood and then die. Snails as young as nine weeks old were observed to reproduce in captive breeding tanks containing water from the Cave Spring (Lepitzki 2007b). These observations may explain to some degree why the Cave population does not fluctuate as wildly and consistently as the other populations in springs less protected from the external environment. It is likely that some of the environmental conditions are less variable in the Cave than in the other springs, allowing early and continuous reproduction but lower overall population growth at the same time. It is therefore not clear at this time, whether these tank observations would apply to populations living in less protected springs.

Generally, fecundity is highly variable and likely dependent on water temperature or other abiotic and biotic environmental conditions. Those conditions may vary among the 7 springs in which the snail resides, resulting in different fecundity and mortality rates, but also carrying capacities. Although the actual constraints for population growth are unknown, carrying capacities (i.e. mean annual maximum abundances) are significantly different across the 7 populations. Analysis of the 12 year abundance data revealed significant differences in mean annual abundance maxima among populations ($F=33.718$, $p<0.001$), suggesting an inherent carrying capacity of each spring. Even recent management interventions, such as habitat enhancement attempts in the Cave or adding over 7000 snails to the Basin outflow stream, increased population levels temporarily only with populations quickly reverting to their previous levels. It is therefore likely that population growth is constrained by spring specific carrying capacities and that such constraints control abundance maxima by means of density dependent effects on either fecundity and/or survival rates of the snails.

The 7 populations are considered to be isolated from each other, because active and passive (e.g. through waterfowl) dispersal seems very unlikely among the springs. No re-colonisations were observed until re-establishment of populations into the Upper Middle and Kidney Springs. For more detailed information see (Lepitzki 2002, 2003; 2007a, 2007b, Lepitzki et al. 2002, Lepitzki and Pacas 2007).

1.2 Population Abundances - Time Series Analysis

Census data for 5 populations have been collected over 12 years in 4 and initially 3 week intervals (Lepitzki et al. 2007a,b). Census data for 2 re-established populations have been collected over 4 or 5 years in 4 week intervals. These data reveal a seasonal pattern with abundance maxima in winter and low population sizes in summer. These time series are the only direct clue for the population model and are therefore subject to a quantitative time series analysis. This analysis addresses the following questions.

1. What is the trend in the population trajectories?
2. What are the typical periods for the seasonal pattern?
3. What is the characteristic reproductive rate for each population?
4. What are the average abundance maxima and minima for each population?
5. What are the differences among the populations?

Figures 1-3 show the corresponding graphs for each of the 8 populations. (Note that the Basin population has been split into “Basin” and “Basin Pool” with the latter not including the Basin outflow stream). The average population sizes per year for all populations, except for the Kidney population, increased between

1996 and 2007. The average annual population size for the Kidney population decreased since it was ~~re-introduced~~ re-established in November 2003.

The results of a spectral analysis of the time series data revealed the period(s) of the cyclic, seasonal pattern in the population trajectory. A peak in the corresponding graphs in Figures 1-3 indicates the period lag. The height of the peak indicates the strength of the period. The periods in Figures 1-3 are approximate values only, because the time series is not entirely equidistant, i.e. the sampling interval has changed from 3 to 4 weeks in 2000. Nevertheless, most populations respond in an annual cycle, indicated by a period peak value at about 12 months. Smaller peaks at other time lags indicate periods at smaller or larger time scales. The reason for these peaks is unknown, but may be attributed to sampling error and random fluctuations. The “Lower Cave and Basin” and the “Cave” populations are likely not to follow a strictly annual cyclic pattern, which is indicated by the lack of strong peaks in the corresponding periodograms. It might be that the environmental conditions, which are believed to control the population sizes, are less pronounced in the habitat of these two populations, resulting in a much smoother and less regular increase and decline in population sizes. In addition, there are portions of the Lower Cave and Basin snail population within the spring’s origin cave which have never been enumerated. Finally, the time series of all populations combined confirms the overall trend and periodicity observed in the single populations (see Figure 4).

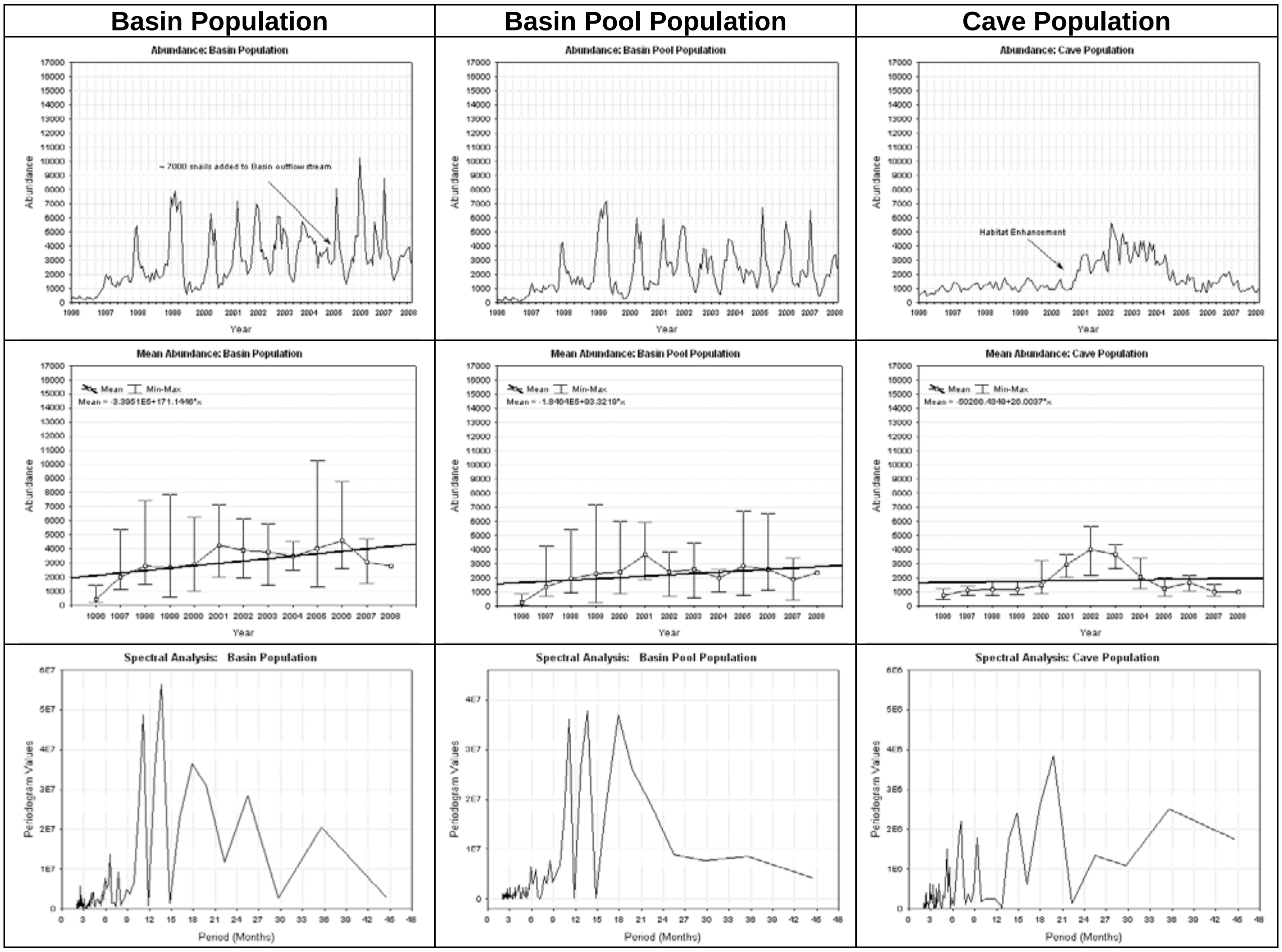


Figure 1: Population abundances, annual mean, min and maxima and periodograms for Basin, Basin Pool and Cave populations.

Another important characteristic of the population trajectories resides in the ratios between annual peak and low population sizes (Figure 5). Assuming that there are no hidden eggs or delayed development of laid eggs (i.e. seed banks) at population lows, the peak following a population low must be the result of the reproductive potential of the remaining adult individuals. The average ratio would than correspond to an average fecundity rate per adult individual. This information is being used in the population models.

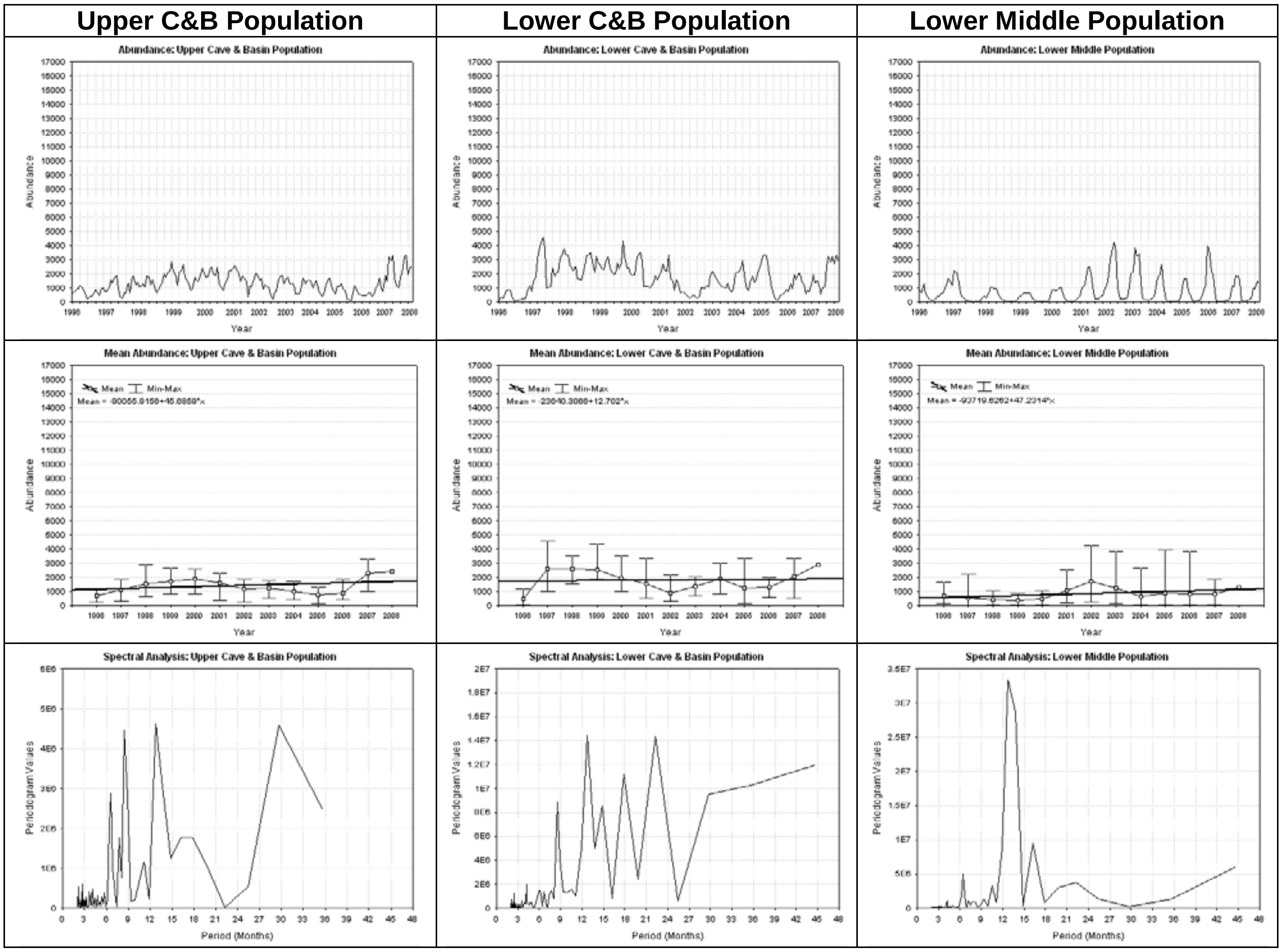


Figure 2: Population abundances, annual mean, min and maxima and periodograms for Upper Cave & Basin, Lower Cave & Basin and Lower Middle populations.

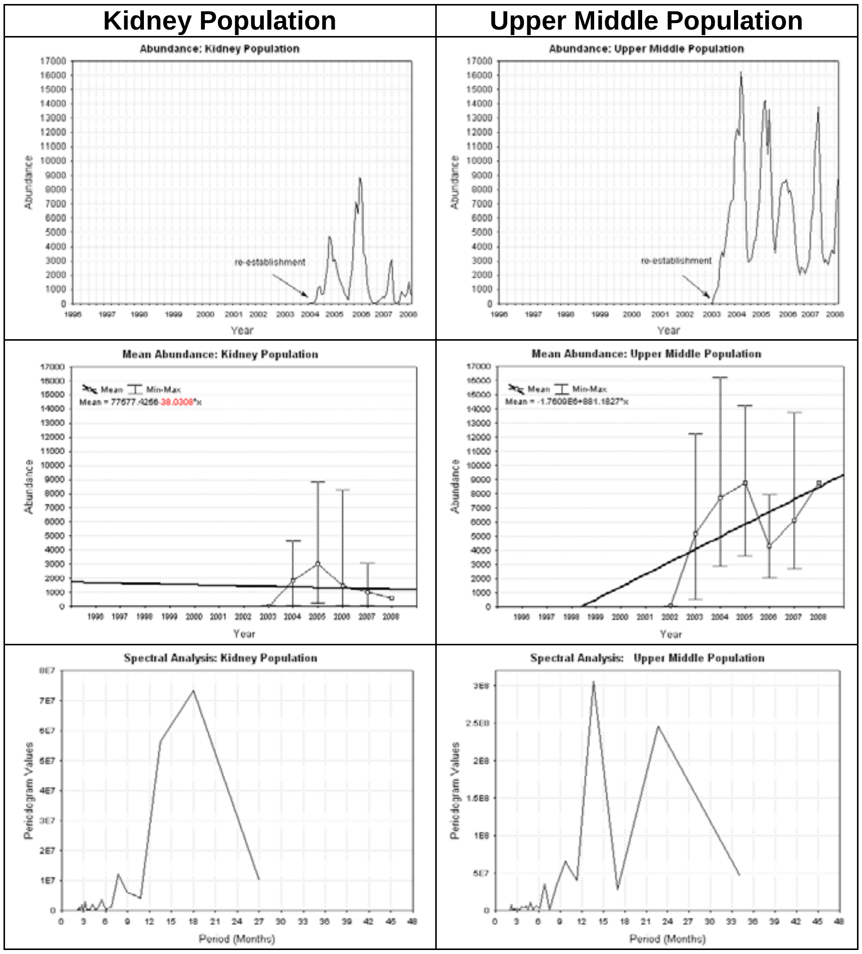


Figure 3: Population abundances, annual mean, min and maxima and periodograms for re-established Kidney and Upper Middle populations.

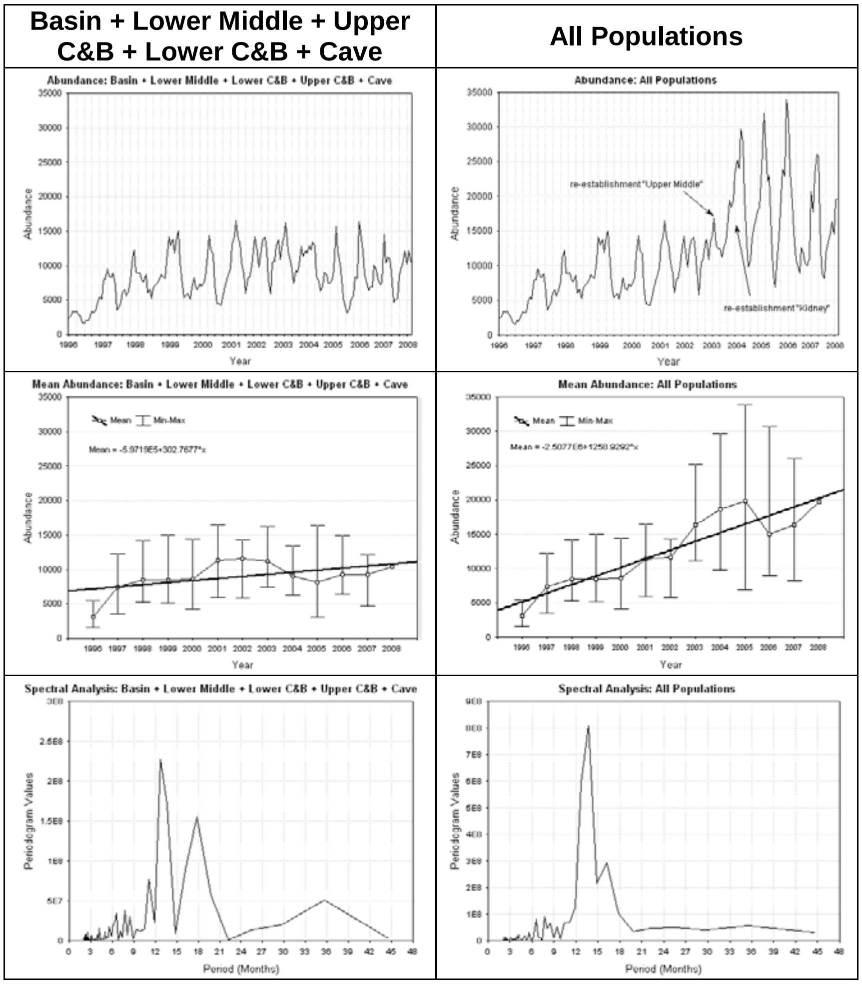
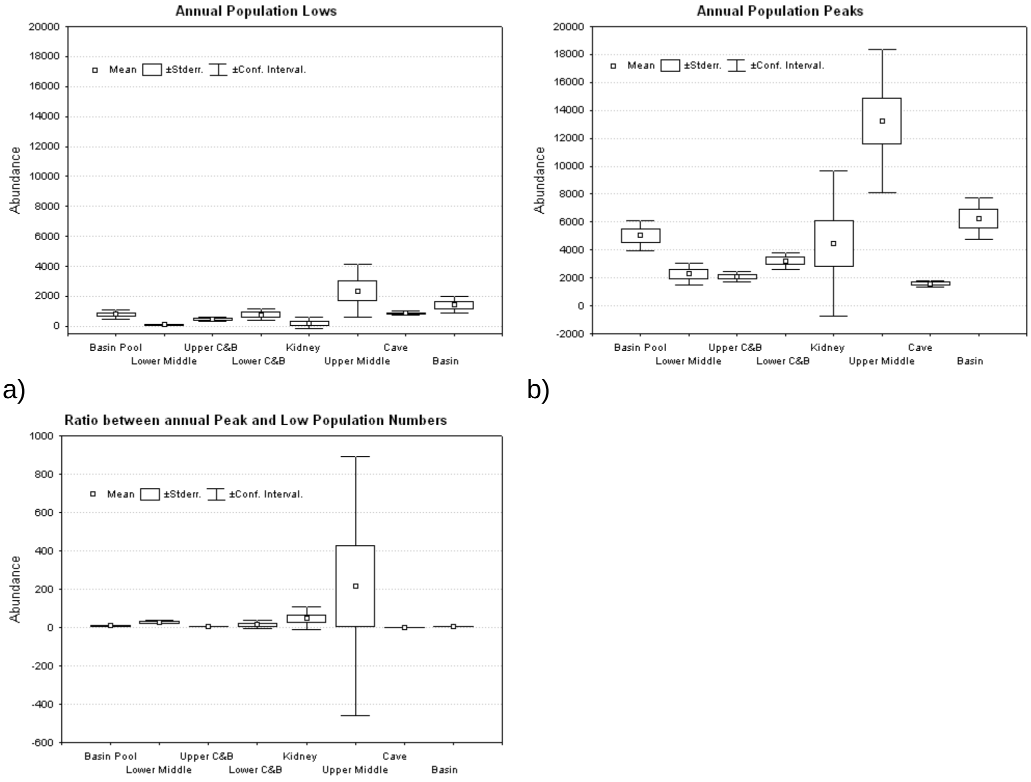


Figure 4: Population abundances, annual mean, min, maxima and periodograms for all original populations and all populations combined.



a)

b)

c)

Figure 5: a) annual population lows of all populations. b) annual population peaks for all populations c) ratios between annual population peaks and population lows for all populations. The large confidence interval for the Upper Middle population is a result of the small sample size (4 seasons) and the extraordinary population growth after re-establishment in November 2002

Overall, time series analyses of the population abundances revealed that:

1. All populations experienced population growth at different rates over the last 12 years except for the re-established Kidney population. The Kidney population shows an overall negative growth trend since it was successfully re-established in November 2003.
2. The typical period for the seasonal pattern in population abundance is still about 12 months, with less pronounced fluctuations for the Cave population.
3. The ratio between annual population peak and low abundances differs among all populations indicating a different reproductive potential for each population.
4. The average annual population peaks and lows differ significantly among all populations. This indicates the existence of spring specific constraints to population growth with resulting carrying capacities at different population levels.
5. All populations differ significantly in almost every aspect of population abundance, reproductive potential (growth rate), carrying capacity and population lows. Still, all populations except for the Cave population show a significant time lag of 12 month in their annual abundance fluctuations.

2 Population Viability Analysis

2.1 Overview

The purpose of this updated PVA was to quantify the inherent extirpation risk for each population and the combined extinction risk for all populations based on the extended census data up to January 2008. The overall approach was very similar to the previous PVA conducted in 2003 (Tischendorf 2003). For each population the following characteristics were extracted from the abundance data.

information from abundance data	implications for population models
mean and standard deviation of ratios between annual population peaks and lows	fecundity estimate for adult snails
mean and standard deviation of annual population peaks	carrying capacity for each population
annual mean population abundances	calibration of simulated population average
overall minimum population abundances	initial population sizes

Table 1: Principal use of population abundance characteristics in the population models

Population models using RAMAS (Akçakaya and Root 2002) were created for each population. The model parameters, in particular survival rates, were then adjusted so that the resulting simulated trajectories of population abundance closely resembled their empirical counterparts over a period of 12 years. Furthermore, the resulting average population size across 1000 replicate simulation runs after 12 years had to match the observed average population size.

Since the population model is stochastic in nature, each simulated population trajectory is different due to the difference in fecundity and survival rates for each year. The resulting population abundances could therefore become zero during the course of single simulations. Such events are counted as extinctions and the proportion of runs out of the number of all replicated simulation runs determines the extinction risk. For example, if population abundance became zero in 233 out of 1000 replicate simulation runs the resulting extinction risk was 23.3%. The models were run over 20, 50 and 100 years and the extinction risk for each of those time periods was recorded for each population and all populations combined.

Furthermore, the minimum viable population size (MVP) was determined by increasing the initial population size of the models until the resulting extirpation risk was zero. In the same way, threshold population sizes (TPS) for extirpation risks smaller than 10 percent were determined. RAMAS also provides the estimated minimum abundance (EMA), “which is the average (over all replications) of the minimum population abundance of the trajectory”.

2.2 Population model structure

The model structure, in particular number of age classes and time step length, is based on the assumed demographic characteristics of the Banff Springs Snail as outlined in section 1.1 and in more detail in Lepitzki (2002).

Generally, the Banff Springs Snail is believed to express two life stages only, juveniles and adults. The transition between the two stages and in particular its time frame is unknown. It is also believed that adults reproduce only once during their life time and that reproduction is triggered by environmental conditions, such as water temperature and/or aspects of water chemistry and food availability.

In the previous PVA the modelled populations were partitioned into 6 juvenile and 6 adult life stages with each stage being one month; transitions from one stage to the next were considered to occur within one month. Juveniles did not reproduce, but experienced mortality from one stage to the next. Adults would reproduce during 4 out of 6 months and die at the end of the 6th month. This approach allowed us to simulate population abundances on a monthly basis and to reproduce the observed seasonal abundance patterns at the same granularity as their empirical counterparts. Furthermore, results of spectral analyses of the simulated abundances were compared with those obtained from the empirical observations. Overall, this approach allowed us to reproduce and to verify the seasonal dynamics of population abundances.

The model structure of the previous PVA was revised and changed due to some new insights but also due to some pragmatic constraints. First of all, the maximum number of time steps in RAMAS is restricted to 999. On the basis of a monthly time step the maximum time frame to be simulated would then be restricted to 83.25 years. The expected time frame for this PVA, however, was 100 years. It was therefore decided to reduce the number of stage classes to one juvenile and one adult stage along with an extended time step of 6 months. All other assumptions remained unchanged. The adjusted model will now progress in 6 month time steps and reveal population abundance changes at the same granularity, i.e. every 6 months. This approach eliminates the potential of measuring the characteristic time lag of the seasonal cycles in the simulated population abundances, but does not actually change the overall results.

A different model structure was used for the Cave population model. Observations from the captive-breeding program revealed that juveniles as young as nine weeks old could reproduce and most likely continued to reproduce throughout their adult life span. It was agreed upon (Lepitzki, pers. com.) that this observation was likely connected to the protected nature of the captive breeding tanks and supplemental feeding, with the tanks being supplied with Cave water. A four stage population model was therefore used for the Cave population with one juvenile life stage and 3 adult life stages along with a time step of 3 months. Snails would therefore start reproducing at month 4 and continue to do so throughout their remaining 9 months as adults. This approach results in a less seasonal cyclic pattern of simulated population abundances, which in turn resembles the observed abundances much better.

Finally, not all data from the 12 year abundances could be used for the model. Data between August 2000 and September 2004 were excluded for the Cave population. During this time the observed population abundances were affected by habitat enhancements in the Cave. Since population levels reverted to their previous numbers after about 4 years, the administered habitat enhancements did not have a permanent effect on overall population size and should therefore not be considered in the PVA. Likewise, data between December 2004 and March 2006 were excluded from analysis for the Basin population. During this time, the Basin population abundance was “temporarily inflated” after more than 7000 snails were added from captive breeding tanks to the Basin outflow stream. Again, this increase in population abundance did not persist over more then 2 years and was therefore excluded from analysis for this PVA.

2.3 Model Parameters

The model parameters for the RAMAS population models were derived in part from the abundance time series for each population and adjusted so that the resulting simulated abundance trajectories closely matched their empirical counterparts.

2.3.1 Cave Population

Parameter	Value/Range	Comments
stage classes	4 juvenile_1 adult_1 .. adult_3	snails may reproduce after 9 weeks in captivity and likely in the Cave, therefore the population was partitioned into 4 age classes where adults can reproduce as of month 4
juvenile fecundity	0	
adult fecundity per 3 months	adult_1 – adult_4 = 0.6411 ± 0.15899 (25% stddev)	extracted from the population data from the Cave Population average overall fecundity per year (between low and peak) is 1.9233 ± 0.4763, which is split across 3 adult age classes, i.e. 1.9233 / 3 = 0.6411
juvenile survival per 3 months	0.76± 0.076 (10% stddev)	adjusted to observed population abundances
adult survival per 3 months	0.76 ± 0.076 (10% stddev)	adjusted to observed population abundances
density dependence	ceiling exp. growth up to carrying capacity of 1585	extracted from the population data from the Cave Population
Initial population size	474	observed minimum abundance
simulated years	20,50,100	
replications	1000/10000	
dispersal	none	Lepitzki, pers. comm.
demographic stochasticity	yes	number of survivors and dispersers (emigrants) to be sampled from binomial distributions, number of young from a Poisson distribution.
environmental stochasticity	lognormal	statistical distribution (normal or lognormal) to be used in sampling random numbers for vital rates

Table 2: Parameter values for the Cave population model

2.3.2 Basin Population

Parameter	Value/Range	Comments
stage classes	2: juvenile, adult	Snails reproduce during their adult life span only, i.e. between month 7 and 12
juvenile fecundity	0	
adult fecundity per 6 months	5.46 ± 2.81 (51% stddev)	extracted from the population data from the Basin Population average overall fecundity per year (between low and peak) is 5.46 ± 2.81
juvenile survival after 6 months	0.25± 0.025 (10% stddev)	adjusted to observed population abundances
adult survival after 6 month	0	adjusted to observed population abundances
density dependence	ceiling exp. growth up to carrying capacity of 5000	extracted from the population data from the Basin Population
initial population size	162	observed minimum abundance
simulated years	20,50,100	
replications	1000/10000	
dispersal	none	Lepitzki, pers. comm.
demographic stochasticity	yes	number of survivors and dispersers (emigrants) to be sampled from binomial distributions, number of young from a Poisson distribution.
environmental stochasticity	lognormal	statistical distribution (normal or lognormal) to be used in sampling random numbers for vital rates

Table 3: Parameter values for the Basin population model

2.3.3 Upper Cave & Basin Population

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Upper C&B population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	4.989 ± 0.1.8744 (37% stddev)	extracted from the population data from the Upper C&B Population
juvenile survival after 6 months	0.265± 0.09 (30 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 2082	extracted from the population data from the Upper C&B Population
initial population size	147	observed minimum abundance

Table 4: Parameter values for the Upper Cave & Basin population model

2.3.4 Lower Cave & Basin Population

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Lower C&B population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	5.36 ± 4.18 (78% stddev)	extracted from the population data from the Lower C&B Population
juvenile survival after 6 months	0.32± 0.032 (10 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 3223	extracted from the population data from the Lower C&B Population
initial population size	43	observed minimum abundance

Table 5: Parameter values for the Lower Cave & Basin population model

2.3.5 Lower Middle Population

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Lower Middle population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	27.688 ± 12.91 (46% stddev)	extracted from the population data from the Lower Middle Population
juvenile survival after 6 months	0.05± 0.005 (10 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 2284	extracted from the population data from the Lower Middle Population
initial population size	30	observed minimum abundance

Table 6: Parameter values for the Lower Middle population model

2.3.6 Kidney

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Kidney population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	47.7899 ± 36.36 (76% stddev)	extracted from the population data from the Kidney Population
juvenile survival after 6 months	0.06± 0.03 (50 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 4455	extracted from the population data from the Lower Middle Population
initial population size	50	observed minimum abundance

Table 7: Parameter values for the Kidney population model

2.3.7 Upper Middle

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Upper Middle population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	42.54 ± 84.5 (198% stddev)	extracted from the population data from the Upper Middle Population
juvenile survival after 6 months	0.10± 0.02 (20 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 13239	extracted from the population data from the Upper Middle Population
initial population size	50	observed minimum abundance

Table 8: Parameter values for the Upper Middle population model

2.3.8 Basin Pool

For the complete list of parameter values see 2.3.2. Only the parameter values specific to the Basin Pool population are shown here.

Parameter	Value/Range	Comments
adult fecundity per 6 months	8.62 ± 5.63 (65% stddev)	extracted from the population data from the Basin Pool Population
juvenile survival after 6 months	0.16± 0.024 (15 % stddev)	adjusted to observed population abundances
density dependence	ceiling, exp. growth up to carrying capacity of 5041	extracted from the population data from the Basin Pool Population
initial population size	77	observed minimum abundance

Table 9: Parameter values for the Basin Pool population model

2.4 Results

2.4.1 Population abundance trajectories

Population dynamics for each of the above described populations were simulated using RAMAS (Akçakaya and Root 2002). The results are shown in Figures 6 and 7.

The first columns in Figures 6 and 7 show observed population abundances between 1996 and January 2008. The middle columns show a single, typical simulated population trajectory for each corresponding population model. Although the simulated trajectories are less granular than their empirical counterparts (due to the model structure adjustments described in 2.2), they resemble empirical abundance fluctuations with respect to lows, peaks and average. The third row shows simulated average population abundances over 10,000 replicate simulation runs. The red trapezoids depict the recorded abundance peaks and lows.

Overall the results in Figure 6 and 7 reveal simulated population trajectories very similar to those observed for each population.

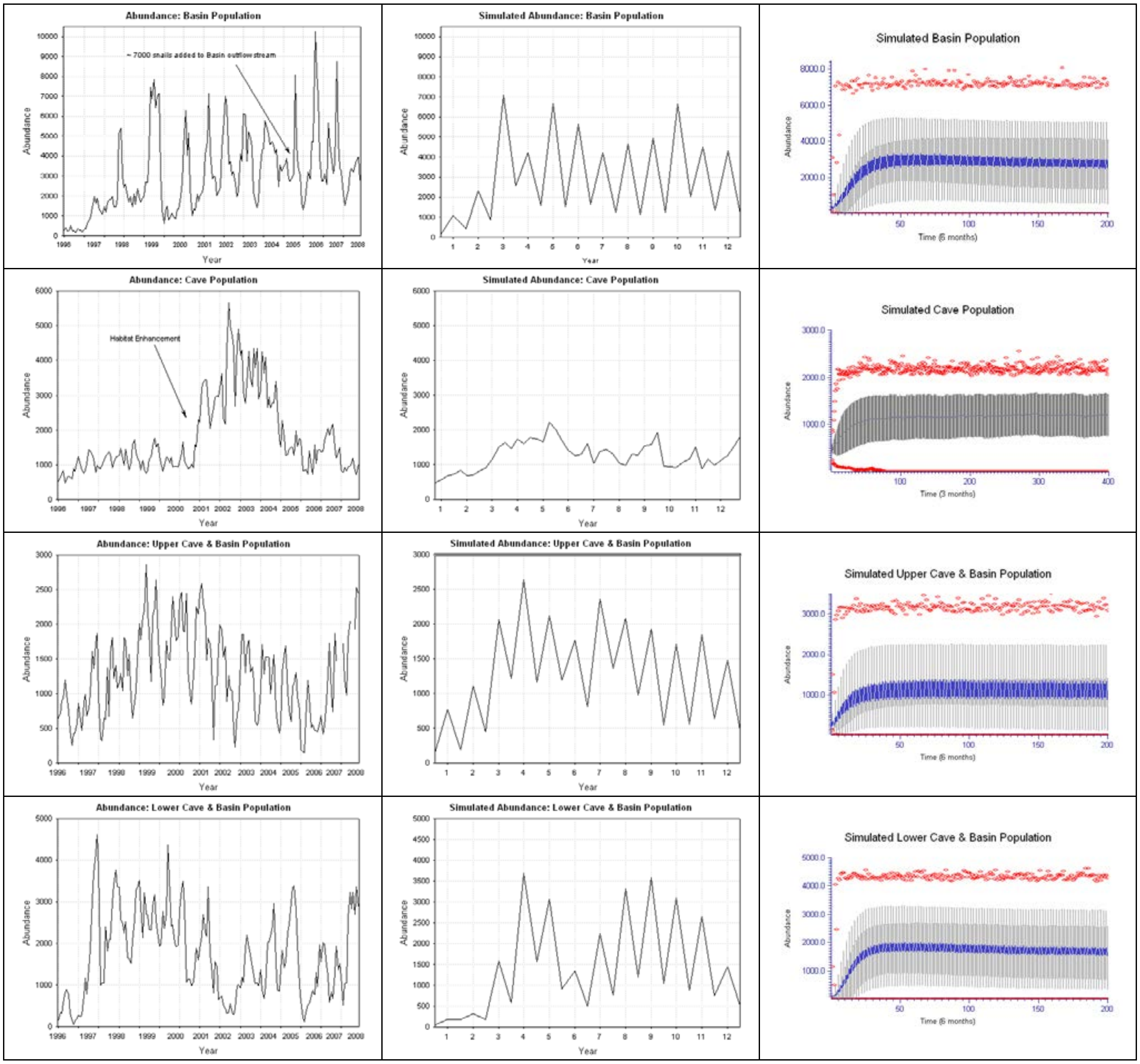


Figure 6: Simulated population abundances for Basin, Cave, Upper Cave & Basin and Lower Cave & Basin populations. The left column shows the observed abundances between 1996 and 2007. The middle column shows exemplary simulated population abundances (trajectories from one single simulation run) to demonstrate the similarity in fluctuations, lows and peaks. The right column shows the simulated average population trajectories over 10,000 replicate simulation runs and the "min/max envelope" of the recorded population abundances.

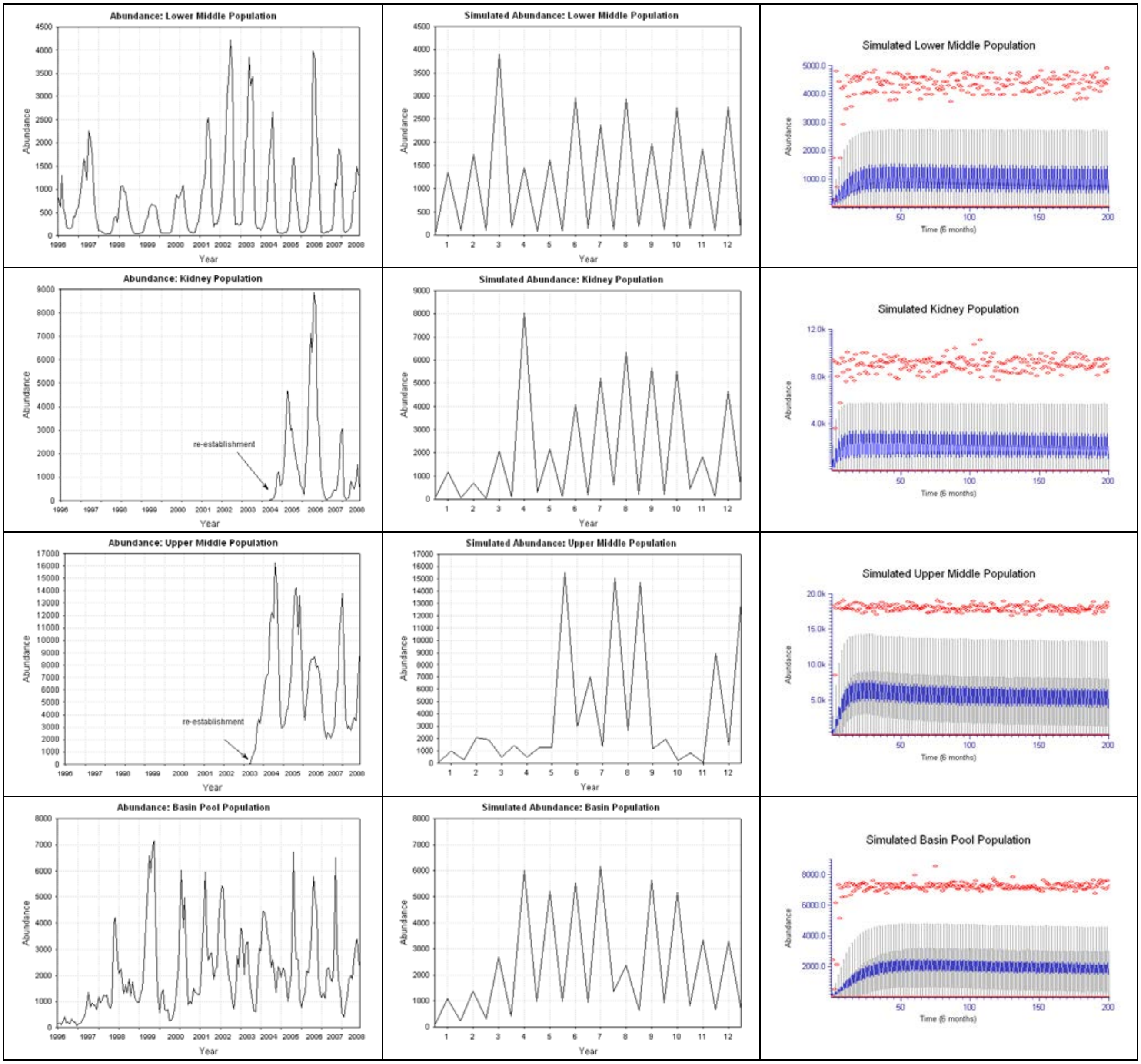


Figure 7: Simulated population abundances for Lower Middle, Kidney, Upper Middle and Basin Pool populations. The left column shows the observed abundances between 1996 and 2008. The middle column shows exemplary simulated population abundances (trajectories from one single simulation run) to demonstrate the similarity in fluctuations, lows and peaks. The right column shows the simulated average population trajectories over 10,000 replicate simulation runs and the "min/max envelope" of the recorded population abundances.

2.4.2 Extinction Risk

The extirpation risks for each population and the extinction risks for all populations combined are shown in Table 10. The results reveal and confirm that extirpation risk generally increases with increasing time frames. The highest risk of extirpation over 100 years is about 8 percent for the Basin Pool and for the Kidney populations. Similar risks of extirpation exist for the Upper and Lower Middle populations. The Cave population has the lowest extirpation risk. The results indicate no risk of extinction over all populations combined.

Population	Time Frame (years)		
	20	**50**	**100**
1. Basin Pool	3.5%	6.2%	8%
2. Basin	0.1%	0.2%	0.2%
3. Cave	0.1%	0.1%	0.1%
4. Lower Cave & Basin	1.7%	1.9%	2.5%
5. Upper Cave & Basin	0.8%	2.1%	3%
6. Lower Middle	3%	5%	7%
7. Upper Middle	2.9%	4.2%	7%
8. Kidney	1.9%	4%	8%
9. #2,4,5,6 combined	0%	0%	0%
10.#2,4-8 combined	0%	0%	0%

Table 10: Extinction risk for each population based on 10,000 replicate simulation runs

These extirpation and extinction risks are lower than those obtained from the previous PVA, which is likely attributed, at least in part, to the adjusted structure of the population models and the consideration of spring specific carrying capacities. Furthermore, almost all population abundances show a positive trend and annual average population abundance grew from 3116 in 1996 to 16351 in 2007. This trend affected the demographic parameters of the population models with the logical result of reduced extinction risks. Overall, these numbers are, again, merely well educated guesses and subject to much uncertainty. They should be interpreted with caution. Furthermore, as encouraging as these results might be, the endemic nature of the Banff Springs Snail and its dependence on very sensitive ecological conditions, such as water flow, temperature, water chemistry and the viability of bacteria constitute a fragile system with imminent risks for the populations long term viability, which may not be considered entirely in these models.

2.4.3 Minimum Viable Population

Population	Time Frame (years)		
	20	**50**	**100**
1. Basin Pool	∞	∞	∞
2. Basin	150	400	750
3. Cave	230	550	680
4. Lower Cave & Basin	175	280	∞
5. Upper Cave & Basin	880	∞	∞
6. Lower Middle	∞	∞	∞
7. Upper Middle	∞	∞	∞
8. Kidney	∞	∞	∞

Table 11: Minimum Viable Population sizes for each population. The '∞' indicates infinite MVP's. In those cases, MVP could not be determined.

The MVP's for each population are shown in Table 11. For most populations MVP could not be determined. In those cases initial population sizes were raised to the actual carrying capacity for the population without eliminating risk of extirpation. This indicates that risk of extirpation cannot be entirely mitigated by population size but is primarily controlled by fluctuations in population sizes. It seems therefore impossible to set MVP targets for the Banff Springs Snail populations.

2.4.4 Population Thresholds

Population threshold abundances for extirpation risks of 10 percent were determined and are shown in Table 12. The Committee on the Status of Endangered Wildlife in Canada has set extinction probabilities of 10% over 100 years and 20% over 20 years as thresholds for threatened and endangered categories, respectively (COSEWIC 2007). The numbers in Table 12 were derived by seeding the population models with the lowest possible initial population size above which the resulting risk of extirpation was lower than 10 percent over 20, 50 or 100 years. These thresholds therefore indicate critical population lows, below which the risk of extirpation may rise above 10 percent over the corresponding time frames. It appears that all population thresholds are well below the observed minimum abundances, hence, none of the populations actually faces a risk of extirpation above 10 percent (see Table 10).

Population	**Time Frame (years)**		
	20	**50**	**100**
1. Basin Pool	35	45	64
2. Basin	18	20	19
3. Cave	31	37	46
4. Lower Cave & Basin	12	13	14
5. Upper Cave & Basin	26	36	45
6. Upper Middle	16	17	24
7. Lower Middle	15	18	20
8. Kidney	12	13	22

Table 12: Population thresholds for 10 percent risk of extirpation.

2.4.5 Expected Minimium Abundance

The expected minimum abundance (EMA) is "the average (over all replicated simulation runs) of the minimum population abundance". The EMA can be used to validate or judge how conservative the population models are. If EMA would be significantly higher than the observed minimum population abundances than the population models would likely underestimate the actual extinction risk. Vice versa, if the EMA is significantly lower than the observed minimum population abundances, the model can be regarded as conservative. The EMA's in Table 13 are consistently lower than their empirical counterparts, which lowers the chance of inadvertent underestimations of predicted populations' extirpation risks.

Population	**Time Frame (years)**		
	20	**50**	**100**
1. Basin Pool	72	61	45
2. Basin	178	170	154
3. Cave	351	312	265
4. Lower Cave & Basin	55	52	46
5. Upper Cave & Basin	127	102	78
6. Upper Middle	114	67	37
7. Lower Middle	27	22	16
8. Kidney	65	43	29
9. #2,4,5,6 combined	523	520	524

10.#2,4-8 combined	875	870	867

Table 13: Expected Minimum Abundance for each and all populations combined

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Tables

Figures