APPENDIX C

POPULATION VIABILITY ANALYSIS - SUPPLEMENTARY

Detailed Methods

All population growth models and PVA used herein were created and completed using the RAMAS® Metapop software (Applied Biomathematics, Setauket, New York). The software allows for the viability analysis of stage-structured metapopulations over user-defined time periods and can be replicated to account for probabilistic demographic and environmental stochasticity. Essentially, stage-classified probability matrices which represent vital rates (i.e., survival, fecundity, and transition rates; Lefhobitch, 1965[3]) are used to model population growth. Other data required by the model includes: initial abundances, standard deviations, metapopulation location, relative vital rates, dispersal rates, and density-dependence effects. Using known information from our studies, or data published in the scientific literature, the model parameters were inputted to estimate the population growth models for the three SMH sub-populations.

The following explains the baseline model used and model inputs that take into account different assumptions of the sub-populations and different scenarios that may occur in the South March Highlands.

To complete a PVA that would adequately model the South March Highlands Blanding's turtle population, a number of assumptions have been made:

- The South March Highlands Blanding's turtle population is spatially-explicit and individuals of the three sub-populations are capable of dispersal between each sub-populations (by definition the SMH is Blanding's turtle population is a 'metapopulation'; we will continue to refer to the grouping as the SMH Blanding's turtle population for simplicity). Six activity centres have been identified through the population and radio telemetry study (Dillon Consulting Limited, 2011b), however the frequency of cross-zone movements indicates that the central wetlands along Shirley's Brook tributaries are really one large subpopulation, separate from the Kizell Wetland and Zone 1, which seems to be a separate environment and used less frequently by Blanding's turtle. For the analysis we have defined three subpopulations:
    - The Kizell Wetland (Zone 7A in the Population Estimate Study)
    - The South March Highlands- Central (Zones 2, 3, 4, 5, 8, and 9).
    - The South March Highlands- Upland (Zone 1)
- The Blanding's turtle have three life stages: (1) Eggs/Hatchlings; (2) Juveniles; and, (3) Adults. Any particular stage is affected by stage-specific vital rates (i.e., survival rates are different between stages, but all individuals of each stage are affected similarly).

---

[3] Full citations for all references used can be found in the Report.

- Furthermore, we adjusted the model to assume that eggs/hatchlings have no potential for dispersing between sub-populations, juveniles have a low potential for dispersing, and adults have a moderate potential for dispersing (Congdon *et al.,* 2008). Although there are studies that suggest hatchlings disperse, we are uncertain if this happens in the SMH given that we know of few nesting sites and no hatchling-specific habitat. The model has also been adjusted to reflect that it is more likely for an adult turtle to move between the two South March Highlands sub-populations than between the Kizell Wetland sub-population and either of the South March Highland sub-populations.

- To model the population viability, accurate estimates of survivorship, fecundity, and the ratio of individuals successfully reaching the next stage are needed. The current population study being completed in the South March Highlands has not spanned a long enough time period to accurately determine population-specific vital rates. Thus, vital rates determined from demographic data collected over a span of 37 years have been used (Congdon *et al.,* 1993). The Congdon and colleagues (1993) study followed a population of Blanding's turtles on the University of Michigan's E.S. George Reserve for 27 of 37 years (1953-1991). Survival rate estimates were determined using data collected from all adults sampled over the entire period of study, and fecundity data were collected from data collected after 1976. The reserve is approximately 900 km to the southwest of the South March Highlands (45^o 20' N latitude) and located to the west of Ann Arbor Michigan (42^o 16' N Latitude). Carrying Capacity (K) was also calculated based on the Michigan population (7.5 turtles per hectare). It should be noted that the calculated K value is a conservative estimate and other populations have been found to have over 50 individuals per hectare in Nebraska (Congdon *et al.,* 2008).

- To "populate" the initial abundances, the number of adult Blanding's turtles observed in each sub-population during the 2010-2012 population study was used, along with literature information from Congdon and colleagues (1993) to estimate the number of eggs laid (based on clutch size) in a year and the number of juveniles (based on expected hatchling success, juvenile survivorship, and age to sexual maturity). To calculate the number of juveniles we assumed that the SMH population is currently at stable state (i.e., $\lambda = 1.0$; Enneson and Litzgus, 2008). The stable-state assumption allowed us to determine the initial survivorship for juveniles and the number of juveniles transferring to the adulthood stage based on formulas published in Enneson and Litzgus (2008).

  Only the number of females was modeled. Blanding's turtle exhibit a polygamous mating system which means that females are the limiting sex (i.e., many potential males can sire a clutch of eggs, however the number of eggs laid is dependent on the number of females). The average number of eggs laid was halved to account for an equal sex ratio. Though findings from the Terry Fox Drive extension work indicate that the SMH Blanding's turtle population has more females than males, sex ratios at the hatchling and juvenile stages are unknown. Also, given that the Terry Fox Drive work has only occurred for two annual mark/recapture periods, it would be unwise to oppose other studies which have indicated that Blanding's turtle populations have a 1:1 sex ratio. Life history and demographic models are based on females since they produce offspring (Congdon *et al.,* 1993; Enneson and Litzgus, 2008).

- Density-dependent effects influence all vital rates (i.e., survival and fecundity). A ceiling approach was used because the impact of density-dependence likely occurs only when the population reaches a specific threshold (i.e., carrying capacity). Carrying capacity was based on a density of 7.5 turtles per ha (Congdon *et al.,* 1993) and the total area (combined wetland and upland habitat) of each sub-population.

The following parameters were used in the baseline model:

- The model spans a 500 year period and is replicated 1000 times (the replications are based on stochastic changes to the model parameters based on the standard deviation matrix).
- Density dependence affects all vital rates, but only for the juvenile and adult life stages. The density dependence type was "Ceiling". Hatchlings were excluded from density dependence effects because of high mortality rates due to nest predation and lack of resource competition.
- The population has three life stages: 1) egg/hatchlings; 2) juvenile (1-14 years of age); and, 3) adult (15+ years of age). Reproduction can only occur in the adult life stage and relative dispersal is quartered for juveniles and nil for egg/hatchlings. Hatchlings may however disperse *via* the adult dispersing. Age of sexual maturity (14) was chosen based on the lower estimate by Congdon and colleagues (1993).
- The following is an example of a stage-classified matrix (*A*) and represents the matrix used in the models:

$$A = \begin{bmatrix} 0 & 0 & F_3 \\ P_{21} & P_{22} & 0 \\ 0 & P_{32} & P_{33} \end{bmatrix}$$

Where P_{21} is egg/hatching survivorship (i.e., the percentage of eggs that successfully hatch and become juvenile turtles); P_{22} is juvenile survivorship minus the percentage of juveniles which have transferred into adults; P_{32} is the percentage of juveniles which have transfer into adults each year; P_{33} is adult survivorship; and F_3 is adult fecundity (i.e., number of eggs laid in a year destined to be female).

The following stage-classified matrix was adapted from Congdon and colleagues (1993) and used in the model:

$$\text{Stage Matrix} = \begin{bmatrix} 0.0 & 0.0 & 5.0 \\ 0.261 & 0.775 & 0.0 \\ 0.0 & 0.007 & 0.960 \end{bmatrix}$$

To explain the matrix, approximately 26 % of eggs laid become juveniles; less than 1 % of eggs which become juveniles subsequently become adults; 4 % of adults die each year; and 5 female eggs are laid per female turtle each year.

- The following standard deviation matrix was calculated using a 10 % standard deviation in vital rates and applied to the stage matrix during modeling. The standard deviation matrix represents demographic and environmental stochasticity (randomness) which describes the temporal variation in vital rates. Standard deviations in vital rates is not well discussed in the scientific literature, thus a standard deviation value of 10 % was used to avoid truncation and overestimating extinction risks. The number also represents a biologically-relevant standard deviation, though as stated above, scientific discussion on the topic is limited for turtle populations:

$$\text{Standard Deviation Matrix} = \begin{bmatrix} 0.0 & 0.0 & 0.5 \\ 0.026 & 0.0225 & 0.0 \\ 0.0 & 0.0007 & 0.004 \end{bmatrix}$$

- The following characteristics were applied to the subpopulations:
    - Kizell Wetland:
      Centre point: 427037 m E, 5019794 m N (UTM +18)
      Relative fecundity, survival, and dispersal were set to 1 for the baseline model.
      The carrying capacity of the Kizell Wetland habitat is 61 turtles based on 6.3 ha
    - SMH-Central:
      Centre point: 425647 m E, 5020492 m N (UTM +18)
      Relative fecundity, survival, and dispersal were set to 1 for the baseline model.
      The carrying capacity of the SMH-Central habitat is 1639 turtles based on 437.0 ha.
    - SMH-Upland:
      Centre point: 424485 m E, 5020566 m N (UTM +18)
      Relative fecundity, survival, and dispersal were set to 1 for the baseline model.
      The carrying capacity of the SMH-Upland habitat is 415 turtles based on 110.7 ha.

- Initial abundances for the three sub-populations were calculated using the number of adult females found in the sub-populations during the *Population Estimate and Range Study* (Dillon Consulting Limited, 2011a; Unpublished Data; one more year of recapture will be undertaken, but current estimates suggest that there are more adult females than what is represented here, thus our initial abundances are a minimum). The number of eggs and juveniles were calculated using the vital rates presented in Congdon and colleagues (1993) and formulas described in (Enneson and Litzgus, 2008). Specifically, the matrices used were as follows:

$$\text{Initial Abundance}_{Population} = \begin{bmatrix} Eggs \\ Juveniles \\ Adults \end{bmatrix}$$

$$\text{Initial Abundance}_{KW} = \begin{bmatrix} 30 \\ 27 \\ 6 \end{bmatrix}$$

$$\text{Initial Abundance}_{SMH-Central} = \begin{bmatrix} 215 \\ 193 \\ 43 \end{bmatrix}$$

$$\text{Initial Abundance}_{SMH-Upland} = \begin{bmatrix} 15 \\ 13 \\ 3 \end{bmatrix}$$

- Two catastrophes were added to the model to account for randomly occurring events that may cause negative effects on the populations. One catastrophe halved adult abundances in each population and is analogous to a large poaching event or a fatal disease outbreak. The second catastrophe halved each vital rate and was regional, meaning each metapopulation was affected equally. A rate impacting catastrophe is analogous to a more systemic event, such as climate change, which may alter survivorship, fecundity, and development over a large area. Catastrophes were set to occur once in one hundred years.
- Dispersal was incorporated into the model to account for turtle movements between the sub-populations. Dispersion between the sub-populations was calculated using the following formula:

  $\rho_{ij} = a \bullet \exp\left(\frac{-D_{ij}^{c}}{b}\right)$, a, b & c are known as the function parameters where D_{ij} is the distance between the two population centers and a, b, and c are constants (no definition provided by Applied Biomathematics, the software developer).

  The function parameters were estimated using information collected during the *Population Estimate and Range Study* (Dillon, 2011a and 2012 Unpublished Data) and Blanding's turtle biology (Congdon *et al.*, 2008). The resulting relationship is depicted below and shows the declining rate of dispersal as distance (m) between sub-population increases:

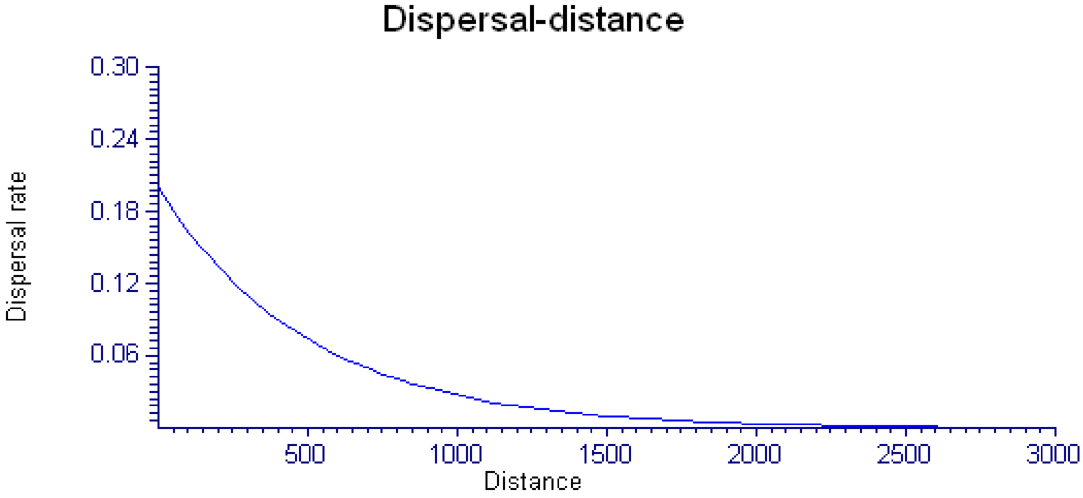

Figure C1. The relationship of disperal likelihood and distance used in the PVA.

Figure C1 shows that the turtles will disperse at a rate of 0.2 which decreases as distance (m) increases. The following Dispersal Matrix was calculated using the depicted function (KD, SMH-CEN, SMH-UP):

$$\text{Dispersal Matrix} = \begin{bmatrix} & 0.009 & 0.0001 \\ 0.009 & & 0.02 \\ 0.0001 & 0.02 & \end{bmatrix}$$

<u>Results not presented in the Report</u>

The mean population growth rate (λ) of females in the baseline scenario was 1.005 which indicates that based on the initial abundances and the assumed vital rates from the Congdon and colleagues (1993) study, the population is essentially stable (**Table C1**). However, over the course of the model, the SMH population did become extirpated, likely due to the catastrophes (**Table C1**). The baseline scenario considers all three sub-populations equal, with respect to dispersal and survival rates, and is an objective estimation of the population demographics of the SMH Blanding's turtle population. The result of a slight increase to 1.005 is not surprising, considering that model inputs have assumed $\lambda = 1.0$, in order to calculate juvenile transition and survival rates based on the Congdon and colleagues (1993) paper. The baseline scenario should not be misinterpreted as being the present day situation and the scenario with the highest likelihood of being fulfilled because the model uses Blanding's turtle specific vital rates measured from a long-term studied population (Congdon *et al.*, 1993) and the SMH-specific initial abundances and spatial locations. As well the model does not take into consideration population-specific differences in vital rates and/or other considerations such as dispersal rates. The model does however serve as a common-ground model for which comparisons may be made. The alternatives to the baseline model will be explored below in the sensitivity analysis, as separate and combined scenarios.

In general, the demographic data in the baseline scenario allows for the calculation of 1) Reproductive value, 2) Stable stage abundance and 3) Resident time. Reproductive value indicates the contribution of an individual to future generations. Stable stage abundance is the population breakdown with respect to stages between age classes. Resident time is the length of time that an individual spends in a given stage.

Adults have a high reproductive value, as the following vector of reproductive value (ν) was calculated:

$$\nu = (1 \quad 3.83 \quad 123.48)$$

On average, ν means that juveniles will contribute 3.83 times more to future generations as compared to eggs/hatchlings, and that the average adult will contribute 123.48 times more to future generations as compared to the eggs/hatchlings. Had we assumed the SMH population has a decreasing rate of growth, the reproductive value of adults would be lower, but still greater than the juvenile and egg/hatchling reproductive values. Alternatively, high rate of growth results in an exponential increase in adult reproductive value. High reproductive value for adults is typical for long-lived turtle species and lends support to protection programs and management objectives that promote survivorship among adults (e.g., the Terry Fox Drive Extension Wildlife Guide System, Turtle Crossing signage, community Turtle Watches; See Section 6 below). Below in our management strategy we explain in detail options for protecting adult Blanding's turtles and particularly mobile females that are more vulnerable.

Stable stage distribution indicates the percentage of individuals within each stage that are required for the population to be stable. The following stable stage distribution (ω) was calculated from the baseline stage matrix:

$$\omega = \begin{bmatrix} 0.42 \\ 0.49 \\ 0.09 \end{bmatrix}$$

The values indicate that a stable population of Blanding's turtles would have an abundance distribution of 42% eggs/hatchling, 49% juveniles and 9% adults. If a lower λ been assumed in the model, adults would have made up more of the stable population, and vice versa (17% for λ = 0.5, 7% for λ= 1.3). In general, a stable population of Blanding's turtle should have a high abundance of eggs/hatchlings and juveniles. In order for a stable population, few juveniles need to reach adulthood as relatively few adults can sustain a population if the mortality rates of adults remain low and recruitment is high (i.e., nesting sites are available, egg loss is low, and hatchlings are becoming juveniles). Management options which promote increased hatchling success and protection of juvenile habitat are important if nesting sites are rare and nest predation is high. If ample nesting habitat is available and high hatchling success is occurring, then initiatives to promote recruitment should be considered secondarily to the protection of adults (see Report for further discussion on options to increase recruitment).

With respect to the resident time that individuals spend in each stage, juveniles spent on average 4.4 years (note that 4.4 years is an average and 22% of juveniles die each year). Adults spent on average 25 years in the population. Eggs/hatchlings, by design, spend one year in the stage. Resident times remain stable across different assumptions for λ and therefore are influenced by stage-specific survival rates (Enneson and LItzgus, 2008). Adult Blanding's turtles have been known to live in excess of 80 years (Congdon *et al.,* 2008) and thus management options that will increase adult reproductive lifetimes should be considered to prolong the reproductive value of adults. Likewise, management options which can increase survival rates for juveniles would increase the number of juveniles becoming adults. It is likely that habitat protection focused on adults would indirectly increase juvenile survivorship as their habitat needs are similar at a macro-scale (see Section 6 below for management options associated with habitat protection).

Sensitivity and Elasticity

The following sensitivity matrix (*S*) was calculated from the Stage Matrix used in the baseline model. Note that the same stage matrix is used in each model, so each model will have the same sensitivity matrix.

$$S = \begin{bmatrix} 0.0332 & 0.0384 & 0.0066 \\ 0.1271 & 0.1471 & 0.0254 \\ 4.0956 & 4.7396 & 0.8197 \end{bmatrix}$$

Each element in the matrix represents the sensitivity (*S*) of the corresponding element in the stage matrix described above. Meaningful elements are the values with a corresponding number in the Stage Matrix (e.g., F_3, P_{21}, P_{22}, P_{32}, P_{33} from matrix *A*), the other elements are ignored. The meaningful element that is the most sensitive to the model outcome is the rate of transition from juvenile to adult ($P_{32} = 4.7396$). The next most sensitive element is adult survival ($P_{33}=0.8197$). P_{32} and P_{33} are the two rates most sensitive in turtle population models (e.g., Congdon *et al.,* 1993; Enneson and Litzgus, 2008). As reported above, the juvenile transition rate was calculated using the assumption that λ = 1. Had a population growth rate below one been used, the transition rate would have been greater and more adults would be present in the stable state and their reproductive value would be lower (as previously mentioned). Had a greater than one population growth rate been assumed, fewer adults would be required for a stable state and adults would have a higher reproductive value.

The following elasticity matrix (*E*) represents the elasticity of the corresponding element in the Stage Matrix:

$$E = \begin{bmatrix} 0.0000 & 0.0000 & 0.0332 \\ 0.0332 & 0.1140 & 0.0000 \\ 0.0000 & 0.0332 & 0.7865 \end{bmatrix}$$

High elasticity means that a small change in the corresponding element of the Stage Matrix will cause larger changes in the population growth rate. Elasticity was highest for the matrix element representing adult survival rate (P_{33}=0.7865%), followed by the probability for a juvenile to survive (P_{21}=0.0332%) and remain a juvenile (P_{32}=0.332%). Again, the above findings are typical for Blanding's turtle population growth models (e.g., Congdon *et al.*, 1993; Enneson and Litzgus, 2008). This finding further supports the conclusions made above that management options promoting adult survivorship will have the largest impact on Blanding's turtle population viability.

Scenario Results

Table C1 outlines the quantitative results of the PVA used in the report. The table is provided below.

Table C1. A comparison of the baseline PVA to each scenario.

Scenario	Sub-Population	Rate of Population Growth (λ)	% change in λ from baseline model	% change in median years to quasi-extinction from baseline model (negative indicates earlier)	% change in maximum number of adults at final stage from baseline model (negative indicates decline)
Baseline	KW	1.0005	-	-	-
	SMH-CEN	1.0005	-		-
	SMH-UP	1.0005	-		-
Baseline- Decreased Survival (1)	KW	0.9521	-5.3 %	-30.2%	-100%
	SMH-CEN	0.9908	-1.41%		-100%
	SMH-UP	1.005	0%		-100%
Baseline- Low Egg Survival (2)	KW	0.9824	-2.3%	-42.2%	-100%
	SMH-CEN	0.9824	-2.3%		-100%
	SMH-UP	0.9824	-2.3%		-100%
Isolation - KW Low Dispersal (3)	KW	1.0005	-	-3.7%	-14.3%
	SMH-CEN	1.0005	-		-11.1%
	SMH-UP	1.0005	-		+166.7%
Urbanization (4)	KW	0.9521	-5.3 %	-29.3%	-100%
	SMH-CEN	0.9908	-1.41%		-100%
	SMH-UP	1.0005	0%		-66.7%
Transplant-Baseline (5A)	KW	1.0005	-	-3.0%	0%
	SMH-CEN	1.0005	-		-22.2%
	SMH-UP	1.0005	-		100%

Scenario	Sub-Population	Rate of Population Growth (λ)	% change in λ from baseline model	% change in median years to quasi-extinction from baseline model (negative indicates earlier)	% change in maximum number of adults at final stage from baseline model (negative indicates decline)
Transplant-Isolation(5B)	KW	1.0005	-	-12.8%	-33.3%
	SMH-CEN	1.0005	-		-100%
	SMH-UP	1.0005	-		-100%
Transplant (5C) – Urbanization	KW	0.9881	-1.68%	-32.5%	-100%
	SMH-CEN	1.0274	-2.23%		-77.8%
	SMH-UP	1.0372	-3.20%		-100%
Increased Hatchling Success from nest protection-Baseline (6A)	KW	1.0169	+1.18%	n/a	0.0%
	SMH-CEN	1.0169	+1.18%		+613.3%
	SMH-UP	1.0169	+1.18%		+217.6%
Increased Hatchling Success from nest protection -Isolation (6B)	KW	1.0169	+1.18%	n/a	0.0%
	SMH-CEN	1.0169	+1.18%		+966.7%
	SMH-UP	1.0169	+1.18%		+211.8%
Increased Hatchling Success (6C) from nest protection - Urbanization	KW	0.9682	-3.66%	+54.6%	-8.3%
	SMH-CEN	1.0072	+0.22%		+226.7%
	SMH-UP	1.0169	+1.18%		+194.1%
Increased Hatchling Success from head start program -Baseline (7A)	KW	1.0418	+3.66%	n/a	+8.3%
	SMH-CEN	1.0418	+3.66%		+860.0%
	SMH-UP	1.0418	+3.66%		+176.5%
Increased Hatchling Success from head start program -Isolation	KW	1.0418	+3.66%	n/a	+16.7%
	SMH-CEN	1.0418	+3.66%		+846.7%

Scenario	Sub-Population	Rate of Population Growth (λ)	% change in λ from baseline model	% change in median years to quasi-extinction from baseline model (negative indicates earlier)	% change in maximum number of adults at final stage from baseline model (negative indicates decline)
(7B)	SMH-UP	1.0418	+3.66%		+176.5%
Increased Hatchling Success from head start program –Urbanization (7C)	KW	0.9927	-1.22%	n/a	+8.3%
	SMH-CEN	1.0320	+2.69%		+786.7%
	SMH-UP	1.0418	+3.66%		+176.5%
No Catastrophe-Baseline (8A)	KW	1.0005	-	n/a	+16.7%
	SMH-CEN	1.0005	-		+166.7%
	SMH-UP	1.0005	-		+188.2%
No Catastrophe-Isolation (8B)	KW	1.0005	-	n/a	+8.3%
	SMH-CEN	1.0005	-		+126.7%
	SMH-UP	1.0005	-		+129.4%
No Catastrophe-Urbanization (8C)	KW	0.9521	-5.3 %	+81.2%	-41.7%
	SMH-CEN	0.9908	-1.41%		+6.7%
	SMH-UP	1.0005	0%		+17.6%
Removal of 60 eggs from SMH-CEN for 30 years starting 5 years from present- Baseline (9A)	KW	1.0005	-	-4.5%	-66.7%
	SMH-CEN	1.0005	-		-60.0%
	SMH-UP	1.0005	-		-58.8%
Removal of 60 eggs from SMH-CEN for 30 years starting 5 years from present-Urbanization (9B)	KW	0.9521	-5.3 %	-34.0%	-100%
	SMH-CEN	0.9908	-1.41%		-100%
	SMH-UP	1.0005	0%		-100%

Scenario	Sub-Population	Rate of Population Growth (λ)	% change in λ from baseline model	% change in median years to quasi-extinction from baseline model (negative indicates earlier)	% change in maximum number of adults at final stage from baseline model (negative indicates decline)
9A and introduction of 60 juveniles each of the 30 years- Baseline (10A)	KW	1.0005	-	+27.6	-41.7%
	SMH-CEN	1.0005	-		-46.7%
	SMH-UP	1.0005	-		-52.9%
9A and introduction of 60 juveniles each of the 30 years- Urbanization (10B)	KW	0.9521	-5.3 %	-8.2%	-91.7%
	SMH-CEN	0.9908	-1.41%		-93.3%
	SMH-UP	1.0005	0%		-88.2%