Rákosi Vipera

Species Conservation Planning for the Hungarian Meadow Viper (*Vipera ursinii rakosiensis*)

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Report from a workshop conducted on:
20 – 22 March 2024
Budapest Zoo
Budapest, HUNGARY

Back row: B. Kocsis, G. Erdélyi, Z. Vajda S. Ursenbacher, O. Hadj-Bachir, M.A. Marchand, B. Lauš, S. Kalmár, T. Sos, P. Miller, D. Rödder
Front row: B. Major, J. Vörös, A. Egerer, L. Faust, A.K. Garn, B. Halpern, E. Sós, E., Mizsei, I. Buric, G. Păun, Cs. Gulyás

Cover photo: Bálint Halpern, MME Hungary.

A contribution of the IUCN/SSC Conservation Planning Specialist Group, in collaboration with MME Hungary, Budapest Zoo and Botanical Garden, and workshop participants.

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Species Conservation Planning for the Hungarian Meadow Viper (*Vipera ursinii rakosiensis*)

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Executive Summary

The Hungarian meadow viper (*Vipera ursinii rakosiensis*) is a rare snake subspecies that once occupied a large range in the Pannonian steppe, from eastern Austria to western Romania. In the early years of this millennium, the viper was restricted to perhaps a dozen sites in Hungary and only a few sites in Romania. Major factors leading to the decline of the viper included conversion of steppe habitat to agricultural land, intensive water management, and collection of individuals for trade.

A conservation planning workshop held in Budapest in 2001, facilitated by the IUCN SSC Conservation Breeding Specialist Group (now Conservation Planning Specialist Group, CPSG) highlighted the potential value of an ex situ breeding program for the Hungarian meadow viper as a component of an integrated conservation effort for the species. Soon after the 2001 workshop, the Hungarian Meadow Viper Conservation Center (HMVCC) was established, and large numbers of individuals produced in this facility have now been released to the wild, no doubt improving the long-term viability of threatened viper populations across the species' range. Key participants from this original workshop were interested in updating the action plan produced nearly 25 years ago, and once again contacted the Conservation Planning Specialist Group to assist in workshop design and facilitation.

This updated workshop, hosted by the Budapest Zoo in March 2024, brought together a range of experts on the species and its management from across Europe. This in-person workshop was preceded by a virtual workshop held in the online environment in November 2023. An important output of that meeting was a consensus vision statement for conservation of the Hungarian meadow viper. The vision is meant to be aspirational, and describe an ideal future for conservation of the species when the range of conservation activities are successful. In this way, it provides a long-range target that guides more immediate conservation action:

> *In the year 2100, the Hungarian meadow viper is thriving, without the need for direct human intervention, in multiple connected populations across their well-managed historic landscape. These viable populations are able to adapt to changing climatic conditions in a rapidly evolving world. The Hungarian meadow viper is an ambassador for grassland conservation in its native habitat, and local communities actively promote and support its conservation.*

A key feature of this project was a detailed population viability analysis (PVA), led by CPSG collaborators from the Lincoln Park Zoo in the United States. This detailed analysis, using available demographic data from both wild and HMVCC population and computer simulation modeling techniques, was designed to predict relative responses of simulated viper populations to alternative management strategies into the future. These insights can be used as key pieces of information to justify specific management decisions moving forward in time. The PVA highlighted the strong capacity for the HMVCC to produce substantial numbers of individuals for release to the wild, while also maintaining favorable conditions in the Center to facilitate long-term stability of that valuable source population. The simulations also helped to highlight key gaps in our knowledge of the growth dynamics of wild populations; despite these data gaps, the modeling sharply focused experts' attention on the vulnerability of small, fragmented populations to future instability in the face of increasing threats from human disturbance (conversion of native grassland habitats to agricultural lands) and long-term changes to habitat availability through climate change.

Based on conclusions drawn from the PVA and from structured discussions across three working groups established early in the workshop (Threats to Habitat, Threats to Populations, and Human Sociocultural Issues), participants developed a detailed set of conservation goals and actions that, when implemented, can be expected to mitigate both biological threats to Hungarian meadow viper persistence

and non-biological challenges to effective conservation. By mitigating these threats and challenges, the status of the species across its range is expected to improve.

Highlighted conservation goals and actions from the three working groups are summarized below. The more detailed reports and recommendations from each working group can be found in the respective working group reports in this document.

Hungarian Meadow Viper Habitat: Threats and Their Management

Threat: Limited habitat area

Goal: In the next ten years, the available grasslands are expanded (through buying or renting) by at least 80 ha in Hanság National Park and 15 ha in Kiskunság National Park, so that Hungarian meadow viper populations can be stronger and grow in abundance.

Action: Buy or lease additional land in Hanság and Kiskunság National Parks to convert it from agricultural to grassland in the time-period of 2025-2027.

Action: Convert the leased or bought arable land in Hanság and Kiskunság National Parks to grassland in the time-period of 2028-2033.

Threat: Overgrazing, burning, mowing

Goal: Viper-friendly grasslands management: All sites have proper grassland management on 100% of the occupied grasslands in order to achieve strong and growing population of Hungarian meadow viper. This applies to grazing, burning and mowing of grasslands.

Action: Create a detailed viper-friendly grassland management plan for occupied sites in Romania starting in 2025.

Action: Revise and expand in detail existing grassland management plans for occupied sites in Hungary starting in 2024, through the yearly land-use plans, each following year.

Action: Implementation of yearly land-use plans on occupied sites in Hungary starting in 2024, each following year.

Hungarian Meadow Viper Populations: Threats and Their Management

Threat: Small, fragmented populations

Goal: Increase small populations to a minimum of 100 individuals with proper size space available and for positive growth for them within ten years, in order to reduce their vulnerability over the long-term.

Action: Define targeted populations and require measures for each viper population to reach suitable population size.

Action: Implement the measures defined above for each population by increasing habitat size and/or releasing vipers.

Goal: Increase the demographic connectivity of fragmented populations within ten years, increasing the ability of vipers to disperse and colonize while reducing genetic differentiation between populations.

Action: Identify obstacles to movement among wild Hungarian meadow viper populations in order to create connections between favourable habitats in the first three years.

Action: Remove obstacles between populations as defined above to create connections between favourable habitats in the next ten years.

Human Sociocultural Issues Impacting Hungarian Meadow Viper Conservation

Goal: Mitigate local land-use conflicts

Action: Ensure collaboration by setting up a platform for conservation experts and decision-makers and create decision-making criteria and protocols on how to decide on which species to protect in a certain area.
Action: Harmonize different management strategies by identifying the needs of each stakeholder and ensuring transparent two-way communication.

Goal: Promote long-term viper-friendly grassland management.
(Note that this goal overlaps with a similar goal from the Habitat working group; the focus here is on developing effective communication of the proposed management activity, and not development of the techniques.)

Action: Create guidelines describing how to implement viper-friendly management.

Action: Ensure and coordinate training for farmers and shepherds based on the above guidelines.

Introduction

The Hungarian meadow viper (*Vipera ursinii rakosiensis*) is a rare snake subspecies that once occupied a large range in the Pannonian steppe, from eastern Austria to western Romania. In the early years of this millennium, the viper was restricted to perhaps a dozen sites in Hungary and only a few sites in Romania (Edgar and Bird, 2006). Major factors leading to the decline of the viper included conversion of steppe habitat to agricultural land, intensive water management, and collection of individuals for trade.

In 2001 a population and habitat viability assessment (PHVA) workshop was conducted for the Hungarian meadow viper, organized and hosted by the Budapest Zoo and led by the IUCN's Conservation Breeding Specialist Group, now the Conservation Planning Specialist Group (Kovács et al., 2002). One of the main reasons for undertaking this project was the fact that, despite various legal protection measures and other dedicated conservation efforts, observed population trends suggested that the future survival of the species in Hungary was questionable. Many of the conclusions and recommendations developed at that workshop were included in the Species Conservation Plan, officially announced in 2004 by the Hungarian Ministry of Environment and Water Affairs (reference?).

Since the PHVA workshop, many achievements have improved the outlook for the viper in the wild: habitat restoration on National park lands, creation and operation of a dedicated *ex situ* breeding facility, reintroduction of vipers to restored habitats, and continuous monitoring of reintroduction sites and other key habitat areas. These activities were funded through consecutive LIFE-projects, funded by the European Commission and the Hungarian national government. The most recent funding period lasts until the end of 2024 and targeted the renewal of the Species Conservation Plan, setting a conservation work plan for the viper over the coming decades. As the original PHVA proved to be very helpful in assembling and analyzing species information and in drawing important conclusions to assist conservation planning, the participating organizations of the recent LIFE-project agreed that updating the conservation planning workshop process would be very useful once again in catalyzing positive outcomes for meadow viper conservation. The LIFE-Project also allocated a budget for covering costs for such an event, including extending invitations to key international experts in the taxon and in species conservation planning. Additionally, an updated conservation planning process would help species managers identify new or existing knowledge gaps, and how conservation priorities have changed since the first planning effort more than 20 years ago. The proposed planning revision would give an important boost to the existing conservation program, and would no doubt generate useful information that could be of interest to the broader audience of species conservation experts in the region.

Based on this recognized need, MME BirdLife Hungary and the Budapest Zoo invited the Conservation Planning Specialist Group (CPSG), part of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN), to design and facilitate a conservation planning workshop process for the Hungarian meadow viper. The planning process was based on CPSG's One Plan Approach (Byers et al. 2013) that emphasizes participation by a broad range of stakeholders and integrates both *in situ* and *ex situ* population management activities into a coherent set of conservation strategies and actions. The action plan that will be produced is intended to synthesize the best available science and information to critically assess prevailing circumstances and generate recommended priority near-term actions across (10 years) that advance the long-term strategic direction (100 years) towards recovery of the species within collaborating nations in Europe.

The Species Conservation Planning Workshop Process

Since its inception, CPSG has developed tools and processes to facilitate the One Plan approach, a method for integrated species conservation planning that considers all populations of the species, inside and outside their natural range, under all conditions of management (both *in situ* and *ex situ*), and engages all responsible parties and all available resources from the very start of any species conservation planning initiative. The One Plan approach aims to: establish strong partnerships; ensure that intensively managed populations are as useful as possible to species conservation; increase the level of trust and understanding among conservationists across all conditions of management of a species; accelerate the evolution of species planning tools; and lead species conservation towards the aspirations embodied in global biodiversity conservation targets. This approach has been accepted by the Species Survival Commission and the wider IUCN as the desired methodology for effective species conservation planning.

In addition, CPSG promotes the following set of principles that forms the foundation of any successful conservation planning process:

Plan to Act: The intent of planning is to promote and guide effective action to improve conservation management to save this species. This principle underpins everything we do.

Promote Inclusive Participation: People with relevant knowledge, those who direct conservation action, and those affected by that action are all key to defining conservation challenges and deciding how those challenges will be addressed. Inclusivity refers not only to who is included in the planning process, but also to how their voices are valued and incorporated.

Use Sound Science: Working from the best available science is crucial to good conservation planning. Using science-based approaches to integrate, analyze and evaluate this information supports effective decision making.

Ensure Good Design and Neutral Facilitation: Good species planning is designed to move diverse groups of people through a structured conversation in a way that supports them to coalesce around a common vision for the species and to transform this into an achievable, effective plan. Facilitators skilled in planning are essential in guiding these processes. Critically, neutral facilitation eliminates potential or perceived bias in the planning process, helping participants to contribute their ideas and perspectives freely and equally.

Reach Decisions Through Consensus: Effective species conservation planning results in decisions that all participants can support or accept. Recognizing shared goals, seeing the perspective of others, and proceeding by consensus helps galvanize participants behind a single plan of action that is more likely to be implemented.

Generate Shared Products Quickly: Producing and sharing the products of a conservation planning process quickly, freely and widely are important factors in its success. Delays carry a cost in terms of lost momentum, duplicated or conflicting effort or missed opportunities for action.

Adapt to Changing Circumstances: Effective plans are those that evolve in response to new evidence and knowledge, and to changing circumstances – biological, political, socio-economic, and cultural – that influence conservation efforts. Plans are considered living documents that are reviewed, updated and improved over time.

This approach to conservation planning encourages the development of a shared understanding across a broad spectrum of training and expertise. Importantly, CPSG's role as a neutral third-party facilitator encourages a more active level of intellectual participation by the appropriate national or regional management authorities. This neutrality should effectively reduce perceptions of any biased approach to developing stakeholder invitation lists and workshop process design by those entities tasked with implementing the resulting product. Consequently, these principles more effectively support the creation of functional working agreements that directly address the conservation problems at hand, along with the management decisions and actions required to mitigate those problems. As participants work as a group to appreciate the complexity of the conservation problems at hand, they take ownership of the process and of the management recommendations that ultimately emerge. This is essential if those recommendations generated by the workshop participants are to succeed.

Workshop process overview

The workshop was held 20 – 22 March 2024 at the Budapest Zoo. A total of 23 people attended the meeting, with the large majority of them participating for the full three days of analysis and discussions. Dr. Gergö Halmos (Director, MME BirdLife Hungary) opened the workshop, with Bálint Halpern (Project Manager, MME BirdLife Hungary) and Dr. Endre Sós (Director, Budapest Zoo) also giving opening remarks to participants. Dr. Philip Miller (Director of Science, Single-Species Planning) of the Conservation Breeding Specialist Group, serving as overall workshop facilitator, then gave a brief overview of CPSG and the organization's philosophical approach to species conservation planning.

Following these opening activities, a series of brief presentations were delivered that summarized species status and current management activities:

- Bálint Halpern: Species status in situ
- Dr. Endre Sos: Species status ex situ
- Gábor Takács: Management activities in Fertö-Hanság National Park
- Borbála Major: Management activities in Duna-Ipoly National Park
- Edvard Miszei: Management activities in Kiskunság National Park

Each of these presentations highlighted both successes resulting from past and present management efforts, as well as continued threats to viper populations and their habitats and the challenges to implementing effective conservation actions into the future.

Workshop participants then reviewed a conservation vision statement that had been developed during an earlier online workshop held 27 November 2023 and refined by a subset of online workshop participants soon thereafter. This vision describes the idealized future state of the species in the year 2100 and provides an aspirational target for long-term conservation of the meadow viper.

Dr. Lisa Faust (Lincoln Park Zoo, USA) then presented a detailed summary of a population viability analysis (PVA) that was conducted as part of the larger planning process. This PVA used computer simulation modeling techniques to evaluate current status of both in situ and ex situ populations, to assess the relative impacts of biological threats to future stability of those populations, and to critically evaluate the relative efficacy of proposed management alternatives designed to mitigate those threats. A series of in-depth discussions with species experts was conducted online December 2023 – March 2024 to assemble population demographic information, enumerate threats to species stability, and to solicit alternative management scenarios suitable for quantitative analysis. Results from this PVA were to, where appropriate, provide key evidence in order to inform specification of management recommendations developed by workshop participants.

After presentation and discussion of the PVA results, workshop participants were divided into thematic working groups to facilitate more detailed discussions and deliberations that would compose the remainder of the workshop. The working group topics were:

- Hungarian meadow viper habitat: Threats and their management
- Hungarian meadow viper populations: Threats and their management
- Human sociocultural issues impacting Hungarian meadow viper conservation

Each working group was first instructed to review the threats to the Hungarian viper that were appropriate to their topic, i.e., threats to the stability of viper populations or their habitats, and the challenges to effective viper conservation. Information developed in the preceding PVA effort held before the planning workshop was to be used here as a guide. Working groups were then asked to identify longer-term goals for meadow viper conservation as well as more detailed action steps designed to achieve those goals. These action steps were presented to the full plenary body of participants and subject to discussion. This report is the written record of those discussions and the conservation actions recommended to be advanced collectively by the group.

A Vision for Hungarian Meadow Viper Conservation

The development of a shared vision—or a desired future state—is a common approach to helping stakeholders define what success will look like in a conservation planning project. A vision statement should be aspirational, with those creating it encouraged to think about what a future could look like when conservation has been fully successful. Common components to consider integrating into a vision include the desired future geographic representation of the species, how dependent it is on human intervention, and how it interacts with and is valued by people.

Participants in the Hungarian meadow viper planning workshop agreed upon the final vision statement presented below. The original statement was developed beginning with the online planning workshop held in November 2023, with subsequent review and slight revision of the statement to improve clarity and meaning.

> *In the year 2100, the Hungarian meadow viper is thriving, without the need for direct human intervention, in multiple connected populations across their well-managed historic landscape. These viable populations are able to adapt to changing climatic conditions in a rapidly evolving world. The Hungarian meadow viper is an ambassador for grassland conservation in its native habitat, and local communities actively promote and support its conservation.*

Some participants noted that it may be unrealistic to expect that the species could thrive "...without the need for human intervention", and could be "...able to adapt to changing climatic conditions in a rapidly evolving world". While it may indeed be difficult to achieve these ambitious aims, these phrases were retained in the final version presented in this report in the spirit of creating an aspirational vision for long-term conservation that underlies all subsequent management activity.

A Summary of Threats to Hungarian Meadow Viper Viability

In the early stages of developing the population demographic model as part of the PVA, species experts identified and characterized the primary threats to continued persistence of Hungarian meadow viper populations across their current range. High-priority threats emerging from this exercise include:

- Conversion of viper habitat to arable land – plowing, etc. This form of grassland habitat destruction/degradation reduces both the quantity of suitable viper habitat and the quality of remaining habitat.
- Improper management of habitat – mowing, burning, and grazing. These activities also reduced viper habitat availability and suitability.
- Increasing density of invasive plant species. This introgression of non-native species reduces both habitat quality and availability of native prey.
- Habitat loss through increased urban development. A larger human footprint in rural grassland habitats reduces viper habitat quantity and quality.
- Increased predation pressure by native wildlife species. As the density of other native birds like hawks and mammals such as foxes and wild boar increases, rates of viper mortality rates can increase to unsustainable levels.

Threats considered to be comparatively lower priority but also important to address include:

- Decreasing water table, leading to reduced grassland habitat quality.
- Off-road vehicle use, which can both degrade viper habitat and lead to additional human-caused (anthropogenic) mortality.
- Reduced availability of native prey (rodents, insects, etc.), resulting in reduced level of successful reproduction and survival.
- Genetic isolation of local populations, which can lead to reduced fitness of populations through inbreeding.
- Disturbance of local habitats through ecotourism, leading to reduced grassland habitat quality and/or quantity.

In addition to these more contemporary threats, significant threats to Hungarian meadow viper in the longer-term include:

- Widespread impacts of climate change, which can increase the frequency of catastrophic events (droughts, floods, etc.) and alter normal patterns of temperature and rainfall and, consequently, lead to major changes in grassland habitat distribution and abundance.
- Continued expansion of the human population across Hungary, which would likely lead to high rates of urban development, conversion of native grasslands for agriculture, etc.
  [Editor's note: It is worthwhile noting here that recent projections show a likely decrease in human population abundance across Hungary over the next 75 years to 2100, perhaps related to a similar projection of increasing economic production as analyzed by the Organization for Economic Co-operation and Development, or OECD (Riahi et al. 2017; Samir and Lutz 2017; Dellink et al. 2017).

These threats, as well as others that were not identified in the earlier exercise, are discussed in more detail in the following sections. In addition, specific challenges to effective management of these threats – economic, political, social, cultural, etc. – are discussed, with recommended actions designed to address those impediments to effective conservation action. Finally, a digital database presenting detailed information on each known Hungarian meadow viper population across its known range, which includes data on estimated population abundances, trends, and threat intensity, is distributed in combination with this report.

Hungarian Meadow Viper Habitat: Threats and their Management

Participants: Boris Lauš (facilitator), Oscar Hadj-Bachir, Csenge Gulyás, Zoltán Vajda, Borbála Major, Gábor Takács, Dennis Rödder, Tibor Sos, Edvárd Mizsei, Márton Szabolcs, Dénes Nagy

Threats to Hungarian meadow viper habitat

1. Limited habitat area

   The surface area of current available grasslands in Hungary is not sufficient to support stable population of Hungarian meadow vipers. Restoration of previously occupied areas is needed.

   A recognized challenge to mitigating this threat: Are the owners of this additional land willing to sell or rent the land?

2. Uncontrolled grazing

   No proper management plans for controlled grazing. Not enough herders. In Hungary, there is a recognized need for smaller fenced parcels. In Romania, there is a need for restriction of the number of sheep.

   A recognized challenge to mitigating this threat: How to help National Parks and other managers of protected areas to enforce management plans?

3. Invasive alien plants

   These invasive species reduce habitat area and prey availability.

   A recognized challenge to mitigating this threat: How do we fill knowledge gaps in order to control alien species?

4. Shrub/forest overgrowth

   This overgrowth of unwanted species is reducing grassland area, promoting forest habitat development, reducing quality of habitats, starting fragmentation, and increasing predator pressure.

   A recognized challenge to mitigating this threat: How do we fill knowledge gaps in order to control alien species?

5. Frequent weather extremes

   These extreme events lead to changes in the affected plant community and in prey availability. In addition, the shifts in extremes ultimately lead to catastrophic events more frequently.

   A recognized challenge to mitigating this threat: How does the meadow viper successfully adapt to weather extremes?

6. Ground water level drop

   It's due to historic water management actions and current climate conditions. Leads to change in plant community, shrub overgrowth, and degradation of grassland habitat.

   A recognized challenge to mitigating this threat: How to persuade water management institutions to restore ground water level?

7. Insufficient protection level

   Not all sites in Hungary and Romania are within the borders of Natura 2000 or benefitting from a country-based level of protection. In addition, not all sites for *V. ursinii* are under protection.

   A recognized challenge to mitigating this threat: Are protected areas enough to maintain viable populations of *V. ursinii*? Is the government willing to increase the extent of protected areas?

8. Land-use type

   This threat arises from improper book-keeping, in other words, grasslands are sometimes classified as forest clearings or arable land.

   A recognized challenge to mitigating this threat: How to make changes in the register of land-use?

9. Mowing

   Since mowing is a more damaging activity to meadow viper habitat, it would be more beneficial to snake populations if local farmers were to switch completely to grazing activities.

   A recognized challenge to mitigating this threat: How do farmers ensure that they generate or procure enough hay for their animals to last through the winter? In addition, how can farmers reduce the number of mowing activities per year?

10. Burning

    In Romania, uncontrolled burning occurs throughout the year, which reduces habitat quality as vipers don't have enough vegetation cover to hide in, and prey availability is reduced.

    A recognized challenge to mitigating this threat: Is it possible to stop this tradition of burning grassland habitat, or is it at least possible to adjust it to reduce the rate of habitat degradation?

Goals and actions to mitigate threats to Hungarian meadow viper habitat

PRIORITY THREATS

Threat 1: Limited habitat area

Goal: In the next ten years, the available grasslands are expanded (through buying or renting) by at least 80 ha in Hanság and 15 ha in Kiskunság, so that Hungarian meadow viper populations can be stronger and grow in abundance.

Action 1.1. Buy or lease additional land in Hanság and Kiskunság to convert it from agricultural to grassland in the time-period of 2025-2027.

Responsibility: Kiskunság and Hanság National Park Directorates

Timeline: 2025 – 2027

Measurable: 80 ha of land in Hanság and 15 ha in Kiskunság were leased or bought, contracts with the owners were signed, management rights are assigned to NATIONAL PARKs

Collaboration or partners: National parks, land owners, National land management institution, Ministry of agriculture

Resources: 1.000.000 EUR for land in Hanság, 120.000 EUR in Kiskunság, if leased for 100 years price is approximately the same, payment could be yearly in rates (or however is stated in the contract)

Personnel/time: 30 days of work, 1 personnel per National Park, few hours of work for legal department of the National Parks

Consequences of inaction: Habitats are not expanded and not sufficient to support larger population of Viper

Obstacles: some landowners are not willing to sell, politicians are stopping the possible expropriation process, lack of funds.

Action 1.2. Convert the leased or bought arable land in Hanság and Kiskunság to grassland in the time-period of 2028-2033.

Responsibility: Two National Parks (Kiskunság and Hanság)

Timeline: 2028 – 2033

Measurable: 80 ha of land in Hanság and 15 ha in Kiskunság were converted from arable to grasslands, coverage of native plants is at least 60 % on monitoring plots, at least 25 % of seeded plant species are detected (some pioneer plant species might grow faster than seeded plant species)

Collaboration or partners: National parks, external contractors for collecting, sawing

Resources: 40.000 EUR for seeds for both Kiskunság and Hanság (harvester machine + operating person to collect seeds from existing grasslands), 25.000 for seed sawing, post treatment after seeding is 150.000 EUR (treatments last for 3 years)

Personnel/time: 2 weeks of supervising the harvest (in Kiskunság), 2 months in Hanság, for sawing 2 days of supervising in Kiskunság, one week in Hanság, treatments supervision one week in Hanság per year (x3), in Kiskunság 2 days each year.

Consequences of inaction: Invasive plant species can occupy arable land that was not converted

Obstacles: extreme draughts are reducing the amount of necessary seeds, slowing the process of seed growing.

Threat 2: Overgrazing, burning, mowing

Goal: Viper-friendly grasslands management: All sites have proper grassland management on 100 % of the occupied grasslands in order to achieve strong and growing population of Hungarian meadow viper. This applies to grazing, burning and mowing of grasslands.

Action 2.1. Create a detailed viper-friendly grassland management plan for occupied sites in Romania starting in 2025.

Responsibility: MILVUS group

Timeline: 2025 – 2026 (one year)

Measurable: Management plans for 8 sites

Collaboration or partners: Milvus group, ANAMP institution, Ministry of environment, Ministry of agriculture

Resources: personnel and travel expenses, expenses for meetings with stakeholders

Personnel/time: 2 personnel from Milvus group, 30 % of their time

Consequences of inaction: We cannot implement viper friendly management actions, nobody knows their role and what to do.

Obstacles: some stakeholders are not willing to participate, implementation is questionable and needs to be resolved, lack of necessary knowledge what is Viper friendly management for Romanian habitats.

Action 2.2. Revise and expand in detail existing grassland management plans for occupied sites in Hungary starting in 2024, through the yearly land-use plans, each following year.

Responsibility: Three national parks in Hungary (Kiskunság, Hanság, Duna-Ipoly)

Timeline: Each year starting in 2024.

Measurable: 3 yearly land-use plans each year, plans are finished in April

Collaboration or partners: Three national parks, BirdLife Hungary

Resources: One week for each national park for each year

Personnel/time: One person from each National Park, one week

Consequences of inaction: Improper land use, overgrazing

Obstacles:

Action 2.3. Implementation of yearly land-use plans on occupied sites in Hungary starting in 2024, and in each following year.

Responsibility: Three national parks in Hungary (Kiskunság, Hanság, Duna-Ipoly)

Timeline: Each year starting in 2024.

Measurable: Each land-use plan is successfully implemented, grasslands are monitored each year, there is less than 5% of area that was overgrazed.

Collaboration or partners: Three national parks, land-use contractors

Resources: Monitoring – one person for 2 months per year in Kiskunság, in Hanság 4 people to manage the fences whole year, 3 people/machine operators/4 tractors for 7 months, 2 rangers are doing monitoring for 2 months per year (few days in those 7 months), external farmer (1) who has 2 sheperds, one ranger is monitoring every two weeks during season (April-October)

Personnel/time: (separate it later)

Consequences of inaction: Improper land use, overgrazing

Obstacles: Contractors for land-use are not following the land-use plan properly

Threat 3: Invasive alien plants

Goal: All sites in Hungary have continuous invasive plant control in areas occupied by Hungarian meadow vipers in the next ten years, so available habitats would not loose quality and surface area.

Action 3.1. Continuation of alien species control in Kiskunság, Hanság and Duna-Ipoly and start of control in additional 500 ha in Kiskunság and 400 ha in Hanság, with monitored results each year.

Responsibility: Three National Parks

Timeline: Each year for continuation, and new areas from 2025 each year

Measurable: Alien plant species controlled in designated areas each year

Collaboration or partners: Three National Parks, external contractors

Resources: 2.000 – 50.000 EUR per year in Hanság for external contractors, 500 EUR per ha per year in Kiskunság,

Personnel/time: no extra personnel required as it is covered through action for mowing and grazing

Consequences of inaction: alien plants will overgrow the grasslands, degradation of habitat, change of plant community, lesser resilience to environmental changes

Obstacles: lack of funding, knowledge gap in case of appearance of new alien plants, weather extremes can lower the effectiveness of alien plant control

Action 3.2. Maintenance of existing wild boar fences in three National Parks and building new fences in 2000 ha Kiskunság, 200 ha in Hanság, 10 ha in Duna-Ipoly

Responsibility: Three National Parks

Timeline: Maintenance in all National Parks each year, reparations every 5 years, new areas in Kiskunság, Hanság and Duna-Ipoly will be fenced 2025 - 2030

Measurable: Maintained fences in all existing fenced areas, new fences erected in 2000 ha in Kiskunság, 200 ha in Hanság and 10 ha in Duna-Ipoly

Collaboration or partners: Three National Parks, external contractors for building

Resources: price of the fence and building it: 26.000 EUR for Duna-Ipoly, 20 EUR per meter in Kiskunság and Hanság

Personell/time: one person in each park every two days to check the fences

Consequences of inaction: wild boar dig the soil, make changes in plant community, facilitate the expansion of alien plants

Obstacles: lack of funding

Threat 4: Shrub/forest overgrowth

Goal: In the next ten years all sites have continuous maintenance against shrub spreading, and additional XY ha of grasslands are cleared from shrubs.

Action 4.1. Monitoring and continuously removing shrubs to keep it under 10 ha in surface on 200 ha of grasslands in Duna-Ipoly National Park and appropriate surface area in Kiskunság and Hanság National Parks each year (*Crataegus, Prunus spinoza, Salix*)

Responsibility: Three National Parks

Timeline: Each year

Measurable: maximum 10 ha of shrubs in 200 ha of grasslands in Duna-Ipoly, appropriate number of shrubs on grassland surface area in Kiskunság and Hanság,

Collaboration or partners: Three National Parks, external contractors

Resources: Kiskunság and Duna-Ipoly 800 EUR per ha, 1700 EUR per ha in Hanság for first cutting, 250 EUR for second and third cutting

Personell/time: one person few days per year to check the progress of removal activities

Consequences of inaction: shrubs overgrowing grasslands, change surface area of grasslands, fragment grassland habitat

Obstacles: lack of funding

Goal: In the next ten years all trees are removed from the 300 ha of grasslands occupied by the Viper in Kiskunság in order to maintain habitat quality and reduce predation pressure.

Action 4.2. Monitoring and appropriately removing trees on 1.5 ha of grasslands in Duna-Ipoly National Park and appropriate surface area in Kiskunság and Hanság National Parks each year. (*Populus alba, Ailanthus, Acer, Robinia, Alnus, Fraxinus*)

Responsibility: Three National Parks

Timeline: Every two year monitoring, removal as needed

Measurable: 1.5 ha cleared of trees in Duna-Ipoly, appropriate number of ha of trees on grassland surface area in Kiskunság and Hanság, *Collaboration or partners*: Three National Parks, external contractors

Resources: 2.000 EUR per ha for chemicals, 500 EUR for cutting down the trees

Personnel/time: one person few days per year to check the progress of removal activities

Consequences of inaction: trees overgrowing grasslands, change surface area of grasslands, fragment grassland habitat, predator increase

Obstacles: lack of funding

Threat 5: Ground water level drop

Goal: In the next ten years ground water levels are sufficient to support *Molinia* meadows as a seasonal habitat for the Hungarian meadow viper.

Action 5.1. Build at least 30 retention structures within 15 existing canals in Kiskunság, within 2025 – 2030 timeframe

Responsibility: Kiskunság National Park

Timeline: 2025 – 2030

Measurable: the yearly water level minimum have rised for at least 25 cm

Collaboration or partners: Kiskunság National Park, external contractor

Resources: ca 10.000 EUR for planning and permits, 80.000 EUR for implementation of activities, personnel 1 person 20% for 2 years for monitoring

Personnel/time:

Consequences of inaction: Water level dropping, degradation of habitat, draught consequences are stronger

Obstacles: if National Park doesn't get the permit.

OTHER THREATS

Threat 6: Frequent weather extremes

Goal: Areas that are more susceptible to negative effects of weather extremes are recognized

Goal: Plant communities of occupied grasslands are functionally diverse and resilient to weather extremes

Action 6.1. Enhance plant diversity on secondary grasslands (30 ha in FHNPD, 1200 ha in KNPD)

Responsibility: Kiskunság National Park, Hanság National Park

Timeline: 2025 – 2030

Measurable: seed sowing done 3 ha of land in Hanság and 120 ha in Kiskunság, at least 25 % of seeded plant species are detected

Collaboration or partners: Kiskunság National Park, Hanság National Park, external contractor

Resources: cca 5000 EUR/a for implementation of activities, 615 000 EUR

Personell/time: 2 weeks of supervising the harvest (in Kiskunság), 2 months in Hanság, for sawing 2 days of supervising in Kiskunság, one week in Hanság, treatments supervision one week in Hanság per year (x3), in Kiskunság 2 days each year.

Consequences of inaction: habitat is not resilient to maintain quality due to drought

Obstacles: extreme droughts are reducing the amount of necessary seeds, slowing the process of seed growing.

Threat 7: Insufficient protection level

<u>Goal</u>: In the next ten years all known sites of suitable areas are legally protected in HU and RO.

<u>Action 7.1.</u> Establish spatial protection on all habitats

Habitats will be surveyed and all habitats are recognized. Proposals will be prepared and submitted to Ministry.

Responsibility: Milvus Group, KD

Timeline: 2025 - 2030

Measurable: all potential sites are surveyed with sufficient effort to detect the species, all sites are covered by protected area

Collaboration or partners: Ministry-government

Resources: 4WD truck 40000 EUR, travel costs 30000 EUR, equipment 5000 EUR

Personnel/time: 2 person, full time for three years

Consequences of inaction: loss of habitats

Obstacles: low detection probability of the species, lack of funding, lack of human resources, lack of interest from the side of the government

Threat 8: Land-use type

<u>Goal</u>: Land use types are corrected in the proper registry for all the parcels with grasslands in protected areas in HU and RO.

<u>Action 8.1.</u> Check and correct land parcel registry

Identify owner, land use type of all parcel within viper habitats. We will make a proposal to the Ministry to change land use type in cases of grasslands in reality and arable fields in the registry.

Responsibility: Milvus Group, KNPD

Timeline: 2025 - 2026

Measurable: all sites are registered as grassland

Collaboration or partners: Ministry-government

Resources: 30000 EUR personnel

Personnel/time: 1 person, full time for one year

Consequences of inaction: grassland converted to arable fields, loss of habitats

Obstacles: lack of interest from the side of the government

Hungarian Meadow Viper Populations: Threats and their Management

Participants: Sylvain Ursenbacher (facilitator), Endre Sós, Ivona Buric, Marc-Antoine Marchand, Gergő Erdélyi, Viktória Sós-Koroknai, Bálint Halpern

Threats to Hungarian meadow viper populations

1. Small fragmented populations
    - Lack of metapopulation structure and dynamics (possibility to recolonize)
    - Lack of resilience to catastrophic events (fire, drought, flood)
    - Low genetic diversity – lack of resilience
    - Illegal collection and human disturbance
2. Increased predation pressure – mammals
    - lack of game management
    - feral cats
    - philosophic and ethical considerations
    - careful communication of predator removal towards the public
    - intelligent predators – how to define optimal release strategy
3. Increased predation pressure – birds
    - protection status of the predatory birds
        - question of active disturbance of potential predators
        - careful communication towards hunters
4. Climate change
    - spatial challenges of range shift
    - increased frequency and effect of catastrophic events
    - negative change in habitat structure
    - altered dispersal abilities to find optimal resources
5. Population health
    - Ex situ
        - disease occurrence, transmission through release, no defined health protocol
        - define optimal husbandry technique
        - single facility is vulnerable
    - In situ
        - emerging diseases (Snake Fungal Disease, …)
6. Low food availability
    - low or no reproduction
    - increased age- and sex-specific mortality
    - disease affecting prey species
7. Key knowledge gaps
    - Survival rate (annual, seasonal, demographic level)
    - carrying capacity (maximum viable population size)
    - optimal habitat and demographic parameters
    - location specific release strategy
    - minimum separation distance between populations (dispersal capability)
    - what do we consider an impenetrable obstacle between populations
    - food preference (age-specific and population level differences)

8. Difficulty in maintaining positive conservation momentum
    - despite promising results to maintain achievements (proper management, monitoring,…)

Goals and actions to mitigate threats to Hungarian meadow viper populations

Threat 1: Small, fragmented populations

Goal: Increase small populations to a minimum of 100 individuals with proper size space available and for positive growth for them within ten years, in order to reduce their vulnerability over the long-term.

Action 1.1. Define targeted populations and require measures for each viper population to reach suitable population size.

Responsibility: MME BirdLife Hungary

Timeline: One year

Measurable: list of targeted population and actions set up for each of them

Collaboration or partners: Researchers

Resources: Personnel

Personnel/time: Biologist, biostatistician

Consequences of inaction: Add later

Obstacles: Lack of agreement about measures to be done

Action 1.2. Implement the measures defined in Action 1.1. for each population by increasing habitat size and/or releasing vipers.

Responsibility: MME BirdLife Hungary, National Parks, national authorities

Timeline: 2025 - 2035

Measurable: Number of populations which have a documented increase in habitat size

Collaboration or partners: Researchers, MME BirdLife Hungary

Resources: Funding of personnel

Personnel/time: One full-time manager for ten years

Consequences of inaction: Populations are not viable

Obstacles: Lack of funding

Goal: Increase the demographic connectivity of fragmented populations within ten years, increasing the ability of vipers to disperse and colonize while reducing genetic differentiation between populations.

Action 1.3. Identify obstacles to movement among wild Hungarian meadow viper populations in order to create connections between favourable habitats in first three years.

Responsibility: MME BirdLife Hungary

Timeline: 2025 – 2027

Measurable: Categorization and localization of obstacles regarding vipers

Collaboration or partners: National Parks, research institutions

Resources: Funding personnel

Personnel/time: One GIS specialist for six months

Consequences of inaction: Fragmentation is maintained

Obstacles: Lack of quality GIS data

Action 1.4. Remove obstacles that are defined after in Action 1.3 between populations for connection of favourable habitat in next ten years.

Responsibility: National Parks and authorities

Timeline: 2025 - 2035

Measurable: Number of populations and areas that are functionally connected

Collaboration or partners: Research Institutions, MME Bird Life Hungary, local stakeholders, land owners

Resources: Funding personnel, equipment

Personnel/time: Dependent on the extent and number of obstacles after data are collected per Action 1.3

Consequences of inaction: Fragmentation is maintained

Obstacles: Cost-benefit ration, lack of adequate resources, lack of adequate research interest

Threat 2: Increased predation pressure

Goal: Reduce predators and improve released vipers' ability to avoid predators within 5 years, increasing survival rate of viper populations and higher post-release survival of introduced vipers.

Action 2.1. Expand the predator exclusion fencing for 100 ha in Hanság area for three land parcels in five years

Responsibility: Fertő-Hanság National Park

Timeline: 2025 – 2030

Measurable: Number and extent of established predator exclusion areas in the National Park

Collaboration or partners: MME BirdLife Hungary

Resources: Funding personnel, equipment, 20 EUR/meter to install the fence

Personnel/time: Two days of planning, 2 – 3 people / year for maintenance

Consequences of inaction: Increased viper mortality

Obstacles: Lack of adequate funding and/or manpower for maintenance

Action 2.2. Set up approximately 50 km of wild boar electric fencing in Kiskunság, Bugac, in five years

Responsibility: Kiskunság National Park

Timeline: 2025 - 2030

Measurable: Linear extent of installed fence, and area covered/protected by fences

Collaboration or partners: Land owners, local farmers, MME BirdLife Hungary

Resources: Funding personnel, equipment, 20 EUR/meter to install the fence

Personnel/time: Two days of planning, 1 – 2(?) people / year to maintain

Consequences of inaction: Extended disturbance by wild boar

Obstacles: Lack of adequate funding and/or manpower for maintenance

Action 2.3. Monitor presence of bird of prey nests on all viper habitats in the spring of each year; if there are many nests don't release vipers that year or put adisturbance system on viper habitats.

Responsibility: National Parks

Timeline: 2025 – 2035

Measurable: Number of days of disturbance by raptors (bird of prey), number of nests detected

Collaboration or partners: MME BirdLife Hungary, local volunteers

Resources: Personnel, equipment, 500 EUR per disturbance system, 1 automated camera trap to monitor the system (cost unknown)

Personnel/time: Two weeks, one biologist per site, one day to install the system and three months each year per maintenance

Consequences of inaction: Higher viper mortality

Obstacles: Conservation priority conflicts, such as bird protection efforts

Action 2.4. Develop an anti-predator training protocol in the Hungarian Meadow Viper Conservation Center – train the vipers and test the anti-predator behaviour before releasing vipers in the wild

Responsibility: MME BirdLife Hungary

Timeline: 2026 – 2031

Measurable: Percentage of vipers to have an observed change in their reaction to a nearby bird of prey

Collaboration or partners: National Parks, researchers

Resources: HMVCC personnel, raptor trainer, material (cost unknown)

Personnel/time: One person ever year during the season

Consequences of inaction: Vipers release efforts remain limited by predation pressure

Obstacles: Lack of adequate funding, failure in training, no measurable effect of training

Threat 3: Population health

Goal: Set up and early detection protocol of potential pathogens for screening natural populations within three years, in order to avoid the negative impacts and/or spread of any disease.

Action 3.1. Maintain oversight of population heath in the HMVCC and have regular check-up of 10 % of animals that will be released

Responsibility: Budapest ZOO

Timeline: Ongoing – each time before release to the wild

Measurable: Number of individuals tested

Collaboration or partners: Local and/or national laboratories

Resources: Cost per sample unknown

Personnel/time: One veterinarian, 5 – 10 days per year

Consequences of inaction: Individuals in the breeding center are infected with pathogens

Obstacles: Lack of adequate time for proper sampling and testing

Action 3.2. Take a minimum of 20 samples from wild population in three region (Hanság, Upper Kiskunság, Bugac) first year for baseline data and. following years, screen 10 samples per region every year.

Responsibility: MME BirdLife Hungary

Timeline: 2025 – 2035

Measurable: Number of individuals tested, number of pathogens detected

Collaboration or partners: Budapest ZOO, veterinarians

Resources: 150 EUR per animal to conduct metagenomic analysis

Personnel/time: One field biologist for 30 days, one veterinarian for five days

Consequences of inaction: The individuals are affected with pathogens and population health is declining

Obstacles: Lack of adequate knowledge of viper pathogens

Threat 4: Climate change

Goal: Impacts of climate change* are mitigated within ten years, increasing the resilience of Hungarian meadow viper populations and resulting in stable population sizes within ten years.

* Reduce spatial challenges of range shift enabling dispersal to find optimal resources and introduce prevention measures targeting reduction or elimination of the effect of potential catastrophic events (fire, drought, flood) within 10 years

Action 4.1. Make buffer zones around grassland to allow vipers to spread out: no chemicals from agriculture, water access, shelters access, micro-habitat providing shade and humidity (bushes and trees) to mitigate impact of climate change on Hungarian meadow viper populations in the next 10 years.

Responsibility: National Parks

Timeline: 2025 – 2035

Measurable: Surface area of buffer zones created and the ratio of buffer zones where viper-friendly measures are applied

Collaboration or partners: MME BirdLife Hungary, public authorities, land owners and land users

Resources: GIS expert, local National Parks

Personnel/time: one GIS expert for planning over a few months, and a manager for three months / year / buffer zone

Consequences of inaction: Lack of possibilities to find alternative habitat while the actual suitable one become unsuitable

Obstacles: Land ownerw do not agree to create buffer zone, climate change is too extreme and no habitat will remain suitable anymore, with no alternative habitat options in buffer zone

Action 4.2. Create “fire breaks” for fire prevention to eliminate the effect of fire on viper habitats

Responsibility: National Parks

Timeline: 2025 – 2035

Measurable: Number of fire breaks created

Collaboration or partners: Public authorities, land owner and land users, MME BirdLife Hungary

Resources: Personnel, equipment

Personnel/time: One GIS expert for planning / a few month and helpers to create this breaks

Consequences of inaction: An increase in significant fire events over larger areas

Obstacles: Lack of adequate commitment to conduct the work

Action 4.3. Define and apply proper water management of each viper habitat over the next 10 years.

Responsibility: National Parks and water management authorities

Timeline: 2025 - 2035

Measurable: For each habitat, minimum water management requirements and maximum tolerated water level are defined, number of water management objects

Collaboration or partners: Land owners and land users

Resources: Personnel, equipment

Personnel/time: One GIS expert for planning, one botanist, one hydrologist, one engineer (xx days per site)

Consequences of inaction: Reduced viper reproductive success due to lack of adequate water

Obstacles: Lack of accessible water due to climate change

Human Sociocultural Issues Impacting Hungarian Meadow Viper Conservation

Participants: Ann-Katrine Garn (facilitator), Anna Egerer, Judit Vörös, Georgiana Păun, Borbála Kocsis, Eszter Kovács, Örs Ábrám, Ágnes Kalóczkai

Goals and actions to address human sociocultural issues impacting viper conservation

Goal 1. Mitigate local land-use conflicts

Action 1.1. Ensure collaboration by setting up a platform for conservation experts and decision-makers and create decision-making criteria and protocols on how to decide on which species to protect in a certain area

Responsibility: Hungarian Meadow Viper Conservation Coordination Group (HMVCCG)

Timeline: End of 2024

Measurable: The platform has been set up. Protocol written and criteria listed. The platform will meet when needed but at least every once a year. Decision minutes recorded and circulated to the wider group.

Collaboration or partners: HMVCCG, project coordinators, species experts

Resources:

Personnel/time:

Consequences of inaction: declining viper-friendly habitats, loss of vipers, escalating conflicts

Obstacles: If a leader is not identified, the platform will not be operational

Action 1.2. Harmonize different management strategies by identifying the needs of each stakeholder and ensuring transparent two-way communication

Responsibility: HMVCCG

Timeline: After the establishment of Action 1.1.

Measurable: Needs of each stakeholder identified; for example, SWOT analysis and two-way, transparent communication are in place by holding annual forums.

Collaboration or partners: HMVCCG, farmers, game managers, forestries, conservation experts, National Parks, municipalities

Resources:

Personnel/time:

Consequences of inaction: If a lead is not identified, then the analysis will not happen, the needs will not be identified, and conflicts will remain or even escalate, which can lead to the loss of viper habitat.

Obstacles: The lack of will to communicate between stakeholders

Goal 2. Promote long-term viper-friendly grassland management
(Note that this goal overlaps with Action 2.1 of the Habitat working group; the focus here is on developing effective communication of the proposed management activity, and not development of the techniques.)

Action 2.1. Create guidelines describing how to implement viper-friendly management

Responsibility: Grassland management and viper experts

Timeline: End of 2024

Measurable: Guidelines for viper-friendly grasslands management are in place

Collaboration or partners: HMVCCG, farmers, (game managers), conservation experts, National Park rangers

Resources:

Personnel/time:

Consequences of inaction: Mismanagement of grassland, loss of HMV habitats

Obstacles: The lack of will to collaborate and communicate, too many competing interests among different stakeholders

Action 2.2. Ensure and coordinate training for farmers and shepherds based on the guidelines

Responsibility: MME BirdLife Hungary

Timeline: After completion of Action 2.1

Measurable: One training course per area, additional advice provided when needed. Evaluation based on regular monitoring of land use.

Collaboration or partners: MME, farmers, National Park rangers

Resources:

Personnel/time:

Consequences of inaction: Loss of viper-friendly habitat, lack of knowledge of farmers

Obstacles: Lack of resources at MME, resistance of farmers

Action 2.3. Create effective compensation programs and financial incentives to promote effective grasslands management

Responsibility:

Timeline:

Measurable:

Collaboration or partners:

Resources:

Personnel/time:

Consequences of inaction:

Obstacles:

Action 2.4. Construct a viper-friendly product brand or certification

Responsibility: MME BirdLife Hungary

Timeline: 2025 and beyond

Measurable: Brand/certification is established, farmers are involved, and a marketing campaign is running

Collaboration or partners: MME BirdLife Hungary, farmers, marketing specialists

Resources:

Personnel/time:

Consequences of inaction: Lack of awareness, lack of dedication

Obstacles: Lack of funding/resources, lack of knowledge on certification, no public interest

Goal 3. Increase public awareness about Hungarian meadow vipers and change the way people perceive them

Action 3.1. Develop effective methods of communication about the vipers through different platforms

Responsibility: MME BirdLife Hungary

Timeline: 2024 and beyond

Measurable: All local schools have received viper talks, viper-friendly products are selling well, and a national campaign has been created, several events are held, social media is widely used

Collaboration or partners: MME BirdLife Hungary, marketing specialists, zoos, local schools, farmers, celebrities/ influencers, communication students

Resources:

Personnel/time:

Consequences of inaction: Lack of awareness, lack of money from fundraisers, no positive behavioral change towards viper

Obstacles: Lack of resources, lack of partner engagement

Goal 4. Establish a network for the conservation of the HMV in Romania based on the knowledge from Hungary

Action 4.1. Contact and engage the different groups by knowledge sharing and supporting the establishment of a HMVCCG in Romania

Responsibility: Viper experts in Romania

Timeline:

Measurable: The network exists, knowledge sharing between Hungary and Romania

Collaboration or partners: MME BirdLife Hungary, HMVCCG Hungary, Romanian viper experts, IUCN Viper specialist group, Romanian conservation experts, NGOs, Romanian ministry, volunteers

Resources:

Personnel/time:

Consequences of inaction: No effective network, no knowledge sharing, less vipers

Obstacles: No engagement by the partners, lack of adequate funding

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Appendix I: Workshop Participants

Last Name	First Name	Email address	Institution	Position / Field of Research
Ábrám	Örs	orsabram@gmail.com	MATE - Hungarian University of Agriculture and Life Sciences	Ecosystem services
Buric	Ivona	ivona.buric@hhdhyla.hr	Association Hyla	Vipera ursinii macrops
Egerer	Anna	egerer.anna@mme.hu	MME BirdLife Hungary	Organizer, communication manager
Erdélyi	Gergő	erdelyigergo14@gmail.com	MME BirdLife Hungary	Zoological Information Management System (ZIMS)
Faust	Lisa	lfaust@lpzoo.org	IUCN SSC Conservation Planning Specialist Group	PVA analyst
Garn	Ann-Katrine	akg@zoo.dk	IUCN SSC Conservation Planning Specialist Group	Facilitator
Gulyás	Csenge	gulyas.csenge@fhnp.hu	Fertő-Hanság National Park Directorate	Project coordinator
Hadj-Bachir	Oscar	oscar.hadj-bachir@cen-paca.org	CEN Provence-Alpes-Côte d’Azur	Vipera ursinii
Halpern	Bálint	halpern.balint@mme.hu	Eötvös Loránd University (ELTE)	Project manager, organizer
Kocsis	Borbála	kocsis.borbala@zoobudapest.com	Budapest Zoo & Botanical Garden	Zoological Information Management System (ZIMS)
Kovács	Eszter	kovieszti@gmail.com	MATE - Hungarian University of Agriculture and Life Sciences	Ecosystem services
Lauš	Boris	boris.laus@hhdhyla.hr	Association Hyla	Vipera ursinii macrops
Major	Borbála	majorb@dinpi.hu	Duna-Ipoly National Park Directorate	Project coordinator
Marchand	Marc-Antoine	marcantoine.marchand@cen-paca.org	CEN Provence-Alpes-Côte d’Azur	Vipera ursinii
Miller	Philip	pmiller@cpsg.org	IUCN SSC Conservation Planning Specialist Group	Workshop facilitator
Mizsei	Edvárd	edvardmizsei@gmail.com	Kiskunság National Park Directorate	Project coordinator
Nagy	Dénes	nagy.denes@mme.hu	MME BirdLife Hungary	Head of nature conservation department
Păun	Georgiana	paun.georgiana93@gmail.com	Milvus Group – Bird and Nature Protection Association	Vipera ursinii rakosiensis
Rödder	Dennis	d.roedder@leibniz-lib.de	Museum Koenig Bonn	Species Distribution Modelling
Sos	Tibor	tibor.sos@gmail.com	Milvus Group – Bird and Nature Protection Association	Vipera ursinii rakosiensis
Sós, Dr.	Endre	drsos@zoobudapest.com	Budapest Zoo & Botanical Garden	Director, Director of Conservation and Veterinary Services
Takács	Gábor	pokasz@gmail.com	Fertő-Hanság National Park Directorate	Project coordinator
Tokody	Béla	tokody.bela@mme.hu	MME BirdLife Hungary	Ornithologist, GPS tracking of birds
Ursenbacher	Sylvain	sylvain.ursenbacher@infofauna.ch	Info Fauna Karch	Conservation genetics, filogenetics
Vajda	Zoltán	vajdaz@knp.hu	Kiskunság National Park Directorate	Conservation expert
Vörös	Judit	voros.judit@nhmus.hu	Hungarian Natural History Museum	Curator of Herpetology Collection at Hungarian Natural History Museum

Appendix II: Workshop Agenda

Hungarian Meadow Viper (*Vipera ursinii rakosiensis*) A Species Conservation Planning Workshop

20 – 22 March, 2024
Cave Hall – Budapest Zoo, Budapest, HUNGARY

WORKSHOP AGENDA

Meeting Purpose: To review and update the current conservation action plan for the Hungarian meadow viper, which is developed in collaboration with Hungarian wildlife management authorities and species experts working in both *in situ* (wild) and *ex situ* (captive) population biology and conservation.

DAY ONE: 20 March 2024

8:00	Workshop registration
9:00	Workshop opening; logistics
9:15	Participant introductions; overview of agenda; introduction to CPSG: *Phil Miller*
10:00	Background presentations Review of species status – in situ and ex situ: *Bálint Halpern, Endre Sos* Overview of current conservation management activity across the species' range The conservation vision for Hungarian meadow viper from Workshop 1 (November 2023): *Phil Miller*
10:45	Coffee / tea break
11:00	Population viability analysis of the Hungarian meadow viper – Model structure, interpretation of results, and implications for conservation: *Lisa Faust*
12:30	Introduction to analysis of threats and challenges to Hungarian meadow viper population viability
13:00	Lunch (at Budapest Zoo)
14:00	Introduction to working group dynamics; working group formation
14:30	Working Group session 1: Threats and challenges to Hungarian meadow viper conservation
16:00	Coffee / tea break
16:30	Plenary Session 1: Working group reports on identification of threats and challenges
17:30	Adjourn
18:30	Dinner with workshop participants

Hungarian Meadow Viper (*Vipera ursinii rakosiensis*)
A Species Conservation Planning Workshop

20 – 22 March, 2024
Cave Hall – Budapest Zoo, Budapest, HUNGARY

WORKSHOP AGENDA

Meeting Purpose: To review and update the current conservation action plan for the Hungarian meadow viper, which is developed in collaboration with Hungarian wildlife management authorities and species experts working in both *in situ* (wild) and *ex situ* (captive) population biology and conservation.

DAY TWO: 21 March 2024

8:00	Workshop registration
9:00	Review of Workshop Day 1: *Phil Miller*
9:15	Working Group session 2: Introduction to setting conservation goals; Identifying and prioritizing conservation goals for the Hungarian meadow viper (available during this session)
11:00	Coffee / tea break
11:30	Plenary session 2: Working group reports on prioritized conservation goals
12:30	Plenary prioritization of conservation goals across working groups
13:00	Lunch (at Budapest Zoo)
14:00	Working Group session 3: Introduction to developing conservation actions; Specifying conservation actions for the Hungarian meadow viper (Coffee / tea available during this session)
16:30	Plenary session 3: Working group updates on identification of conservation actions
17:30	Adjourn

Hungarian Meadow Viper (*Vipera ursinii rakosiensis*)
A Species Conservation Planning Workshop

20 – 22 March, 2024
Cave Hall – Budapest Zoo, Budapest, HUNGARY

WORKSHOP AGENDA

Meeting Purpose: To review and update the current conservation action plan for the Hungarian meadow viper, which is developed in collaboration with Hungarian wildlife management authorities and species experts working in both *in situ* (wild) and *ex situ* (captive) population biology and conservation.

DAY THREE: 22 March 2024

8:00	Workshop registration
9:00	Review of Workshop Days 1 and 2: *Phil Miller*
9:15	Working Group session 4: Specifying conservation actions for the Hungarian meadow viper (continued from Day 2); Finalize presentation of conservation actions in afternoon plenary session (Coffee / tea available during this session)
11:00	Coffee / tea break
13:00	Lunch (at Budapest Zoo)
14:00	Plenary session 4: Presentation of conservation actions for the Hungarian meadow viper
14:45	Coffee / tea break
15:00	Plenary session 5: Implementation of the Hungarian meadow viper action plan; next steps
17:30	Workshop closing
18:30	Dinner with workshop participants

OPTIONAL FIELD TRIP: 23 March 2024

8:30	Departure (travel details will be announced later)
10:00	Visit to the Hungarian Meadow Viper Conservation Center and nearby habitats
14:00	Lunch
17:00	Arrival back to Budapest

Appendix III: Population Viability Analysis Report

Hungarian Meadow Viper
(*Vipera ursinii rakosiensis)*
Population Viability Analysis
FINAL REPORT
May 2024

Analysis conducted by

Lisa Faust, Ph.D.

Senior Director of Population Ecology, Lincoln Park Zoo, Chicago, IL;

IUCN SSC Conservation Planning Specialist Group

In Consultation with

The Hungarian Meadow Viper PVA Team

Cover photo by Bálint Halpern, BirdLife Hungary

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A contribution of the IUCN/SSC Conservation Planning Specialist Group and the Alexander Center for Applied Population Biology, Lincoln Park Zoo, in consultation with the PVA Team.

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PVA Team includes: Bálint Halpern, Borbála Kocsis, Dennis Rödder, Edvárd Mizsei, Endre Sós, Fernando Martinez Freira, Gábor Herczeg, Gábor Takács, Gergely Erdélyi, Gergely Szövényi, Jelka Crnobija-Isailovic, Judit Vörös, Márton Horváth, Oleksander Zinenko, Georgina Paun, Sándor Bérczes, Sylvain Ursenbacher, Tibor Sos, Viktória Koroknai, Zoltán Vajda, Dénes Nagy, Anna Egerer, Csenge Gulyás, and Arielle Parsons.

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Hungarian Meadow Viper (*Vipera ursinii rakosiensis)* Population Viability Analysis

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Executive Summary

Background

A population viability analysis (PVA) is a quantitative computer model that can be used to project a population's long-term demographic and genetic future. This PVA was conducted as part of a Hungarian meadow vipers (*Vipera ursinii rakosiensis,* hereafter HMV) species conservation planning workshop by the IUCN Conservation Planning Specialist Group (CPSG). The PVA for HMV was developed virtually ahead of a March 2024 workshop in Budapest, and reviewed and refined with workshop participants during the March meeting.

PVA Approach

We developed a stochastic, individual-based population model in Vortex (version 10.6.0). We approached the HMV PVA by creating two different models: 1) an *ex situ* population model based on the snakes held at the Hungarian Meadow Viper Conservation Center (HMVCC); and 2) a wild population model that includes subpopulations with three different life histories, high (strongly growing at stoch-r = 0.22), medium (moderately growing at stoch-r = 0.05), and low (slowly growing at stoch-r = 0.03). The HMVCC and wild populations are not directly connected, but reintroductions are modeled conceptually via harvests from HMVCC and releases into wild populations.

The HMVCC captive PVA is based on robust studbook data from 2004-2023. Because of this, model conclusions for the HMVCC are more likely to be predictive of future dynamics. The theoretical approach for the wild populations was necessary because while the species is found at 21 sites across Hungary (within Kiskunság National Park, Fertő-Hanság National Park, and Duna-Ipoly Nemzeti Park) and Romania, monitoring at these sites is not intensive enough to yield robust empirical estimates of site-specific population demographics, population sizes, or trends. Because of this, model conclusions for the wild population model should be viewed as general principals which may guide management but also require further evaluation if/when more wild demographic data become available.

PVA Results & Conclusions

For the HMVCC captive population:

1. Given the mortality and reproductive rates used in the baseline scenario, the population is robust and has a strong ability to grow if needed to support releases or fill available spaces.
2. The genetic predictions of the baseline scenario suggest that the population has a strong chance of remaining genetically healthy with minimal loss of gene diversity (GD) over the next 75 years. While historic data indicate an impact of inbreeding depression on the juvenile (0-1) mortality rate, when projected forward this relationship has little long-term impact on the population's demographics. Model scenarios suggest that bringing in new founders had minimal impact on long-term GD retained.
3. The catastrophe scenarios indicated that HMVCC is demographically robust to the types of catastrophes considered. However, there is still some inherent risk in maintaining a single population as the assurance population and source for reintroductions.
4. HMVCC can comfortably support the baseline annual release targets (200 1-3 year old snakes released/year plus surplus adults) for the next 20 years. If more snakes for release are needed, managers should consider 1) staying below the threshold of 325 1-3 year old snakes/year, or 2) using periodic instead of sustained high levels of harvest.

5. After releases stop, the HMVCC population can be maintained at a smaller size (at least 100 individuals) and still be a demographically and genetically viable to provide an assurance population that protects against total extinction if wild populations are lost. However, these values should be reevaluated at the point where the program is transitioning to that assurance mode from its current stage of being a source for reintroduction to verify a final target number based on more up-to-date information.

For wild populations:

1. Focusing on monitoring wild populations to yield better estimates of survival, reproduction, population size and population growth rate will be helpful to ground-truth model conclusions and better guide conservation actions.
6. Population growth (stoch-r) was most sensitive to subadult (age 1-3) mortality (45% of variation explained) followed by % of females breeding, adult mortality, and litter size (11-17% of variation explained). These parameters are most important to estimate accurately and may be good targets for management actions. Investments in research to understand these parameters would be helpful in guiding management activities.
7. Smaller population sizes make HMV populations more vulnerable to extinction, especially at sizes below 100, with the strongest probability of extinction (P(E)) at 20 individuals (Medium P(E) = 0.68, Low = 0.82). Currently, most HMV sites are estimated at $\leq$ 50 (Fig. 2, App. C). Increasing size or connectivity across sites is likely important to decreasing extinction risk.
8. Releases can eliminate extinction risk, even for small starting populations, in the absence of catastrophes. Releasing adults or 3-year-olds is the best strategy to grow a population quickly. Releases to establish a new population required at least 5 years of releases (post-release survival=20%) or as little as 3 years (post-release survival = 60%) to establish populations with less than P(E) = 0.10. Better estimates of post-release survival under different conditions (e.g., habitat quality, predation pressure) will help fine-tune the most effective release strategies. Testing hypotheses about the impacts of different release group sizes, frequencies and/or ages will be helpful to guide release strategies. Given the apparent ability of the *ex situ* population to support large numbers of annual releases, managers could take an experimental approach to investigate many of these variables.
9. The catastrophes envisioned by the modeling group could result in increases from baseline extinction risks to the range of 0.48-0.99, depending on the catastrophe and population. Drought was the most likely catastrophe to impact populations across the range, with possible P(E) between 0.64-0.84, suggesting further research into drought effects and mitigation could be important. Under the drought scenario, reintroduction substantially lowers extinction risk but cannot eliminate it. Drought substantially increased extinction risk of newly established populations, with few modeled combinations under the P(E)=0.10 threshold.

Ultimately, the PVA model supports reintroduction as a strong conservation action that can be taken to counteract the impacts of potentially declining population dynamics. We can’t know which of these scenarios best replicates what is happening in the wild, so investing time in understanding wild population dynamics and what occurs post-release at populations that are supplemented will provide better insights into wild dynamics for future decision-making.

Introduction

Project Background

The Hungarian meadow viper (*Vipera ursinii rakosiensis,* hereafter HMV) is a subspecies of the meadow viper and is listed as vulnerable under the IUCN red list (Joger et al., 2008), with a distribution now limited to Hungary and Romania (Edgar and Bird, 2006). Original causes of decline include habitat fragmentation and degradation due to intensification of agriculture, including negative impacts from draining grasslands (i.e. changing hydrology), grazing, burning, mowing, and ploughing, as well as direct poaching and persecution (Péchy et al., 2015).

In 2001 a population and habitat viability assessment (PHVA) workshop was conducted for the HMV, organized and hosted by the Budapest Zoo and led by the IUCN's Conservation Breeding Specialist Group, now the Conservation Planning Specialist Group (CPSG) (Korsós et al., 2002). This workshop resulted in production of a Population Viability Analysis (PVA) and recommendations for a Species Conservation Plan, which was officially ratified by the Hungarian Ministry of Environment and Water Affairs in 2004.

As part of a current LIFE project, CPSG was contracted to conduct a species conservation planning workshop with a goal of updating the conservation action plan for HMV. This updated PVA for the species was developed virtually ahead of a March 2024 workshop in Budapest, and reviewed and refined with workshop participants during the March meeting.

Species Status Since 2004

Since 2004, conservation efforts in Hungary, organized under multiple European Commission LIFE projects, have focused on improving habitat quality and increasing size of existing habitats. In addition, a major focus has been on building a captive breeding population at a specialized facility, the Hungarian Meadow Viper Conservation Center (HMVCC), which has been the source of over 800 individuals released into wild populations (Péchy et al., 2015).

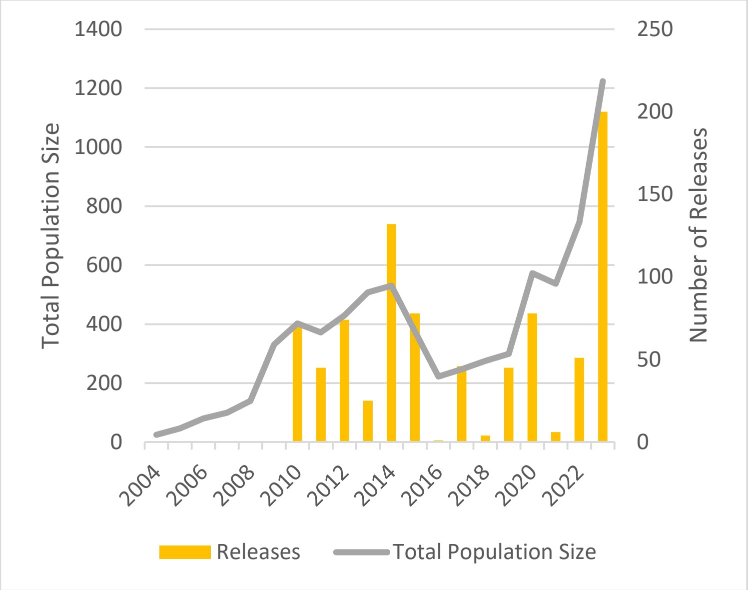

Figure 1. Total size for the snake population at HMVCC as of July 1st of each year (directly before reproduction), and the total number of annual releases produced by HMVCC and released to sites across Hungary.

The species is now found in Hungary at multiple sites within Kiskunság National Park, Fertő-Hanság National Park, and Duna-Ipoly Nemzeti Park, and at eight sites within Romania. While monitoring is ongoing at different levels of intensities across the range, HMV have not been monitored closely enough to yield robust empirical estimates of site-specific population demographics, population size, or trend, as is the case for many snake species (Böhm et al., 2013). During the PVA process, species experts used their best judgement to categorize the size and population trend at the 21 sites across the range where HMV are known to occur (Fig. 2 and Appendix C). While these are only rough estimates, they represent our best summary of population status on a site-by-site basis, and helped provide context as we designed the PVA.

While many of these sites have active management, the species still faces threats due to habitat degradation/loss, high predation from both avian predators (birds of prey) and mammals (badgers, boars, fox), potential catastrophes, and climate changes that will affect hydrology, habitat, and more. Given the potentially small population sizes (Fig. 2), we can also anticipate challenges due to small population dynamics and population isolation.

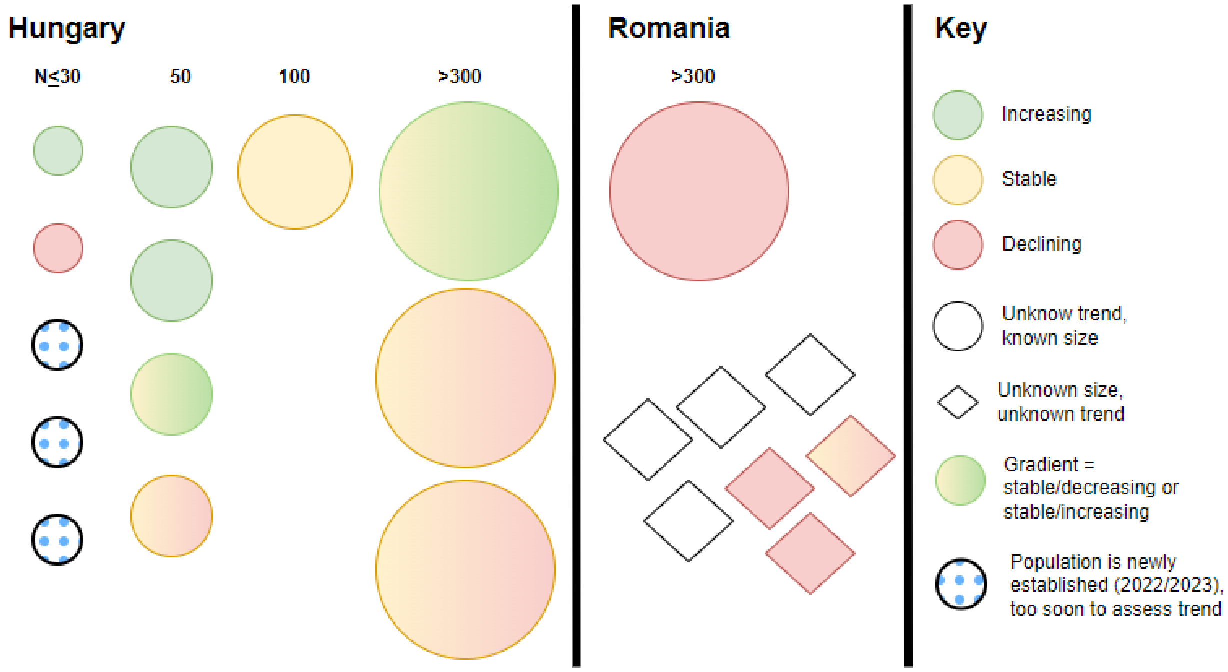

Figure 2. Species expert's best judgement of the current population size (N) and population growth rate trend of HMV at 21 sites in Hungary and Romania; for most sites data are not available to make empirical estimates. Populations where experts were able to make some kind of guess at size are represented by circles; diamonds are used where experts did not feel comfortable making a guess. Trend is represented by color, with green indicating increasing populations, red indicating declining populations, yellow indicating stable, and a color gradient indicating that the experts thought there was a chance at multiple trends. White indicates that experts did not feel comfortable guessing a trend.

PVA Model Questions/Objectives

There is still a good deal of information that is not known about HMV population status and wild population dynamics. Workshop participants identified these key questions they wanted the models to address:

- Wild population viability:
    - Which demographic characteristics should wild populations have to be able to persist?
    - How might potential changes in climate and other catastrophes influence persistence?
    - What is the sensitivity of the species to changes in survival or reproduction?
    - How does population size influence viability? Is there a minimum viable population size?

- Releases/Translocations/*Ex situ* population:
    - What would be the minimal number of animals to be released to assume a steady support of the remaining populations?
    - What is the minimal number of released individuals to create a sustainable population?
    - What is the frequency/number of migrants between subpopulations to avoid genetic drift?
    - Should we include more founder individuals to maintain the genetic diversity of ex situ populations? If yes, how many and ideally from which populations?
    - Should we create new populations to link existing ones or we should concentrate first on the support of the existing ones? What is the cost benefit of the latter (eg. disease transmission vs. genetics)?
- Questions that the working group identified that cannot be answered by PVA (i.e. they are more qualitative questions based on values discussion by the group), or not by the PVA as we designed it (i.e. they require a spatial or metapopulation approach that we could not incorporate into the model given data and time limitations):
    - What do we consider ideal size for a HMV habitat?
    - How many habitat patches at minimum should be provided for metapopulation to persist until 2100?
    - How many populations are required? How many self-sustaining populations should we target by 2050 or 2100?

Methods

Modelling Approach

We developed an individual-based population model in Vortex (version 10.6.0), a widely used PVA modeling software package (Lacy and Pollak, 2023). For more detailed descriptions of Vortex and how it is applied in PVAs, see (Lacy, 2000b, 2000a) and (Lacy et al., 2021). The model is individual-based, meaning it tracks every animal (current and future) in the population over time. After being initiated with the starting population, the model steps through an annual event cycle (e.g., births, transfers between subpopulations, deaths, aging, censusing) for all individuals. It also includes multiple sources of stochasticity: 1) demographic stochasticity, the randomness in mortality, reproduction, and birth sex ratios among individuals, which is especially important for small populations; 2) environmental stochasticity, the variability in demographic rates due to normal fluctuations in the environment as well as environmental catastrophes; 3) genetic stochasticity, the variability due to randomness in inheritance and drift in small populations. Because of this stochasticity, we run each model scenario 1000 iterations, allowing us to determine the range of potential outcomes a population could experience under a given set of conditions.

We approached the HMV PVA by creating two different models, one for the *ex situ* population held at the HMVCC, and one for the wild populations. While in reality these subpopulations are connected in a metapopulation structure (via releases/reintroduction), we modelled harvesting from HMVCC and releases to the wild sights using hypothetical animals without explicit connection between the populations. We took this approach for model efficiency and because we didn’t have enough detailed information to build a full metapopulation. Our analyses considered four populations:

- HMVCC = the *ex situ* population at the Hungarian Meadow Viper Conservation Center; this population model is based on 20 years of rigorous data, and is most likely to represent realistic future dynamics
- Wild_High = a suite of theoretical demographic rates resulting in a very strongly growing wild population (projected population growth rate, or stoch-r = 0.22)
- Wild_Med = a suite of theoretical demographic rates resulting in a strongly growing wild population (stoch-r = 0.05)
- Wild_Low = a suite of theoretical demographic rates resulting in a slightly growing wild population (stoch-r = 0.03)

Demographic and Genetic Input Data

The *ex situ* population is in a studbook, an electronic database maintained in ZIMs by Borbála Kocsis and Gergely Erdélyi. The studbook contains the HMVCC's full demographic and genetic history including births, deaths, and releases to and from HMVCC to wild sites, with data for over 5000 individuals. We downloaded and analyzed the historic studbook data to yield model parameter estimates (Table 1), taking temporal subsets (date windows) that reflect current husbandry, which has changed significantly over the population's history. In the last three years the program has increased its prey breeding program to support HMVCC and has been able to feed a substantially richer diet with more mice, hypothesized to benefit HMV reproduction. Thus, for many of the model parameters related to reproduction, we used a date window of 2021-2023. For mortality rates, current husbandry (2019-2023) of maintaining enclosures at a lower juvenile density has resulted in higher survival rates. Thus, we restricted 0-1-year-old mortality to reflect that range, but needed to extend to 2004-2023 for older age classes to increase sample sizes. Full details on data analysis can be found in Appendix A.

There are minimal data available on population dynamics at wild HMV sites in Hungary, although some mark recapture monitoring work has been ongoing. Initial analysis of the mark recapture data yielded unrealistic survival estimates (for example, and adult female mortality rate of 3%; B. Halpern & A. Parsons, unpub data). More intense monitoring and further analysis may yield estimates appropriate for input into a PVA in the future. We used theoretical mortality rates as well as some limited reproductive data available from wild-caught females (Table 1).

Information was analyzed and aggregated by L. Faust, and then a small group of participants (Bálint Halpern, Georgiana Păun, Tibor Sos, and Jelka Crnobija-Isailovic, Phil Miller, Simon Valle) met to refine and make decisions on how to apply any analyses within the models.

Table 1. Model parameters used in HMV PVA models (Baseline Scenarios)

Parameter	Ex Situ (HMVCC)	Notes		Wild - High Growth Rate	Wild - Medium Growth Rate	Wild - Low Growth Rate	NOTES
Reproduction							
Age at First Breeding (i.e. mean age at which 1st offspring are born)	M, F = 4	**Female** mean age at first birth = 4.3; median = 4.0 (158 dams with 4788 offspring, whole studbook) **Male** mean age at first conception = 4.2, median = 4.0 (147 sires with 4360 offspring). Management also controls this based on when snakes are placed together for breeding.		F: 4 M: 3			In wild populations, males can breed slightly earlier than how they are managed in the HMVCC
Age at Last Breeding	19, no reproductive senescence	**Oldest female** = 19 (SB ID4, offspring birthdate = 2010); multiple 15,17,18-year olds **Oldest male** = 17 (SB ID13, offspring birthdate = 2015); multiple 14/15/16-year olds		no reproductive senescence (19)			Based on captive data
Female prob. of breeding	90% SD = 8	The number of pairs made in the year is constrained by space as the model attempts to "breed to K"; this is set at 90% (plenty of females available to be paired if space allows). In model calibration, varied this from 40-90% and it didn't strongly change the # of pairs made.		80%, SD = 16%	50% SD = 12%	50% SD = 10%	Based on expert judgement. Our logic: High: Although typically only 1/3 of females breed annually, close to annual reproduction has been observed in good years (B. Halpern, pers comm); Low: More disturbance, lower chance to restore fat reserves, shortage of prey, likely lower reproduction
Brood Size (mean and Standard Deviation) # of live-born offspring	Observed distribution with mean of 13.5, SD 3.8	Increased mice fed in diet in last 3 years, so 2021-2023 date window is most appropriate for many reproductive parameters. During that period, average litter size = 13.5 (SD = 3.78, N = 100 litters). See Appendix A for more details		12.1, SD=4.1	11.1, SD = 4.2	11.1, SD = 4.2	Based on some wild and captive data. See Appendix A for full details.
Max. brood size	26	2008 litter to female #2		26			Based on captive data
Birth sex ratio	48.9% male	Last 3 years 2021-2023: 48.9% male See Appendix A for more details		48.9% male			Based on ex situ data
% of males in breeding pool	100%	Do not restrict any males from potential breeding, but then select pairings based on mean kinship		100%			Same logic as ex situ, but pairings are random

Parameter	Ex Situ (HMVCC)	Notes		Wild - High Growth Rate	Wild - Medium Growth Rate	Wild - Low Growth Rate	NOTES
Mortality							
Juvenile Mortality – Age 0-1 Same values used for Female, Male for all	12.6%, SD = 4.3	Average and SD calculated for 2019-2022 for N = 1520 births during this time period (excluding 2020). Sexes pooled. This is the value when an individuals' inbreeding coefficient = 0; when inbreeding coefficient is > 0, it is based on the equation in Appendix A. See Appendix A for more details.		70% SD = 10	50% SD = 10	55% SD = 10	High = "Schedule B" from 2001 PHVA Medium = "Schedule A" from 2001 PHVA Low = slight adjustment to Medium rates to get a baseline growth rate = 0.02
Mortality – Age 1-2	19.2, SD = 1%	Calculated from 2004-2023 data for a wider, more robust date window. Sexes pooled together. Used a standard estimate of 1% environmental variation: these snakes live in a more consistent environment (provisioned with food, protected somewhat from predation), but their outdoor housing may lead to some interannual variation. See Appendix A for more details.		20% SD = 8%	30% SD = 8	30% SD = 8	
Mortality – Age 2-3	12.6, SD = 1%			15% SD = 8%	30% SD = 8	30% SD = 8	
Mortality – Age 3-4	15.6, SD = 1%			15% SD = 8%	30% SD = 8	30% SD = 8	
Mortality – Adults – Age 4+	Used values for each age class; average across ages = 19.3% SD = 1%			15% SD = 8 (males start at 3, females at 4)	30% SD = 8 (males start at 3, females at 4)	30% SD = 8 (males start at 3, females at 4)	
Maximum Lifespan	19	**Oldest female** = 19 (SB ID4, offspring bdate = 2010); multiple 15,17,18 year olds **Oldest male** = 17 (SB ID13, offspring bdate = 2015); multiple 14/15/16 year olds		19			HMVCC data
Other Key Parameters							
Initial Population Size	1132 snakes	Initialized with the HMVCC population as of 1 July 2023 with this age and sex structure: 525 males, 607 females; 0 Juveniles (0-1 years old), 816 Subadults (1-4), 316 adults (4+) See Appendix A for full details.		100 snakes			Age/sex structure calculated based on the Stable Age Distribution by Vortex

Parameter	**Ex Situ (HMVCC)**	**Notes**		**Wild - High Growth Rate**	**Wild - Medium Growth Rate**	**Wild - Low Growth Rate**	**NOTES**
Carrying Capacity (K)	1600	Based on maximum holding given space at HMVCC, staff and food source constraints		800			Arbitrarily chosen to not allow model population size to explode
Harvests/ Releases	200 harvests/ year (ages 1-3) + Any excess adults > 100 for the first 20 model years	Sex and age structure of harvests for release is based on 2023 releases. Sex ratio = 0.46% male. Age structure: 1 year olds: 21%; 2 year olds: 21%; 3 year olds: 59% 4+ year olds: only keep 60 females and 40 males, release excess each year. See Appendix A for full details.		None in baseline			
Inbreeding Depression	Observed inbreeding impact built into 0-1 mortality	Significant effect of inbreeding found in meadow vipers born in 2019, 2021, and 2022, and this inbreeding effect is built into 0-1 mortality. See Appendix A for full details.		Inbreeding depression on, with 6.29 lethal equivalents impacting first year survival			Vortex default based on O'Grady et al. 2006 study.

Model Setup

The models are stochastic, and scenarios are run for **1000 iterations**. The projection timeframe is **75 years**, as that is the timeframe of interest in the HMV vision statement developed by the conservation planning group. Vortex's **default model order of operations** is used: EV, Breed, Mortality, Age, Harvest, Supplement, Calculate Stats. The model year starts on 1 July of every year (conceptually), right before births occur; releases happen at the end of the model year (conceptually, May or June).

Model Scenario Sets

HMVCC Model

1. **Baseline scenario:** Model initialized with parameters in Table 1, including: an observed impact of inbreeding on juvenile (0-1) mortality; genetic management by mean kinship; harvesting 200 individuals a year for 20 years
2. **NoInbreeding**: Turns off impact of inbreeding on juvenile (0-1) mortality; juvenile mortality = 12.6 (SD = 4.3) for males and females
3. **Overharvesting**: Varying the number of annual harvests for release from 200 (baseline) to 500 for model years 1-20, using the sex- and age-specific harvest rates from Table 1
4. **New Founders**: Adding 2 or 10 unrelated founders to HMVCC every 5 or 10 years; with breeding by mean kinship, these individuals would be prioritized to breed if they survived
5. **Catastrophes**: see HMVCC catastrophes described in table 2; catastrophes are turned on one at a time

6. **MinimumViableSize:**
    a. Investigating the HMVCC's minimum viable population size once releases stop in year 21, with carrying capacity (K) varied from 50-700
    b. To assess how smaller size interacted with catastrophe vulnerability, added HMVCC Flood catastrophe to scenarios with K = 75, 100, 200

Wild Model

1. **Baseline scenario:** Model initialized with parameters in Table 1, with three wild subpopulations that each represent a different set of vital rates. No releases, no movement between subpopulations, random breeding, inbreeding depression included using values from wild populations (O'Grady et al., 2006).
2. **Sensitivity Analysis**: using a simplified model of wild HMV demography (Medium dynamics, initial N = 100, no releases), we used sensitivity analysis to evaluate the influence of different model parameters on stochastic growth rate.
3. **Catastrophes**: see Wild catastrophes described in table 2; catastrophes are turned on one at a time except for a single combo scenario with all catastrophes turned on
4. **PopSize**: varies the initial population size between 20-600, with age/sex structure dictated by stable age distribution
5. **NoInbreeding**: inbreeding effects turned off in the model
6. **Release scenarios**: snakes are being actively released from HMVCC to wild populations. We explored release scenarios extensively with many combinations varying:
    a. Number of Releases: release 25, 50, or 75 snakes a year into a population; current release groups are typically ~25 snakes. There are many competing hypotheses about the effects of group size: larger group sizes may give an initial demographic boost or help ensure that enough snakes survive and post-release predation. Conversely, they might also attract predators into the site, increasing predation pressure.
    b. Post Release Survival: 20, 40, 60%, or 100% post-release survival. Note that no accurate estimate on post-release survival could be calculated from available data because of low recapture rates, recency of releases, and suspected strong interannual variability
    c. Initial Population Size: initial population sizes of 0 (representing starting a new population), 20, or 100
    d. Release duration: releases for 3, 10, or 20 years
    e. Drought: adding the drought catastrophe, to reflect potential threats and population dynamics that include more chance of decline/extinction; see Table 2 and Appendix D
    f. Varying Age Structure of Releases: release group is either a mixed group structure (21% 1 year olds, 21% 2 year olds, 59% 3 years olds) or only 1 year olds, only 3 year olds, or only Adults.
7. **TempAgriConversion**: One-time event where grassland is plowed and then can come back. Assume that 25% of habitat is impacted and then left fallow for a period. In model, harvest 25% of the population, to reflect that there will be a much higher predation rate and possibly direct mortality on the plowed site.
8. **IncreaseMortality:** general scenarios increasing mortality rate across all age classes by 10% or 25%. The modeling team felt this could occur if grasslands were more intensively used for grazing, which would result in lower vegetation height and increased predation, or by conservation interventions that result in increased predator (raptor) populations which would increase predation.

Table 2. Catastrophe setup for HMVCC and WILD PVA model scenarios

Population	Catastrophe Type	Frequency (% of years)	Severity - Reproduction	Severity - Survival[1]	Description[2]
WILD	Flood	10	1 (no impact)	for High =0*(A=0)+0.88*(A=1)+ 0.91*(A>1) for Medium =0.5*(A=0)+0.79*(A>0) for Low = 0.39*(A=0)+0.79*(A>0)	Extra flooding raises water table, and combined with freezing temperatures during winter can cause higher overwintering mortality and lower prey base in lower/wetter habitats. Previously every 5 years but now more like 10 years. Increases mortality by 50% for all age classes. Only a subset of sites in Hungary have topography that will result in this. HMV sites currently impacted by this: 0/21 HMV sites that might be impacted by this in the future: 6/21
WILD	Drought	20	0 (no reproduction)	for High =0*(A=1)+0.95*(A=2)+1*(A>2) for Medium =0.5*(A=1)+0.91*(A=2)+1*(A>2) for Low = 0.39*(A=1)+0.91*(A=2)+1*(A>2)	Lack of precipitation, high heat, and long periods of aridity; when combined with winter temps that are not optimal for overwintering, snakes may emerge early out of sync with prey; likely on frequency of La Nina (set at every 5 years). Results in no reproduction; 1-2 year old mortality increased by 50%, 2-3 year old mortality increased by 20%. Occurs at sites across Hungary and Romania. HMV sites currently impacted by this: 16/21 HMV sites that might be impacted by this in the future: 16/21
WILD	Fire	10	1 (no impact)	for High = if(A=0;0.33;0.12) for Medium = if(A=0;0.2;0.14) for Low = if(A=0;0.22;0.14)	On active military sites, catastrophic fires are possible; large fire every 10 years. 90% mortality of all individuals HMV sites currently impacted by this: 2/21 HMV sites that might be impacted by this in the future: 2/21

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[1] See Appendix A for more details on calculation of severity factors for survival in catastrophes.

[2] For WILD sites, the description includes context on how widespread this potential catastrophe might be to the existing 21 sites that HMV occupy across Hungary and Romania; experts in the small working group identified whether each site was currently experiencing the catastrophe in question and whether they were likely to in the future, based on their best (sometimes limited) understanding of what is occurring at each site.

Population	Catastrophe Type	Frequency (% of years)	Severity - Reproduction	Severity - Survival[1]	Description[2]
HMVCC	Fire	1.3	1 (no impact)	=IF(A=0;0.6;1)	Catastrophic fire resulting in loss of indoor facility, where 140 0-1 year olds are held indoors overwinter; occurs once within the 75 year time frame. IF statement results in a severity factor of 0.6 if an individual is 0, but for all other individuals there is no survival impact.
HMVCC	Disease	4	1 (no impact)	=if(A>3;0.93;1)	Disease brought in with wild-caught snakes brought in for new founders; enough screening would occur that this is likely controllable from impacting the whole population, but model a disease brought in that impacts adult animals in outside terrarium, impacts that terrarium + 2 adjacent terrariums; loss of 15 adults
HMVCC	Flooding	5	1 (no impact)	0.82	Torrential flooding which impacts outdoor habitats; burrows are flooded out and snakes are forced to come to surface
HMVCC	Early Spring	10	1 (no impact)	=if((A>2 && S=M);0.12;1)	Early spring and then a larger temperature drop affect males who emerge from brumation earlier; causes mortality to adult males but not other age/sex classes which have not yet emerged. Assume 90% adult male loss

Results of PVA Simulations

Output Metrics

We use the following abbreviations for summary statistics:

Abbreviation	Description
P(E)	Probability of extinction in 75 years (i.e. the # of extinct iterations/total # of iterations) across 1000 model iterations.
Stoch-r (SD)	The mean and standard deviation of the stochastic growth rate of the population averaged across all 75 years for all extant (non-extinct) model iterations. When r is > 0.0 (positive), it is a growing population; when r is < 0.0 (negative), it is a declining population, and when r = 0.0 it is a stable population.
GD (SD)	The mean and standard deviation of gene diversity (expected heterozygosity) across all extant (non-extinct) model iterations.

Stoch-r, and GD have variability associated with them due to the stochastic nature of the model and thus we report ± 1 SD to convey the range of possible future outcomes under a model scenario. **Appendix B includes tables with all final model results across all scenarios for each population**. Appendix tables and figures are referenced with a letter and number (e.g. Table B2).

HMVCC (ex *situ*) Population Results

HMVCC: Status Quo (Baseline)

Under the baseline scenario conditions, the *ex situ* population has a P(E) = 0 and a stoch-r = 0.01 (0.07) (Table B1). The population is demographically robust. It is able to provide harvests for release for the first 20 model years, sustaining removal of an average of 313.8 snakes/year over the 20 years (200 individuals ages 1-3/year and any excess adults above 60 females and 40 males). During this period of releases, the population size settles at slightly less than 1000 individuals due to how interactions in model settings ("Breed to K", the number of births planned for a year, and the number of harvests) interact (Fig.3). During this period of releases, the population produces ~540 births/year from ~40 pairs, on par with the 2023 production of 524 offspring from 40 pairs.

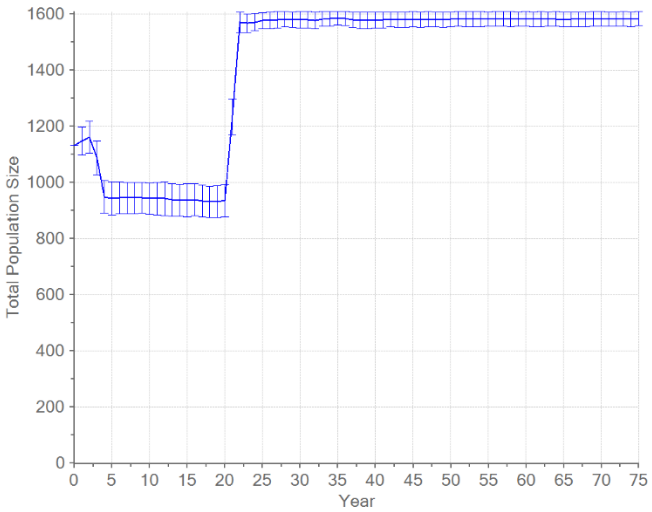

Figure 3. Projected population size for HMVCC under the baseline scenario. The solid line shows the mean population size across 1000 iterations ± 1 standard deviation.

After releases stop in year 20, the population has the capacity to grow rapidly, with single-year growth rates at over 25% year, demonstrating its robust demographic potential, until it reaches its carrying capacity of 1600 (Fig. 3). The overall growth rate is low (0.01) because the population sits for so much of the model at its K. **Given the mortality and reproductive**

rates used in the baseline scenario, the HMVCC population is robust and has a strong ability to grow if needed to support releases or fill available spaces.

Genetically, the baseline scenario that is initialized with the pedigree relationships of the existing HMVCC population starts at gene diversity (GD) = 0.9776, meaning that ~98% of the genetic diversity of the HMVCC population's founding individuals is retained by the current, descendent population (but not that the HMVCC population represents 98% of the full species' wild genetic diversity). The PVA projects that in 75 years the population will retain GD = 0.9729 (SD=0) on average (Table B1). The mean inbreeding level (*F*) at year 0 was 0.0084 and increased over the 75 model years to 0.05, meaning that on average, individual inbreeding (*F*) across the population is less than that expected in the offspring of a pairing where individuals are related at the first cousin level (kinship between first cousins (*F*) = 0.0625).

While there are some caveats to interpretation of genetic projections for this population (see Model Limitations – HMVCC Model Uncertainty), the population is maintained at such a large size, has a large base of wild founders, grew rapidly to its large size, and is strong demographically, which are all recommendations on how to create and maintain a healthy population. These factors mean that the population currently has high levels of GD and model projections suggest that even with animals harvested for release, will retain those high levels. **Ultimately**, **the genetic predictions of the baseline scenario should be interpreted to indicate that the population has a good chance of remaining genetically healthy and robust under current management strategies, with minimal loss of GD over the next 75 years.**

HMVCC: Does the observed inbreeding depression negatively impact the population?

There is negligible difference between summary genetic and demographic statistics for the baseline scenario (which includes the observed inbreeding impact on juvenile mortality) and one with inbreeding depression turned off (Table B1). The only output that showed a slight impact was the mean inbreeding level (F), which increased from the baseline of 0.05 to 0.07 in this scenario, slightly higher than expected in the offspring of a pair of individuals related at the first cousin level. This effect occurs because the baseline scenario is essentially selecting against inbred individuals (by causing higher mortality), while the NoInbreeding scenario does not include that selective effect.

While historic data provides evidence of an impact of inbreeding on the juvenile (0-1) mortality rate (i.e. inbreeding depression), when projected forward this relationship has little long-term impact on the population's demographics. In closed populations, inbreeding will continue to accumulate, and additional demographic rates (litter size, other stage's mortality rates) might start to be impacted in the long-term. Maintaining the studbook data will enable ongoing review of the potential impact of inbreeding on population dynamics.

HMVCC: Can the population be overharvested?

While the population can easily sustain harvesting as modeled in the baseline scenario (200 individuals ages 1-3 and any excess adults for 20 years, resulting in an average of 313.8 harvests/year), higher levels of harvesting can start to increase extinction risk and decrease stoch-r (Fig. 4, Table B1). The tipping point seems to be between scenarios that set the harvest rate at between 325 and 350 snakes/year (i.e. the target rate for harvesting 1-3 year old snakes), with P(E) increasing to 10% at 325 and then over 49% at 350 and above (Fig. 4). Population growth rate flips from growing to declining at 350 harvests (stoch-r = -0.04, SD = 0.33). This modeled rate also interacts with harvest of "excess" adults; Figure 5 illustrates how across all harvest scenarios, in early years excess adults are available and taken (making the actual number of harvests greater than the rate in the scenario name), but that after early years with fluctuations, in model year 5 all harvest scenarios start to coalesce into only being able to harvest 300-320 individuals (likely all 1-3 year olds, with no excess adults available), and then scenarios with harvest rates higher than 325 quickly start being unable to even fill that harvest target as their populations start to decline or go extinct (Fig. 5).

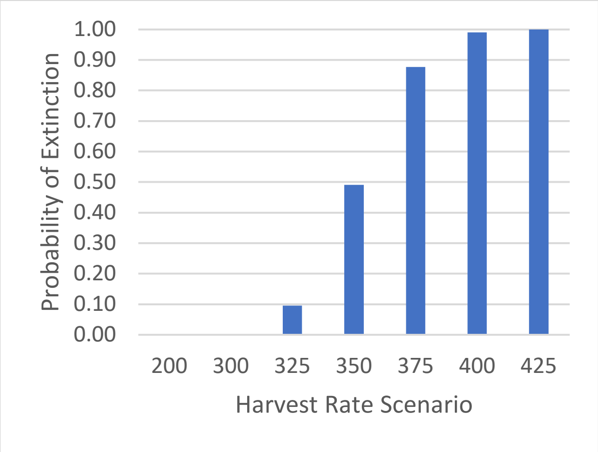

Figure 4. Probability of extinction for HMVCC population based on differing harvest rates for 1-3 year olds. Probability of extinction is based on the number of extinctions that occurred out of 1000 model iterations.

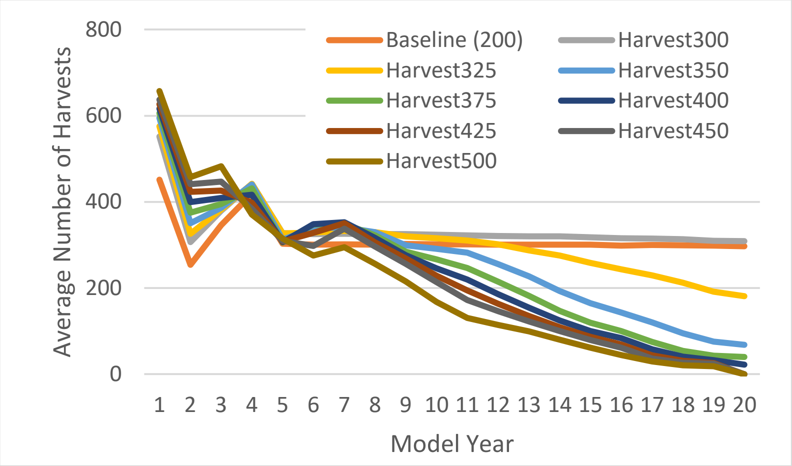

Figure 5. Total number of projected harvests that occur under alternate scenarios with different harvest rates for 1-3 year olds. The number is averaged across any extant model iterations, across 1000 iterations. All scenarios include removal of any excess 4+ year olds above the target adult capacity of 100.

While the HMVCC population is demographically robust, these scenarios highlight that an overharvesting threshold exists (with the modeled parameters, above 325 1-3 year old snakes/year), and managers should carefully balance releases with HMVCC needs. **If it is deemed that the wild populations need more snakes for release, managers should consider strategies like 1) staying below the 325 threshold, or 2) not having a sustained high level of harvest, but instead allowing high harvest for a year or two and then allowing a few years for the population to rebound.**

HMVCC: Does the population need new founders?

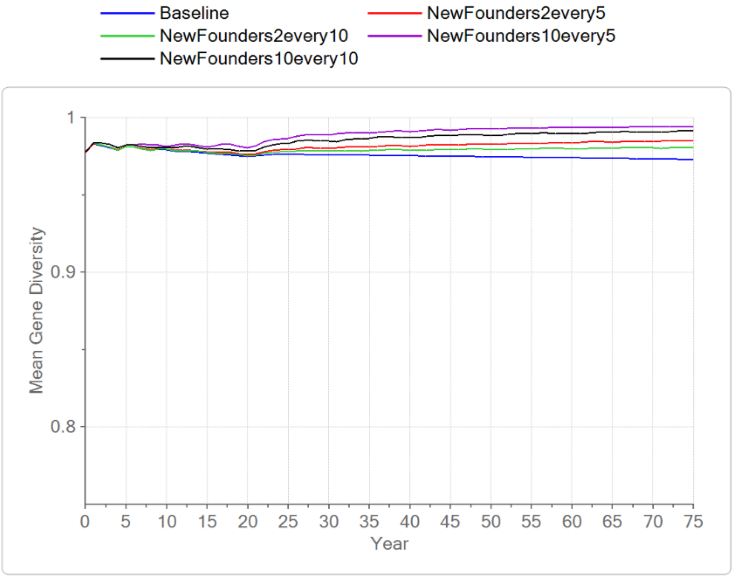

Figure 6. Mean gene diversity for baseline and alternate scenarios that bring new founders into the population. GD is averaged across 1000 iterations.

A genetic founder is an individual unrelated to any individuals in a living population who then contributes reproductively to that population. Model scenarios where 2 or 10 unrelated individuals were brought into the population every 5 or 10 years had essentially no impact, increasing GD at 75 years from 0.97 (SD = 0) to 0.98 (SD = 0) with 2 founders and 0.99 (SD = 0) with 10 founders (Fig. 6). These scenarios may not be completely realistic because individuals in existing wild populations, especially at sites where releases have occurred in the past, may not be completely unrelated to the HMVCC population. Based on these scenarios, we conclude that **while bringing in new wild-caught potential founders to HMVCC can't hurt the population genetically, these model scenarios suggest minimal impact on long-term GD retention.**

HMVCC: How do potential catastrophes put the population at risk?

The HMVCC catastrophes as designed in Table 2 represent the experts' hypotheses about the types of catastrophes that might threaten the HMVCC (fire destroying the holding building, a disease impacting a few enclosures before it can be contained, floods affecting the holding areas, or early spring emergence combined with poor weather resulting in loss of adult males). When each of these catastrophes were added (one by one) to the model, there was essentially no change in dynamics compared to the baseline scenario, including no increased extinction risk (Table B1). **It is reassuring that this population is demographically robust to the types of catastrophes that the group of HMV experts could envision impacting it, even to those catastrophes that were presumed to be dire.**

However, there is an inherent risk to the entire *ex situ* population being held in one facility – if some new catastrophe came along that drastically affected the population or facility, it is a vulnerability to only have captive snakes in that single facility. Managers should consider ways to mitigate this risk, such as by moving an assurance population of snakes into other *ex situ* facilities, or considering feasibility of re-starting the population by harvesting from wild populations if a catastrophe occurs. Luckily strong husbandry and facility expertise has been developed since 2004 at HMVCC.

HMVCC: How small could the HMVCC population be after the period of releases to still remain a viable assurance population for the species?

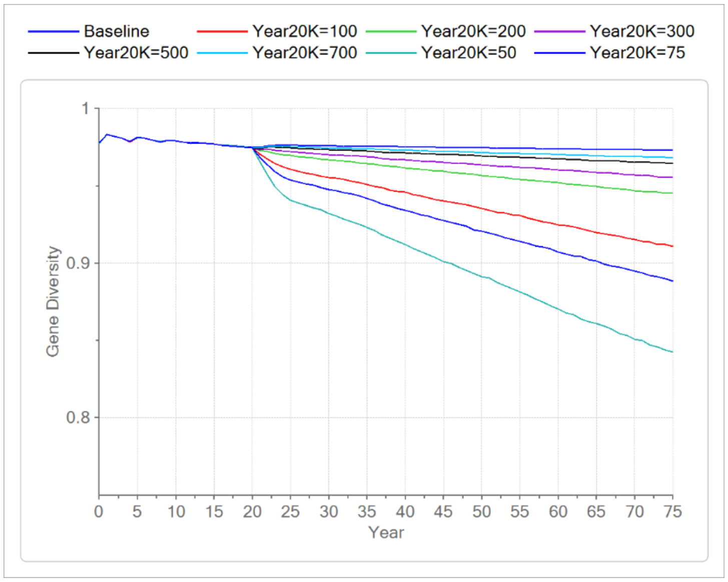

Figure 7. Mean gene diversity for baseline and alternate scenarios that reduce the long-term carrying capacity (K) from 1600 (Baseline) to smaller sizes (50-700). GD is averaged across 1000 iterations.

In these scenarios, we reduced carrying capacity (K) after year 20 to sizes varying from 50 to 700, compared to 1600 in the baseline, to assess an appropriate size to maintain the population at once releases are no longer needed. Under any of these population sizes, P(E) = 0.00, highlighting that the population's strong demographics result in low demographic risk for such management strategies. Smaller sizes did have an impact genetically, however, with final GD ranging from 0.84 (0.04) if K = 50 to equivalent to the baseline rate of 0.97 (0.00) if K = 700. Maintaining final K at 100 or larger kept GD at year 75 over 0.90, which is a common target threshold used for *ex situ* or assurance populations to maintain long-term viability. Smaller sizes also meant more rapid accumulation of inbreeding, even though inbred offspring are selected against within the model; for K=50, average inbreeding in year 75 was 0.16 (higher than the level of an offspring produced by a pair related at the half-sibling which is 0.125), whereas at K=100 or higher, inbreeding was at 0.11 or lower.

Smaller size might also make the HMVCC population more vulnerable to catastrophes. When we included Floods, which was HMVCC's most severe catastrophe, with the smallest sizes (K=50-200), there was still no change in extinction risk or genetic parameters (Table B1), suggesting that managers can reduce size without concerns about the vulnerability to the potential catastrophes identified.

These results support maintaining a final assurance population size of at least 100 individuals after the population is no longer actively releasing to protect against extinction; however, these values should be reevaluated at the point where the program is transitioning to that assurance mode from its current stage of being a source for reintroduction. Because the HMVCC demographic rates do not really reflect full rates of adult mortality (Appendix A), actual dynamics may be different when the population is holding all individuals rather than releasing them. In addition, if releases are stopped because healthy wild populations exist, the HMVCC population's genetic diversity might also be maintained via occasional migrants from the wild, which would enable a smaller population size to be maintained. Managers may target such migrations when the HMVCC inbreeding coefficient increases higher than 0.1 to avoid any future impacts of inbreeding depression and decreased GD.

Wild Population Results

Wild: Baseline Dynamics of Three Hypothetical Population Types

For the wild model, we created three different populations that had baseline dynamics of populations growing at different rates (stoch-r), with no to moderate (P(E) = 0.10) extinction risk.

Scenario	Population	Stoch-r	SD(r)	PE
Wild Baseline	High	0.22	0.24	0.00
Wild Baseline	Medium	0.05	0.24	0.03
Wild Baseline	Low	0.03	0.24	0.10

We cannot interpret these baseline scenarios as representative of any specific HMV population, but will use each of these populations and their general demographic patterns as context for the impacts of changes built into alternate scenarios to address key questions.

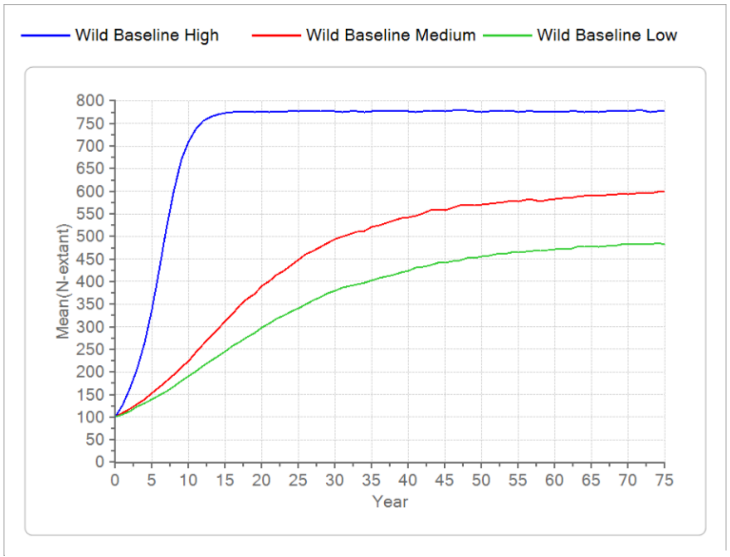

Figure 8. Mean total population size the baseline scenario with three different life histories (High, Medium, Low). The mean is the average across 1000 model iterations for all iterations where populations did not go extinct.

Wild: What are the most important vital rates to population dynamics (Sensitivity Analysis)?

This sensitivity analysis evaluates the impact of key model parameters on stochastic growth rate. We created a simplified model of wild HMV demography using the Medium population dynamics (Table 1).

We used Latin hypercube sampling (LHS) in Vortex to generate random combinations of parameters which were evenly sampled from a range of uncertainty for each parameter of interest; the ranges were generated by the modeling team based on likely minimum/maximum values for parameters. We generated 1000 unique parameter sets and ran each set forward for 75 years and 1000 iterations, to fully explore the parameter space (Lacy et al., 2017). We used R v. 4.1.2 (R Core Team, 2021) to run a simple linear regression assuming a normal distribution for error using stochastic growth rate as the response variable. This approach to a global sensitivity analysis can incorporate interactions between model parameters, making it more robust than “local” or single-factor sensitivity analyses (Cross and Beissinger, 2001; Prowse et al., 2016).

In the HMV model, stoch-r was most sensitive to subadult (age 1-3) mortality, which had a substantially higher value of 45% of variation explained; the next set of important parameters explaining 11-17% were % of females breeding, adult mortality, and litter size.

These results indicate investments in research to understand what contributes most strongly to the most sensitive demography parameters, especially mortality in 1-3 year olds, % females breeding, and adult mortality, would be helpful in guiding management activities to improve these parameters.

Table 4. Sensitivity of HMV population growth rate (stoch-r) to various life history traits

Parameter	**Range Parameter is Varied Across**	**% Variation in stoch(r) explained**
Subadult (1-3) Mortality	10-50	45.1
% Females Breeding	33-100	16.6
Adult Mortality	10-50	15.1
Litter Size	5-13	11.4
0-1 Mortality	10-70	8.0
Environmental Variance	0.25-1.25 * baseline rate of EV in %Pair Success and each stage's mortality rate	0.0
Inbreeding Depression	0.5-1.5 * baseline rate	0.0

Wild: How do potential catastrophes put populations at risk?

The catastrophes as designed in Table 2 represent likely potential impacts of increased drought, catastrophic fire from military activity, and periodic flooding; note that this table also includes the frequency that this catastrophe is thought to currently impact the 21 sites across HMV range as well as what experts felt might be likely in the future. We modeled each catastrophe alone as well as all catastrophes occurring together in the model (but not necessarily in the same model year unless they stochastically happened to co-occur, which would likely be rare).

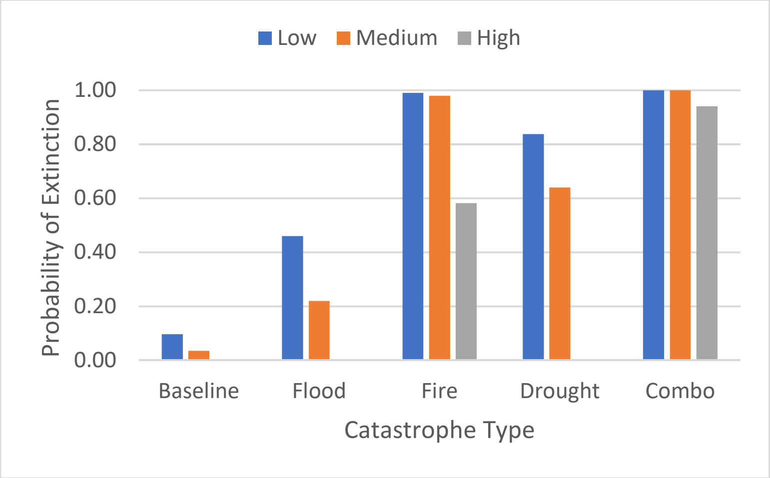

Figure 9. Probability of extinction for three different life histories (High, Medium, Low) when different catastrophes are included. The probability of extinction is the proportion of 1000 model iterations that went extinct.

All catastrophes significantly impacted dynamics, strongly increasing extinction risk for Medium and Low populations and even introducing extinction risk for High populations (Fig. 9). Baseline extinction risks (0-0.10 depending on population) were increased to over P(E) = 0.22 depending on the catastrophe scenario and population. When turned on individually, *Fire* was the catastrophe that increased extinction risk the most across all three population dynamics, resulting in P(E) that increased from baseline levels to 0.58 (High) or over 0.98 (Medium, Low). However, based on expert judgement this catastrophic fire is only a risk at two sites. *Drought* was the second most impactful (Fig. 9), and is quite prevalent across sites (Table 2). *Flood* was the least impactful catastrophe, but still substantially increased P(E) from baseline levels to 0.22 (Medium) or 0.46 (Low). In the *Combo Catastrophes* scenario, extinction was near certain (1.0) for all three life histories.

In terms of growth rate, almost all catastrophe scenarios turned stoch-r from growing to declining for Low or Medium populations (Tables B2, B3). For High populations, growth rate was substantially reduced from the baseline rate of 0.22 (SD = 0.24) but only the *Combo Catastrophes* scenario resulted in a negative growth rate of stoch-r = -0.07 (SD = 0.69; Table B4).

In additional scenarios in combination with other model changes, we used *Drought* to better reflect populations that have inherent higher extinction risk and declining population growth rate; as this risk is wide-spread across sites, this was a good way to explore interactions that might put populations at risk.

Across the HMV range, there are different likelihoods that these catastrophes are affecting the populations currently or in the future (Table 2), with drought being the most likely catastrophe to impact most sites across the range. Although the expert group hypothesized an impact of drought on dynamics, its true potential impact is unknown. Further study on the impact of drought, likelihood at individual sites, and the potential conservation activities that could mitigate impacts is warranted.

Wild: How does initial population size influence population dynamics?

Smaller populations are more susceptible to the stochastic threats that lead to the extinction vortex.

Model results suggest that any population with vital rates/growth rate resembling the High population has the demographic resilience to persist at any population size, since P(E) = 0 across all initial sizes (Fig. 10). For Low or Medium dynamics populations, extinction risk substantially increased as size decreased, with sizes of 100 or below representing at least some extinction risk and small populations of 20 having strong risks (Medium P(E) = 0.68, Low = 0.82; Fig. 10).

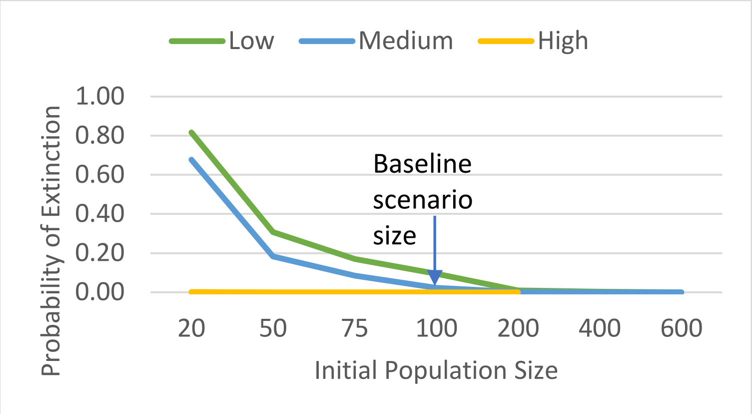

Figure 10. Probability of extinction for three different life histories (High, Medium, Low) with different initial population sizes. The probability of extinction is the proportion of 1000 model iterations that went extinct.

Population growth rate is also an important indicator of viability, and it remained positive (growing) at initial population sizes of 50 or above; however, when Initial N = 20, the Medium population declined at -0.01 (SD = 0.31) and the Low declined at -0.03 (SD = 0.32), highlighting the stochastic risks of smaller population sizes.

These results highlight the risks of small population size, even where there is the potential for strong population growth (e.g. the “Medium” growth rate population). **Based on expert judgement, it is likely that many of the existing HMV sites hold small populations – nine out of 14 sites where size could be estimated were 50 or fewer individuals (Fig. 2, Appendix C). These populations may have elevated extinction risk if their underlying demographic rates mirror or fall below those of the Medium or Low population. Increasing population size or connectivity across sites is likely important for decreasing extinction risk.**

Wild: How does inbreeding depression influence population dynamics?

We compared scenarios with no inbreeding, low inbreeding (lethal equivalents = 3), and the level of inbreeding depression included in the baseline scenarios (lethal equivalents = 6.29). Reduced levels of inbreeding did not substantially change stoch-r or P(E) for the High or Medium population dynamics, but for the Low population, they did (Tables B2-B4). The baseline (i.e. the scenario with the most severe inbreeding depression) scenario's P(E) = 0.10 was reduced to less than 0.03 under scenarios with lower inbreeding.

A population exhibiting Low population dynamics is likely smaller than other populations due to slower growth and higher stochastic dynamics and thus more susceptible to small population dynamics, exacerbated by inbreeding depression. Indeed, models of the Low population with inbreeding depression showed extinction risk of 0.10 while those without inbreeding depression only had P(E) = 0.01 (Table B2). This effect will likely be exacerbated at a starting size smaller than the 100. We have taken the conservative approach of including inbreeding depression in all other scenarios to reflect this potential impact.

Wild: How do different release strategies influence population dynamics?

We mostly focus on the Medium and Low populations for exploration of release strategies, as it is unlikely that managers would feel the need to reintroduce into a population exhibiting High dynamics.

1. **<u>In the absence of drought</u>, releases essentially eliminate extinction risk for these three example populations, and this result is robust to release group size, post-release survival, duration, and initial population size.** For the Low population, where baseline P(E) when initial N=100 was 0.10 and when initial N=20 was 0.82, extinction risk with releases was substantially reduced, to less than 0.05 for the majority of scenarios combining different level of releases (25, 50, 75), post-release survival (20, 100%), initial population size (N=0, 20, 100), and duration of release (20 or 10 years) (Table 5). For the Medium population, where baseline P(E) was 0.03 when N=100 or 0.68 when N=20, P(E) was essentially 0 for almost all scenarios (Table 5). For both populations, the riskiest scenario was the combination of starting a new population (N=0) with low post-release survival (20%), low numbers of releases (25), and only releasing for 10 years – in which case P(E) was 29% for Low and 17% for Medium. That extinction risk is eliminated by releasing longer (i.e. the 20-year scenarios), or releasing more individuals (10 years, 50 or 75 releases) (Table 5). In all these scenarios, once releases stopped the populations maintain strong dynamics (stable/positive growth rates).

Table 5. Probability of Extinction for Low or Medium population dynamics in drought-free scenarios, where scenarios varied post-release survival, annual number of releases, duration of releases, and initial population size. Probability of extinction is the proportion of 1000 model iterations where the population went extinct. Blank cells are scenario combinations that were not run.

		20 Years of Releases						**10 Years of Releases**					
		LOW population			**MEDIUM population**			**LOW population**			**MEDIUM population**		
Post-Release Survival	**Annual Release #**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**
-	0 (Baseline)		0.82	0.10		0.68	0.03		0.82	0.10		0.68	0.03
100%	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00		0.00
100%	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00		0.00
100%	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00		0.00
20%	25	0.05	0.04	0.01	0.02	0.01	0.00	0.29			0.17		
20%	50	0.01	0.01	0.00	0.00	0.00	0.00	0.06			0.03		
20%	75	0.00	0.00	0.00	0.00	0.00	0.00	0.02			0.00		

2. **In scenarios where declining dynamics are more likely (e.g., including the DROUGHT catastrophe), reintroduction lowers extinction risk but cannot eliminate it, and extinction risk remains moderate to high for many combinations.** For the baseline in either the Low or Medium populations, drought led to high extinction risk (0.84, 0.64 respectively), but that risk is strongly reduced (less than 0.27 for Low, 0.11 for Medium) if releases are carried out for 20 years and post-release survival is 100%, regardless of starting population size (Table 6). If post-release survival is lower (20%), P(E) is much worse, ranging as high as 0.76 (Low) or 0.52 (Medium) for the "worst" combination of 20% survival, N=0, and 25 releases/year. If releases only occur for 10 years rather than 20, extinction risk is substantially higher than if they occur for 20 (Table 6, right-hand side).

Table 6. Probability of Extinction for Low or Medium population dynamics in scenarios including drought, where scenarios varied post-release survival, annual number of releases, duration of releases, and initial population size. Probability of extinction is the proportion of 1000 model iterations where the population went extinct. Blank cells are scenario combinations that were not run.

		20 Years of Releases						**10 Years of Releases**					
		LOW population			**MEDIUM population**			**LOW population**			**MEDIUM population**		
Post-release Survival	**Annual Release #**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**	**N = 0**	**N = 20**	**N = 100**
-	0 (Baseline)			0.84			0.64			0.84			0.64
100%	25	0.22	0.27	0.26	0.09	0.11	0.10	0.51	0.49	0.40	0.25	0.25	0.19
100%	50	0.15	0.15	0.15	0.05	0.06	0.05	0.33	0.30	0.28	0.14	0.14	0.13
100%	75	0.14	0.16	0.15	0.06	0.04	0.05	0.27	0.25	0.28	0.11	0.11	0.11
20%	25	0.76	0.71	0.56	0.52	0.47	0.31	0.91	0.89	0.90	0.74	0.75	0.75
20%	50	0.50	0.46	0.41	0.27	0.26	0.20	0.81	0.75	0.61	0.60	0.50	0.35
20%	75	0.36	0.34	0.31	0.17	0.15	0.13	0.67	0.64	0.54	0.43	0.40	0.30

However, while drought-scenario extinction risk is lowered substantially by releases, population trajectories can be different and once releases stop populations will continue to decline (Fig. 11). For this example, in a scenario with 25 releases/year for 20 years (100% post-release survival), a comparison of the mean population size with and without drought illustrates that post-release declines will likely happen even if extinction risk is significantly lower (in this example, P(E) = 0.26 for Low and 0.10 for Medium). While drought is a specific example of something that could turn overall population growth rate negative, many other factors might result in slightly declining populations, and in such populations releases will not “save” the population – demographic rates would need to improve for long-term stability.

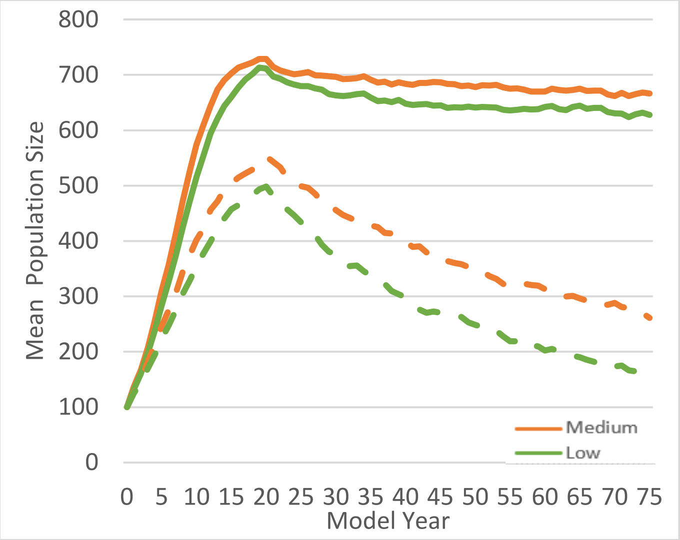

Figure 11. Mean population size for Medium and Low populations with releases (25/year) with (solid) and without (dashed) droughts included in scenario. Mean is the average across any non-extinct iterations, averaged across 1000 model iterations.

3. **Does the age structure of release groups matter?**

As there is a cost to holding snakes at HMVCC for multiple years before releasing them, we compared scenarios where we released snakes in the baseline (mixed age) structure, or only 1 year olds, 3 year olds, or adults. In scenarios with 25 releases/year without drought and 100% post-release survival, there is no difference in P(E) between releasing different age structures (all 0.00), and only minimal difference in stoch-r (range 0.06 – 0.08). This did not change if we were forming a new population (N=0) or starting with a smaller population (N=20), or with the number of releases. However, there was a slight advantage in terms of population growth when adults are released compared to other age structures, as adults are able to reproduce immediately post-release. The slowest growth comes when 1 year olds are released (Fig. 12). Note that all

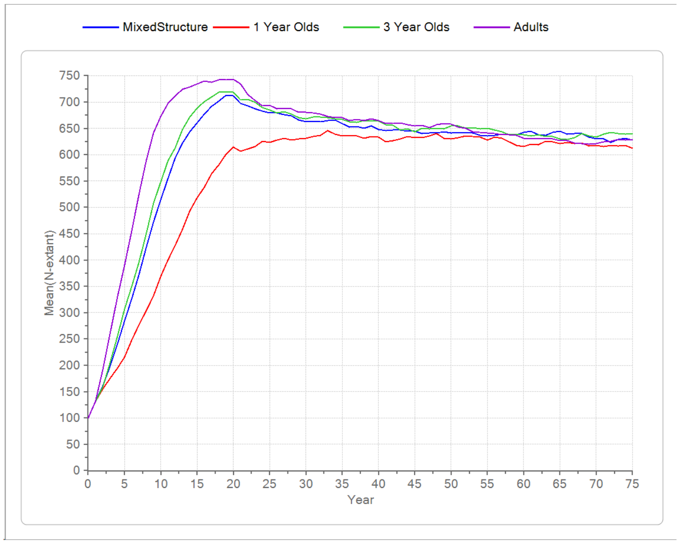

Figure 12. Mean population size for the Low population, with scenarios varying age structure. Mean is the average across any non-extinct iterations, averaged across 1000 model iterations.

scenarios used constant post-release survival across age cohorts; there is no information on the interaction of age and post-release survival, but if it varies it could influence the optimal strategy. **The low observed difference in P(E) and stoch-r suggests managers can release whatever is best for HMVCC's management. However, releasing adults or 3 year olds results in more rapid growth, which might be beneficial if managers desire more immediate results, or if other scenarios not modeled in combination with varying age structure (e.g. shorter release duration, lower post-release survival, drought dynamics, etc.) might be in effect.** The center does release gravid females, a practice that could optimize rapid potential growth at a site.

4. **What is the quickest strategy for building a new wild population?**
Managers suggested that sustaining releases at a site for 20 years might be unlikely, and wanted to identify scenarios that resulted in quicker population establishment. For the purposes of this scenario set we'll define "establishment" as populations that have a P(E) ≤ 0.10.

In the absence of droughts (top of Table 7), if post-release survival is 20%, a Low population can become established by releasing for 5 years but requires 100 animals/year, or releasing for 10 years with 50 or more animals released/year while a Medium population can reach that establishment threshold in 5 years if 75 animals are released. If post-release survival is higher at 60%, there are multiple paths to establishment, with the quickest being releasing 50 or more individuals for 3 years both Low and Medium. However, if droughts are included, all scenarios reflect much higher extinction risk, and the only modeled combinations that resulted in a scenario under the 0.10 P(E) threshold were for a Medium dynamics population with 60% post-release survival and 20 years of at least 50 releases/year (bottom half of Table 7).

Table 7. Probability of Extinction for Low or Medium population dynamics in scenarios where initial population size = 0, where scenarios varied post-release survival, annual number of releases, duration of releases, and drought (yes/no). Probability of extinction is the proportion of 1000 model iterations that went extinct

			Low				**Medium**			
			Annual # Releases				**Annual # Releases**			
Post-Release Survival	**# of Release Years**	**Drought**	**25**	**50**	**75**	**100**	**25**	**50**	**75**	**100**
20%	**3**	**No**	0.90	0.60	0.37	0.23	0.81	0.44	0.23	0.12
20%	**5**	**No**	0.68	0.31	0.13	0.04	0.53	0.15	0.08	0.02
20%	**10**	**No**	0.29	0.06	0.02		0.17	0.03	0.00	
20%	**20**	**No**	0.01	0.00	0.00		0.00	0.00	0.00	
60%	**3**	**No**	0.39	0.10	0.03	0.02	0.23	0.04	0.01	0.01
60%	**5**	**No**	0.15	0.03	0.01	0.00	0.07	0.01	0.00	0.00
20%	**3**	**Yes**	1.00	0.99	0.96	0.94	0.99	0.95	0.86	0.81
20%	**5**	**Yes**	0.99	0.95	0.87	0.81	0.95	0.84	0.70	0.56
20%	**10**	**Yes**	0.91	0.81	0.67		0.74	0.60	0.43	
20%	**20**	**Yes**	0.76	0.50	0.36		0.52	0.27	0.17	
60%	**3**	**Yes**	0.96	0.84	0.76	0.64	0.89	0.64	0.51	0.40
60%	**5**	**Yes**	0.99	0.55	0.42	0.48	0.97	0.30	0.21	0.27
60%	**10**	**Yes**	0.65	0.44	0.35	0.32	0.43	0.22	0.17	0.12
60%	**20**	**Yes**	0.36	0.22	0.17	0.17	0.16	0.07	0.06	0.06

These results may be confusing because the tables don't necessarily reflect the total number of releases but use a rate per duration. When we graph the cumulative releases across different release strategies in comparison to P(E), we can better see the relationship between post-release survival and presence/absence of drought (Fig. 13). Using the same 0.10 threshold, we can see different cumulative numbers needed, e.g. 150 or higher if post-release survival is high without drought, 500 or higher if post-release survival is lower without drought, and no chance at reaching the threshold if drought is present.

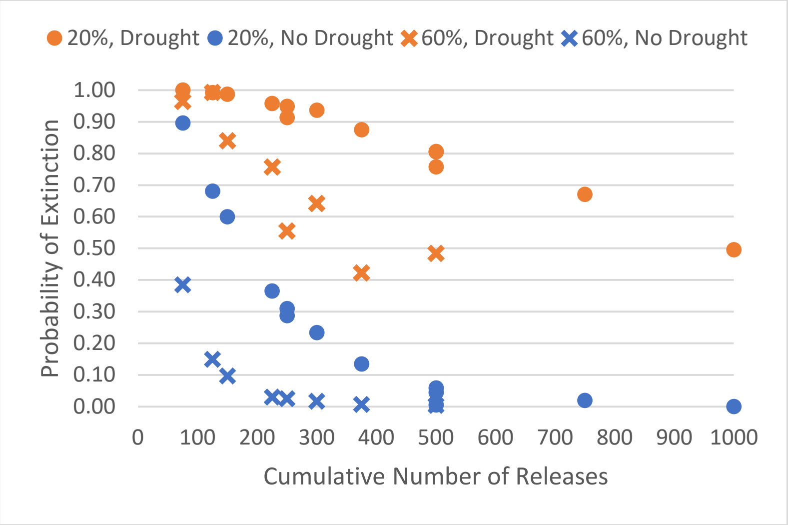

Figure 13. Probability of Extinction for Low population dynamics, with scenarios varying drought (with/without), post-release survival (20%, 60%), and the cumulative number of releases (duration of releases x annual number of releases). Probability of extinction is the proportion of 1000 model iterations where the population went extinct.

Wild: How does a threat of temporarily converting grassland to agriculture impact populations?

This scenario models a one-time event where HMV grassland is plowed and then can recover. We assume that 25% of the habitat is impacted in a single year event, and that mortality is higher due to higher predation rate and possibly direct mortality on the plowed site. This scenario resulted in only a slight increase in P(E) for Medium and Low populations, and no increase for High populations (Fig. 14, Tables B2-B4).

Wild: How does increased mortality across all age classes impact populations?

This scenario models a sustained increase in mortality by 10% or 25%, which could occur with intensive grazing or increased predator pressure. These scenarios substantially increased extinction risk to P(E) = 0.50 or higher, with especially severe impacts for Low and Medium populations (Fig. 14, Tables B2-B4).

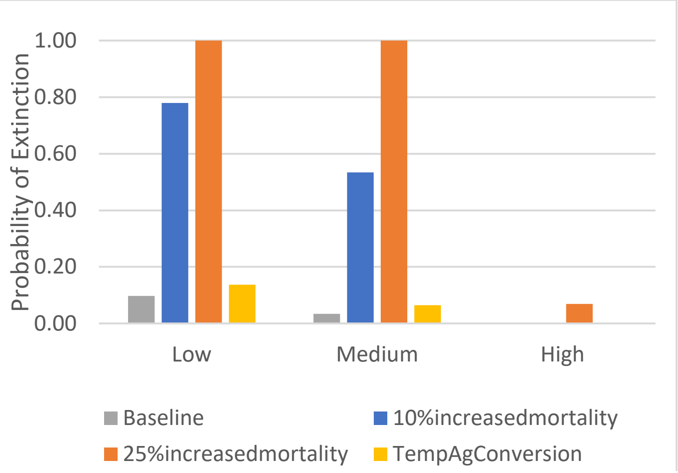

Figure 14. Probability of extinction for three different life histories (High, Medium, Low) with different scenarios representing temporary ag conversion or increased mortality. The probability of extinction is the proportion of 1000 model iterations that went extinct.

Conclusions and Recommendations

Model Limitations - Uncertainty

HMVCC Model Uncertainty

The HMVCC model is based on a studbook containing records on over 5000 snakes, a strong history of reproduction ever since *ex situ* breeding began in 2004, and strong growth over the last 20 years. Despite this rich historical dataset, there are still areas of uncertainty, namely:

- Adult (age 4+) mortality rates: our estimates are based on the full dataset (2004-2022), but although there are over 5000 individuals in the studbook, relatively few make it into the start of the adult age class with very few individuals or deaths are recorded in the oldest ages (>10-19 years old). This is most likely because HMVCC management practice is that once adults have demographically contributed to the next generation, they are released into the wild and their (likely) deaths are not directly observed. While the adult mortality rates from 4-10 are based on better sample sizes, they also likely reflect a time period where many adults are released and thus censored out of adult mortality calculations. Because of this, the HMVCC model likely underestimates true adult mortality for the species. This may be the reason that there was an over-accumulation of adults in test models that then required us to mechanistically release adults anytime there were more than 60 females or 40 males.
- Juvenile (0-1) mortality rates: the modeled baseline rate for non-inbred individuals of 12.6 reflects the period after husbandry changes were made to reduce density of juvenile enclosures to counter-act higher juvenile mortality after 2018, and exclude a catastrophic year in 2020 when heaters malfunctioning caused higher mortality. Using this rate assumes that these husbandry changes will be maintained in the long-term.
- Reproduction (mean litter size) was based on a period from 2021-2023 of improved diets with more mice fed. However, the modeling assumes that that amount of feeder prey production could be sustained even if population size increases.

Overall, HMVCC was in a period of change and rapid growth after the facility expansion in 2022, and that made it challenging to do any historical validation of the model or to compare model output against anything but population performance in 2023. However, in the ways we could validate the HMVCC model, the baseline scenario did create realistic numbers of births, could support releases, and seemed to indicate the ability to continue to robustly grow if needed. The short-term growth from 2022 to 2023 ($r = 0.41$ for the single year, or lambda = 1.5) does indicate a strong demographic potential.

Uncertainty in genetic projections for HMVCC is also important to consider. Vortex is more optimistic in its genetic calculations and projections then other commonly used software for managing *ex situ* populations, such as PMx. One reason for this is that in Vortex all UNK parents are assumed to be WILD, making them completely unrelated to the existing population when in reality there may be good evidence this is true[3]. In addition, wild founders are assumed to be completely unrelated unless some founding relationships are built into the studbook. In the creation of the HMVCC population, five snakes were taken from sites across Hungary, with no assumptions about relationships between the snakes at a

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[3] An example of this is that broods of snakes born at HMVCC on the same birth date but an unknown sire (for example, female studbook # 131's 7 offspring born on 8/1/2011) are likely full siblings (if we assume that multiple paternity is rare), but the Vortex import process would give them each a wild sire giving them more genetic uniqueness then they actually have.

site built into the studbook. Thus, the analysis assumes each of those individuals is unrelated and, assuming they bred, treat them as a founder. In reality, individuals that came from small declining populations may share some level of relatedness, so this assumption may make genetic estimates look more positive than they really are. In the absence of molecular analysis to understand the relationships between founders, such simplifications are necessary. These assumptions can make genetic projections look overly optimistic, as well as hiding or masking potential inbreeding depression that may be impacting the population. However, given the large number of founders, robust population growth, and large population size, it is likely that the HMVCC population does retain robust genetic diversity, and we saw minimal difference in genetic results for the majority of scenarios, indicating that it is likely that the population will remain genetically healthy.

Wild Model Uncertainty

The wild HMV model is based on a small amount of direct data and on experts' best assessments about likely vital rates, both from the 2001 PHVA (Korsós et al., 2002) and from discussions in preparation for this PVA. Although there has been ongoing monitoring of wild populations, especially at sites associated with release of HMVCC snakes, initial attempts at mark recapture analysis to produce survival estimates were unable to yield robust estimates for use in the model, and there is still a great deal we don't know about the population ecology of HMV.

To address this large level of uncertainty, our modeling approach focused on three potential life history patterns representing varying levels of growth, and tried to illustrate how resilient those three life history patterns were to general threats (small population size, stochastic catastrophic events) and potential conservation activities (releases). We cannot necessarily tie any specific model dynamics to any focal HMV site, and should view model results with a healthy dose of caution. However, the larger patterns can help guide general approaches to conservation action, point to important experiments that may help build knowledge over time, and identify the model parameters that were more important to estimate accurately or target for action.

Conclusions/Recommendations:

1. HMVCC:
    a. Given the mortality and reproductive rates used in the baseline scenario, the population is robust and has a strong ability to grow if needed to support releases or fill available spaces. The genetic predictions of the baseline scenario should be interpreted to indicate that the population has a good chance of remaining genetically healthy and robust under current management strategies, with minimal loss of genetic diversity (GD) over the next 75 years.
    b. HMVCC can comfortably support the baseline target of 200 1-3 year old snakes released/year plus surplus adults released for the next 20 years. If the wild populations need more snakes for release, managers should consider strategies like 1) staying below the threshold of 325 1-3 year old snakes/year, or 2) not having a sustained high level of harvest, but instead allowing high harvest for a year or two and then allowing a few years for the population to rebound.
    c. While historic data indicate an impact of inbreeding depression on the juvenile (0-1) mortality rate, when projected forward this relationship has little long-term impact on

    the population's demographics. It is possible that as inbreeding continues to accumulate in the population, additional demographic rates (litter size, other stage's mortality rates) might start to be impacted. Maintaining the studbook data will enable ongoing review of the potential impact of inbreeding on population dynamics.
   d. While bringing in new wild-caught potential founders to HMVCC can't hurt the population genetically (and more founders is typically better), model scenarios suggest that bringing in new founders had minimal impact on long-term GD retained.
   e. The catastrophe scenarios indicated that HMVCC is demographically robust to the types of catastrophes that the group of HMV experts could envision impacting it, even to those catastrophes that were presumed to be dire. However, there is still some inherent risk in maintaining a single population as the source for reintroductions.
   f. After releases stop, the HMVCC population can be maintained at a smaller size (based on scenarios, at least 100 individuals) and still be a demographically and genetically viable assurance population that protects against total extinction if wild populations are lost. However, these values should be reevaluated at the point where the program is transitioning to that assurance mode from its current stage of being a source for reintroduction to verify a final target number based on more up-to-date information.
   g. Despite the rich studbook dataset with over 5000 snakes, there is still some uncertainty in the underlying vital rates for the HMVCC model (see "HMVCC Model Uncertainty above").
2. Wild dynamics:
   a. Since our current lack of understanding on wild demographic rates (mortality, female probability of breeding, litter size) is low, we were limited to a largely theoretical approach (with three different population life histories) to projecting wild dynamics. However, this approach remains useful for drawing general conclusions. Focusing on monitoring wild populations to yield better estimates of survival and reproduction will be helpful to ground-truth these conclusions and the impact of conservation actions.
   b. Sensitivity analysis indicated that population growth (stoch-r) was most sensitive to subadult (age 1-3) mortality, which had a substantially higher value of 45% of variation explained; the next set of important parameters explaining 11-17% were % of females breeding, adult mortality, and litter size. These results indicate the model parameters that it is most important to accurately estimate and the ones that may be good targets for management actions, if actions can be identified that strongly influence them. Investments in research to understand what contributes most strongly to the most sensitive demography parameters, especially subadult mortality, would be helpful in guiding management activities to improve these parameters.
   c. The catastrophes envisioned by the modeling group strongly influenced the three life histories, resulting in increases from baseline extinction risks (0-0.10 depending on population) to P(E) = 0.48 to 0.99 depending on the catastrophe and population. Across the HMV range, there are different likelihoods that these catastrophes are affecting the populations currently or in the future (Table 2), with drought being the most likely catastrophe to impact most sites across the range. The expert group hypothesized an impact of drought on dynamics which resulted in P(E) = 0.64 (Medium) or 0.84 (Low), but we do not know the true potential impact; scenarios as designed may be overly pessimistic or optimistic. Given the potential negative influence of drought on the three

life histories and the likelihood that most HMV sites may be affected by it, identifying its true potential impact, likelihood at individual sites, and/or the potential conservation activities that could mitigate it are likely important.

d. Smaller population sizes make HMV populations more vulnerable. Extinction risk substantially increased for Low or Medium dynamics populations below sizes of 100, and small populations of 20 had strong risks (Medium P(E) = 0.68, Low = 0.82). Based on expert judgement, it is likely that many of the existing HMV sites hold small populations – nine out of 14 sites where size could be guesstimated were estimated at 50 or fewer individuals (Fig. 2, Appendix C). These populations may have elevated extinction risk if their underlying demographic rates mirror those of the Medium or Low population (or worse). Increasing size or connectivity across sites is likely important to decreasing extinction risk.

e. The impact of releases was strongly influenced by whether models included the drought effect or not.

   i. In the absence of drought, releases essentially eliminate extinction risk for these three example populations, and this result is robust to release group size, post-release survival, duration, and initial population size. In scenarios where declining dynamics are more likely (e.g., including the DROUGHT catastrophe), reintroduction substantially lowers extinction risk but cannot eliminate it, and extinction risk remains moderate to high for many combinations. The Low population's P(E) never dropped below 0.14 in any combination, while the Medium population's P(E) only stayed low (below ~0.10) if post-release survival was 100% (Table 6).

   ii. To grow a new population more quickly, it is likely advantageous to release adults or 3 year olds as it results in more rapid growth, although it does not have any impact on extinction risk or long-term growth (Fig. 12).

   iii. If managers want to build a new wild population, we saw very different likelihoods of establishment depending on whether the drought effect was included. Without drought, establishing a population with less than P(E) = 0.10 required at least 5 years of releases if post-release survival was low (20%), but could be done in 3 years if it was 60%. However, if droughts are included, all scenarios reflect much higher extinction risk, and no modeled combinations resulted in a scenario under the 0.10 P(E) threshold (Table 7).

   iv. It would be advantageous for managers to more directly test hypotheses about the impacts of different release group sizes, frequencies, ages, and evaluate how post-release survival and population establishment might vary with different sites that might vary in habitat quality, predation pressure, or other factors. Gaining a better understanding of post-release survival under different conditions will help fine-tune the most effective release strategies. Although post-release survival was not included in the sensitivity analysis, the release scenarios do indicate that it is influential when combined with other stressors that make a population vulnerable (small size, small number of cumulative releases, drought). As the *ex situ* population appears to have the capacity to support large numbers of annual releases, managers could take an experimental approach to help optimize release strategies.

Ultimately, the PVA model supports reintroduction as a strong conservation action that can be taken to counteract the impacts of potentially declining population dynamics. We can’t know which of these scenarios best replicates what is happening in the wild, so investing time in understanding wild population dynamics and what occurs post-release at populations that are supplemented will provide better insights into wild dynamics for future decision-making.

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Appendix III-A. Supporting Analyses

HMVCC Model Parameters

Studbook downloaded from ZIMS 30 January 2024, imported into PopLink 2. 52 (Faust et al., 2019) (to facilitate further analysis), and then exported into Excel. All analyses conducted by L. Faust and A. Parsons.

Brood Size (# of live-born offspring)

Date window: 1 January 2021 – 31 December 2023, based on time period where a prey breeding colony was created to support increased prey (mice) in female diets, with the assumption that these richer diets may affect reproduction (no statistical testing to evaluate that).

Other hypothesis tested: we investigated whether 1st time mothers had smaller litter sizes than multi-parous mothers, under the assumption that either smaller size or less experience may lead to smaller litter size. We used the same date window and found no difference based on parity (Wilcoxon rank sum test, W = 045.5, p = 0.2918).

Value used: Observed distribution (Fig. A1) with mean of 13.5, SD 3.8

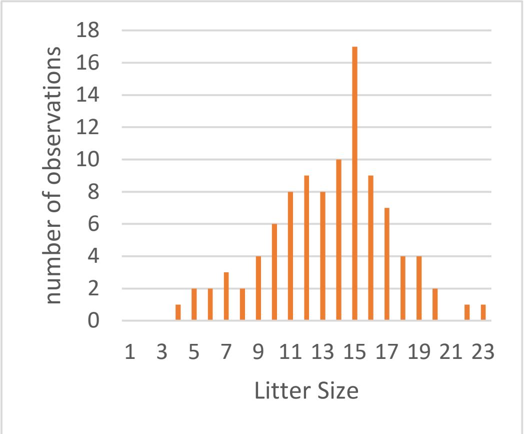


Figure A1. Litter size distribution for 100 litters at HMVCC born in 2021-2023.

Birth Sex Ratio

Date window: 1 January 2021 – 31 December 2023, on the assumption that increased diet (see above) would impact reproduction/sex allocation.

Statistical testing: The observed sex ratio in 2021-2023 (0.489 males, N = 1366 known sex births) was not significantly different from 50:50 (parity) (chi-square = 0.659, df=1, p=0.417).

Value used: Although it was not significantly different, we used the observed value of 48.9% males.

Juvenile (0-1) Mortality

Date window: 1 July 2019 – 30 June 2023 (i.e., encompassing all the mortality from snakes born in 2019 – 2022). This date window was identified as the period of the current husbandry practice, where the juvenile enclosures are maintained at lower density (10 snakes per enclosure) resulting in higher survival compared to earlier years where higher densities were maintained. For our average mortality rate we dropped 2020, which was a year when high mortality (62.8%) occurred because facility heaters malfunctioned causing extra losses that wouldn't be predicted for the future given how equipment is now maintained.

Calculation: This value includes two types of studbook records - deaths and individuals that go lost-to-followup (LTF) in their first year of life; LTF individuals are identified at birth but then at the next enclosure check, they are not found and could have be depredated, escaped, or died due to other causes.

We calculated annual rates as (number of juvenile deaths + number of juvenile LTFs / total number of births). To estimate environmental variation in this and other vital rates, we partitioned out demographic stochasticity from environmental variability by calculating the standard deviation due to environmental variability (σ_{EV}) based on: $\sigma_{EV} = \sqrt{\sigma_{EV}^2} = \sqrt{\sigma_{TOT}^2 - \overline{\sigma_{DS}^2}}$; In which σ_{TOT}^2 is the total variance across the data and $\overline{\sigma_{DS}^2}$ is the mean sampling (binomial) variance across individual rates (Lacy et al., 2021).

Year	# 0-1 Year Old Deaths	# 0-1 Year Old LTF	Total Death/Go LTF	# Births	Annual Juvenile Mortality Rate
2019	20	9	29	396	0.073
2020	147	20		298	
2021	37	5	42	286	0.147
2022	90	9	90	571	0.158
Mean					**0.126**
σ_{EV}					**0.043**

Based on visual inspection of the male and female life tables in PopLink as well as the inbreeding analysis below, there was little to no difference between male and female estimates for this age class so we pooled the sexes together.

Impact of inbreeding on infant mortality:

Arielle Parsons prepared an analysis of studbook data to assess whether inbreeding impacted HMV demographic rates. Using data restricted to the same date window, the probability of infant mortality (death within the first 365 days) did not differ by sex (logistic regression, log-odds coefficient=0.236, N=671, p=0.305), but did increase with inbreeding (logistic regression, log-odds coefficient=7.179, N=683, p=0.0483; Figure A2).

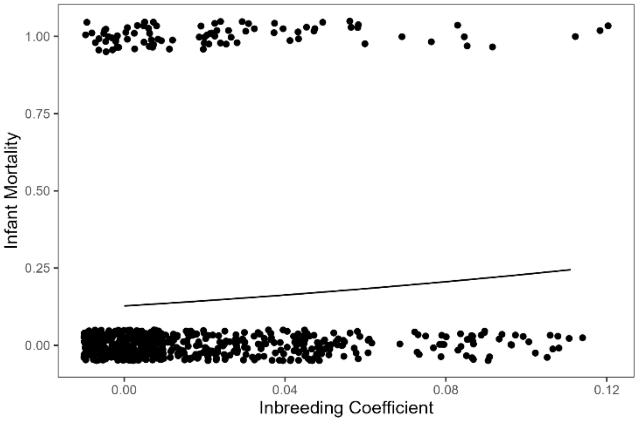


Figure A2: Relationship between inbreeding coefficient and infant mortality for Hungarian Meadow Viper

Value used: Using the general logistic relationship, infant mortality m_o is given by:

$$m_o = \frac{e^{(-1.925+7.179*F)}}{1+e^{(-1.925+7.179*F)}}$$

Where F is the infant inbreeding coefficient. When inbreeding is 0, this resolves to 12.6%, SD = 4.3.

Mortality for Ages 1+

Date window: 1 January 2004 – 31 December 2023 (the entire HMVCC center history), to increase sample sizes.

Calculation: For these calculations, we exported data from the ZIMS studbook to PMx, additional analytical software that calculates life table statistics. We exported the male and female life tables and summed both sex's "Deaths" and "@Risk" columns to make a pooled life table for both sexes, as we did not feel there were enough data to separate out the sexes.

Because these age classes still include some GoLTF individuals that are lost from the breeding population, we added Deaths + age-based GoLTF events that were calculated from the raw events data in the studbook. Like with juveniles, these LTF individuals are identified at birth but then sometime during the year, they are not found and could have be predated in their enclosure, escaped, or dead due to other causes. These rates represent observed mortalities as well as those individuals that just disappear between censuses (similar to apparent survival). Released individuals are removed from the denominator (@Risk).

We calculated annual rates as (number of deaths + number of LTFs / total number of individuals at risk for the event).

Also note that there are relatively few deaths in the adult age classes (deaths = 133, but 940 "snake years at risk" within that time period), reflecting that adults are often released once they've contributed a certain number of offspring, and thus their deaths typically occur in the wild rather than observed in the studbook. Because of this, I believe the adult rates are an underestimate of true *ex situ* mortality.

Statistical testing: None

Value used: age-specific rates using the Vortex equation =LOOKUP(A;12.6;19.2;12.6;15.6;15.8;12.1;12.3;13.2;10.6;24.6;15.5;24.8;0;6.1;7.6;18.3;21.6;47.8;59.3;100); standard estimate of 10% of the rate

Age (years)	@Risk	#Deaths	GoLTF	Deaths+GoLTF	"Mortality"
1	1868.8	115	243	358	0.192
2	1327.5	51	116	167	0.126
3	877.47	35	102	137	0.156
4	241.18	11	27	38	0.158
5	189.46	7	16	23	0.121
6	146.75	9	9	18	0.123
7	106.4	5	9	14	0.132
8	84.671	8	1	9	0.106
9	48.86	5	7	12	0.246
10	32.25	2	3	5	0.155
11	20.151	2	3	5	0.248
12	14.581	0		0	0.000
13	16.471	1		1	0.061
14	13.236	1		1	0.076

Age (years)	**@Risk**	**#Deaths**	**GoLTF**	**Deaths+GoLTF**	**"Mortality"**
15	10.951	1	1	2	0.183
16	9.261	0	2	2	0.216
17	4.186	2		2	0.478
18	1.685	1		1	0.593
19	0				
20	0				
21	0				

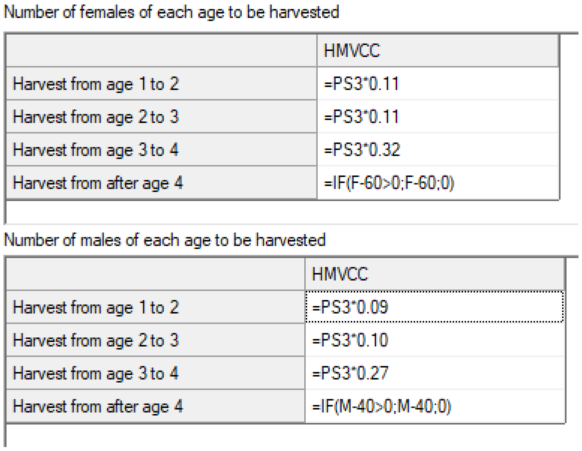
Harvests for release

Date window: Harvest rate (200) and sex/age structure are based on all HMV released in 2023.

Calculation: Sex ratio of releases – 91 males / 200 total = 0.455

Age at Release	Number in 2023	%	Notes	% Male	% Female
0	23				
1	18	**0.21**	Combines 0 and 1 year olds, as we did not set Vortex up to harvest 0 year olds	0.09	0.11
2	42	**0.21**		0.10	0.11
3	106	**0.59**	Combines 3 and 4+, as we were using a different Vortex process to harvest surplus adults	0.27	0.32
4+	11				
	200			0.46	0.55

The Vortex model uses the values above to proportionally multiple by PS3 (the annual target number of releases) (Fig. A3).



Number of females of each age to be harvested

	HMVCC
Harvest from age 1 to 2	=PS3*0.11
Harvest from age 2 to 3	=PS3*0.11
Harvest from age 3 to 4	=PS3*0.32
Harvest from after age 4	=IF(F-60>0;F-60;0)

Number of males of each age to be harvested

	HMVCC
Harvest from age 1 to 2	=PS3*0.09
Harvest from age 2 to 3	=PS3*0.10
Harvest from age 3 to 4	=PS3*0.27
Harvest from after age 4	=IF(M-40>0;M-40;0)

Figure A3. Vortex harvest screen for HMVCC model

In initial testing, a buildup of adults occurred beyond the observed 2023 ratio of adults (28% adult in the initial starting population for the model); in discussions with managers, they would release any excess adults not needed for breeding, and we decided to harvest in a similar way in the model to ensure the modeled population does not have a build-up of old individuals. For adults (above age 4), the Vortex equation ensures that if there are more than 60 females (IF F-60>0), then it harvests the excess (F-60), and if there are less than 60 adult females it doesn't harvest any. The same applies to males, but using 40 as the threshold based on how HMVCC is managed.

Only demographic criteria (age, sex) are used for harvesting, no genetic criteria are used.

Initial Population Size

The initial HMVCC population is read in from a studbook file (HMV_finalstudbook) which includes all individuals and their ancestors to facilitate calculation of starting genetics and demographics. The starting age/sex structure is found in Fig. A4.

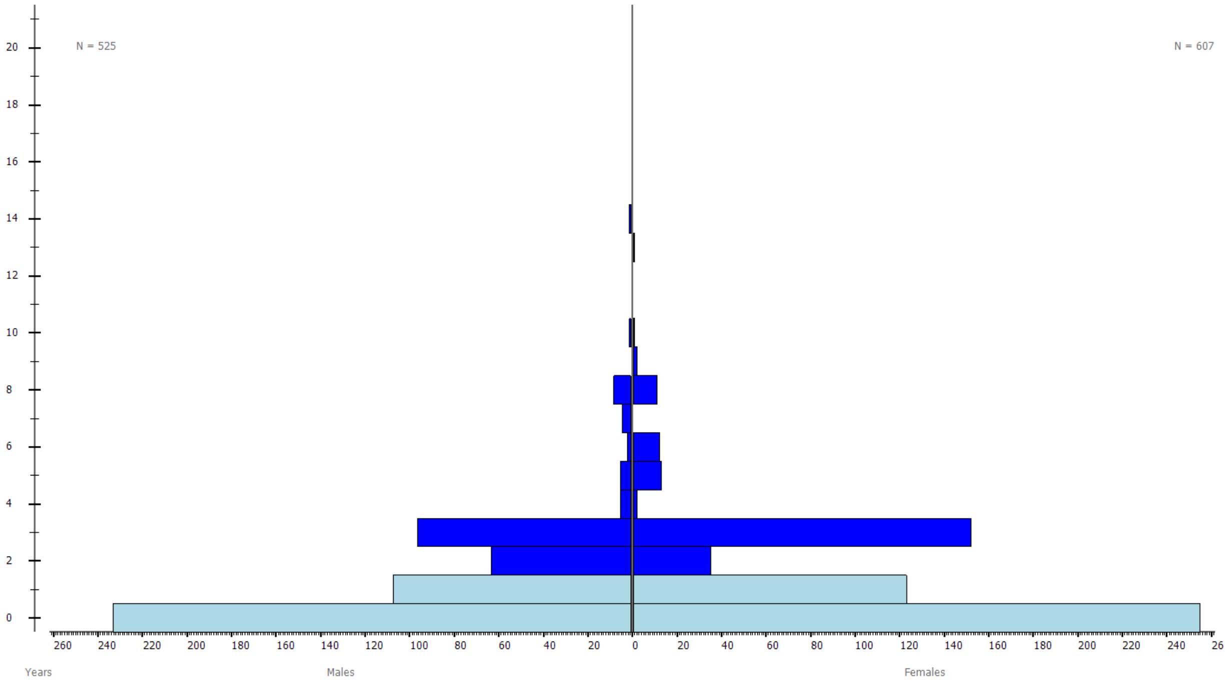


Figure A4. Initial age structure for HMVCC model

Wild Model Parameters

Brood Size

Based on 65 gravid females captured at sites from 1993-2023. We used the observed weights to make an estimate of brood size for each female based on relationships seen within the HMVCC population, (weight*0.35/2.5). We divided sites into High quality (Hánsag, Peszéradacs) or Low quality (Bugac, Dabas, Transylvania), and made average brood estimates at each type of site of 12.5 and 11.4, respectively. Because some offspring within a litter could be still-born, we used the frequency of still-born offspring for the HMVCC population (0.028) to adjust the estimated brood size to only live-born offspring, resulting in High quality sites having a size of 12.1 (SD = 4.1) and Low (and Medium) sites having a size of 11.1 (SD = 4.2).

Wild and Captive Models – Survival Severity Factors in Catastrophes

In a catastrophe year, Vortex uses the Severity (proportion of normal value) for Survival input to adjust that year's mortality rates, along with any specific age/sex or other modifiers. To calculate the Survival Severity factors, we had to translate the PVA group's desired effect from the text description to mortality to survival and then calculate the ratio of survival in a catastrophe year to survival in a normal (baseline) year. Table A1 shows examples of these calculations for the wild Medium dynamics population, and Table A2 shows the calculations for the HMVCC population. In addition, see Appendix D for additional catastrophe-related information.

Table A1. Underlying calculations behind Survival Severity for wild catastrophes, using the example of the Medium Population

	Flood WILD		**Drought WILD**		**Fire WILD**	
Effect being modeled	Increases mortality across all age classes by 50%		1-2 year old mortality increased by 50%, 2-3 year old mortality increased by 20%		90% mortality across all age classes --	
Different age class rates for Medium Population Dynamics Wild model	0-1 mortality	1+ mortality	0-1 mortality	1+ mortality	0-1 mortality	1+ mortality
mortality rate (Baseline)	0.5	0.3	0.5	0.3	0.5	0.3
survival rate (Baseline)	0.5	0.7	0.5	0.7	0.5	0.7
mortality rate (catastrophe) [1]	0.75	0.45	0.75	0.36	0.9	0.9
Survival rate (catastrophe)	0.25	0.55	0.25	0.64	0.1	0.1
Ratio (Survival in catastrophe/ Survival in baseline)	0.50	0.79	0.50	0.91	0.20	0.14

[1] calculated as [baseline mortality rate + (baseline mortality rate*0.5)]

Table A2. Underlying calculations behind Survival Severity for HMVCC catastrophes

	Fire in HMVCC	**Disease in HMVCC**	**Flood in HMVCC**	**Early Spring in HMVCC**
Effect being modeled	**Loss of 140 0-1 year olds (A=0) held indoors**	**Loss of 15 adults (A>3)**	**Doubles all mortality rates**	**90% adult males lost (A>2 && S=M)**
mortality rate (Baseline)	0.126	0.19[2]	0.15[2]	0.19[2]
survival rate (Baseline)	0.874	0.81	0.85	0.81
% mortality in a catastrophe year	0.47	0.25	0.3	0.9
% Survival in a catastrophe year	0.528[1]	0.75[3]	0.7	0.1
Ratio (Survival in catastrophe/ Survival in baseline)	0.60	0.93	0.82	0.12

[1] This % survival is based on the average number of births in the population (405), the number of those that die in a baseline year (51, based on mortality rate of 0.126), the number that die in a catastrophe year (140 based on the definition of catastrophe in the PVA group), yielding total deaths in catastrophe = 191; total survivors = 214, % survival in catastrophe year = 214/405 = 0.528

[2] Use average rates across many age classes for these values rather than age-specific rates

[3] The number of adults in the model output varies widely across years depending on whether releases are occurring or not; this is just a rough approximation of the impact of loss of 15 adults

Appendix III-B. Model Results

Abbreviation	**Description**
P(E)	Probability of extinction in 75 years (i.e. the # of extinct iterations/total # of iterations) across 1000 model iterations.
Stoch-r (SD)	The mean and standard deviation of the stochastic growth rate of the population averaged across all 75 years for all extant (non-extinct) model iterations. When r is > 0.0 (positive), it is a growing population; when r is < 0.0 (negative), it is a declining population, and when r = 0.0 it is a stable population.
GD (SD)	The mean and standard deviation of gene diversity (expected heterozygosity) across all extant (non-extinct) model iterations.

Table B1. HMVCC (*ex situ)* model results

Scenario	**stoch-r**	**SD(r)**	**P(E)**	**GD**	**SD(GD)**
Baseline	0.01	0.07	0.00	0.97	0.00
NoInbreeding	0.01	0.05	0.00	0.97	0.00
Harvest300	0.01	0.09	0.00	0.97	0.01
Harvest325	0.01	0.22	0.10	0.94	0.04
Harvest350	-0.04	0.33	0.49	0.87	0.08
Harvest375	-0.17	0.37	0.88	0.81	0.09
Harvest400	-0.28	0.35	0.99	0.78	0.08
Harvest425	-0.31	0.34	1.00	0.00	0.00
Harvest450	-0.32	0.35	1.00	0.00	0.00
Harvest500	-0.34	0.34	1.00	0.00	0.00
NewFounders2every5	0.01	0.07	0.00	0.98	0.00
NewFounders2every10	0.01	0.07	0.00	0.98	0.00
NewFounders10every5	0.01	0.06	0.00	0.99	0.00
NewFounders10every10	0.01	0.06	0.00	0.99	0.00
Fire	0.01	0.07	0.00	0.97	0.00
Disease	0.02	0.07	0.00	0.97	0.00
Flood	0.02	0.09	0.00	0.97	0.00
EarlySpring	0.01	0.07	0.00	0.97	0.00
Year20K=50	0.04	0.13	0.00	0.84	0.04
Year20K=75	0.02	0.12	0.00	0.89	0.02
Year20K=100	0.02	0.11	0.00	0.91	0.02
Year20K=200	0.01	0.08	0.00	0.95	0.01
Year20K=300	0.01	0.07	0.00	0.96	0.01
Year20K=500	0.01	0.06	0.00	0.96	0.01
Year20K=700	0.01	0.06	0.00	0.97	0.00
Flood+Year20K=50	0.04	0.15	0.00	0.84	0.04
Flood+Year20K=75	0.03	0.14	0.00	0.89	0.02

Scenario	stoch-r	SD(r)	P(E)	GD	SD(GD)
Flood-Year20K=100	0.02	0.12	0.00	0.91	0.02
Flood-Year20K=200	0.02	0.10	0.00	0.94	0.01

Table B2. Select Wild model results – LOW GROWTH POPULATION

Scenario	Population	stoch-r	SD(r)	PE
Wild Baseline	Low	0.03	0.24	0.10
ComboCatastrophes	Low	-0.21	0.63	1.00
Drought	Low	-0.06	0.40	0.84
Fire	Low	-0.13	0.57	0.99
Flood	Low	-0.02	0.29	0.46
TempAgConversion	Low	0.02	0.26	0.14
Wild LowInbreeding	Low	0.04	0.23	0.03
Wild NoInbreeding	Low	0.05	0.23	0.01
Wild N=20	Low	-0.03	0.32	0.82
Wild N=50	Low	0.01	0.26	0.31
Wild N=75	Low	0.02	0.25	0.17
Wild N=100	Low	0.03	0.24	0.09
Wild N=200	Low	0.04	0.22	0.01
Wild N=400	Low	0.04	0.22	0.00
Wild N=600	Low	0.05	0.22	0.00
IncreasedGrazing_10%increasedmortality	Low	-0.05	0.29	0.78
IncreasedGrazing_25%increasedmortality	Low	-0.15	0.34	1.00

Because of the extent of release scenarios it was deemed not helpful to include them in these tables – see results in Tables 5-8 for release scenario results.

Table B3. Wild model results – MEDIUM GROWTH POPULATION

Scenario	Population	stoch-r	SD(r)	PE
Wild Baseline	Medium	0.05	0.24	0.03
ComboCatastrophes	Medium	-0.19	0.63	1.00
Drought	Medium	-0.04	0.39	0.64
Fire	Medium	-0.12	0.58	0.98
Flood	Medium	0.01	0.28	0.22
TempAgConversion	Medium	0.04	0.25	0.07
Wild LowInbreeding	Medium	0.06	0.24	0.01
Wild NoInbreeding	Medium	0.07	0.24	0.00
Wild N=20	Medium	-0.01	0.31	0.68
Wild N=50	Medium	0.03	0.26	0.18
Wild N=75	Medium	0.04	0.25	0.08
Wild N=100	Medium	0.05	0.24	0.02
Wild N=200	Medium	0.06	0.23	0.00

Scenario	Population	stoch-r	SD(r)	PE
Wild N=400	Medium	0.06	0.23	0.00
Wild N=600	Medium	0.06	0.23	0.00
IncreasedGrazing_10%increasedmortality	Medium	-0.03	0.28	0.53
IncreasedGrazing_25%increasedmortality	Medium	-0.12	0.35	1.00

Because of the extent of release scenarios it was deemed not helpful to include them in these tables – see results in Tables 5-8 for release scenario results.

Table B4. Wild model results – HIGH GROWTH POPULATION

Scenario	Population	stoch-r	SD(r)	PE
Wild Baseline	High	0.22	0.24	0.00
ComboCatastrophes	High	-0.09	0.71	0.97
Drought	High	0.13	0.47	0.00
Fire	High	0.02	0.56	0.58
Flood	High	0.19	0.29	0.00
TempAgConversion	High	0.22	0.24	0.00
Wild LowInbreeding	High	0.23	0.24	0.00
Wild NoInbreeding	High	0.23	0.24	0.00
Wild N=20	High	0.20	0.24	0.00
Wild N=50	High	0.22	0.24	0.00
Wild N=75	High	0.22	0.24	0.00
Wild N=100	High	0.22	0.24	0.00
Wild N=200	High	0.23	0.24	0.00
Wild N=400	High	0.23	0.24	0.00
Wild N=600	High	0.23	0.24	0.00
IncreasedGrazing_10%increasedmortality	High	0.16	0.26	0.00
IncreasedGrazing_25%increasedmortality	High	0.03	0.31	0.07

Appendix III-C. Expert Assessments on Existing HMV Populations

Information on 17 existing sites where HMV are present across Hungary and Romania was aggregated by Lisa Faust, Bálint Halpern, Georgiana Păun, and Tibor Sos. Sizes and trends are based on local experts' best guesses, as empirical estimates are not available for any sites at this time.

Locations/Populations	Current estimated or best guess population size	Current Population trend	Country	General Location
Fűzfa-szigetek	100	Stable	Hungary	Hanság
Nagy-domb	50	Increasing	Hungary	Hanság
Pintér-Hany	30	Increasing	Hungary	Hanság
Pap-földje	0-20	Newly established in 2023	Hungary	Hanság
Dabas-Gyón	30	Crashing	Hungary	Dabas-Gyon
Bugac - Nagypuszta	300	Stable / Declining	Hungary	Kiskunság - Bugac
Bugac - Szekercés-szék	50	Increasing	Hungary	Kiskunság - Bugac
Bugac - Tolvajos	50	Stable / Declining	Hungary	Kiskunság - Bugac
Felső-Peszér	300	Stable / Declining	Hungary	Kiskunság
Kettős-hegy	0-20	Newly established in 2022, no sign of success	Hungary	Kiskunság (part of Felső Peszér)
Alsó-Peszér	400	Stable / Increasing	Hungary	Kiskunság
Zsidi-szőlő	0-20	Newly established in 2023	Hungary	Kiskunság (part of Alsó Peszér)
Látó-hegy	50	Stable / Increasing	Hungary	Kiskunság (part of Alsó Peszér)
Suciu's hayfields	300-400	declining	Romania	ROSCI0187 Pajiştile lui Suciu
Radesti hayfields	preliminary data	declining	Romania	ROSCI0187 Pajiştile lui Suciu
Cluj hayfields	preliminary data	TS: uncertain BH: declining	Romania	ROSCI0295 Dealurile Clujului de Est
Bogata hills	preliminary data	declining	Romania	ROSCI0301 Bogata
Tiur hayfields	preliminary data	no data	Romania	expected extension of ROSCI0430 Pajiștile de la Tiur
Borșa hayfields	no data	no data	Romania	ROSCI0295 Dealurile Clujului de Est
Aiton hayfields	no data	no data	Romania	
Bonțida hayfields	no data	no data	Romania	ROSCI0099 lacul Ştiucilor - Sic - Puini – Bonţida