West-Central Lion Ecoregional Population Objective Committee | Winter 2023

Photo courtesy of Cody and LeRee Hensen

The Montana West-central Lion Ecoregional Population Objective Committee met in summer and fall 2023. The committee worked with FWP to define a planning strategy to manage the west-central mountain lion ecoregional population for population sustainability at a target level that maximizes public satisfaction related to lion hunter opportunity, lion conflict, and ungulate population trends. The committee consisted of citizens representing a broad spectrum of mountain lion stakeholders who primarily reside within or close to the ecoregion.

Committee Members

John Barr, Victor

Steven Hawkes, Hamilton

Cody Hensen, Philipsburg

Joshua Lisbon, Missoula

Matt Lumley, Emigrant

John McClernan, Butte

Bill Mitchell, Missoula

Josh Morris, Boulder

Mark Myers, Hamilton

Joshua Pallister, Boulder

Cargill Scott, Whitehall

Todd Seymanski, Great Falls

Trent Sullivan, Boulder

Committee Facilitators

Alex McInturff, PhD, USGS, Washington Cooperative Fish and Wildlife Research Unit, The University of Washington, Seattle, WA

Sarah Sells, PhD, USGS, Montana Cooperative Wildlife Resarch Unit, The University of Montana, Missoula, MT

Science Team

Justin Gude, Wildlife Research Chief, Montana Fish, Wildlife & Parks, Helena

Brian Wakeling, Game Management Bureau Chief, Montana Fish, Wildlife & Parks, Helena

Alixandra Godar, Population Ecologist/Biometrician, Montana Fish, Wildlife & Parks, Helena

Molly Parks, Large Carnivore Coordinator, Montana Fish, Wildlife & Parks, Missoula

Alissa Anderson, Mountain Lion Monitoring Biologist, Montana Fish, Wildlife & Parks, Missoula

Liz Bradley, Region 2 Wildlife Program Manager, Montana Fish, Wildlife & Parks, Missoula

Warren Hansen, Region 3 Wildlife Program Manager, Montana Fish, Wildlife & Parks, Bozeman

Cory Loecker, Region 4 Wildlife Program Manager, Montana Fish, Wildlife & Parks, Great Falls

Rebecca Mowry, Area Biologist, Montana Fish, Wildlife & Parks, Hamilton

Adam Grove Area Biologist, Montana Fish, Wildlife & Parks, Townsend

Jesse Newby, Area Biologist, Montana Fish, Wildlife & Parks, Dillon

Jay Kolbe, Area Biologist, Montana Fish, Wildlife & Parks, White Sulphur Springs

This report was compiled by FWP Science Team, Montana Fish, Wildlife & Parks

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Executive Summary

In 2019, Montana Fish, Wildlife and Parks (FWP) began implementing the Mountain Lion Monitoring and Management Strategy (FWP 2019), which outlines the state's approach to conserving, monitoring, and managing mountain lions (hereafter referred to as lions) within an adaptive management framework. The strategy divides the state into four ecoregions, which delineate the spatial boundaries and scale of all monitoring and management moving forward. Population abundance is estimated in each ecoregion using an integrated population model (IPM) which combines data from mandatory reporting of lion harvest, vital rates estimated from past radio-telemetry studies, and a field-based spatial capture-recapture (SCR) method for estimating population density relative to habitat quality using lion DNA. The IPM is also used to develop projections of future population change under alternative harvest scenarios to inform management decisions.

The West-central Lion Ecoregional Population Objective Committee (LEPOC) was developed to directly engage the public in developing management recommendations upon completion of population monitoring in the West-central ecoregion. The LEPOC was composed of 13 members of the public who reside within or close to the West-central ecoregion, and, as a committee, represented a broad spectrum of lion stakeholder viewpoints. The objective of the LEPOC was to work with FWP to provide a recommendation to the Commission regarding 1) target population trend over a 6-year period, 2) degree of ecoregional population size change (% up or % down), and 3) Lion Management Unit (LMU) emphases (e.g., older-age class harvest, conflict reduction, aid ungulate populations, more opportunity).

Over the course of two sessions in 2023, the LEPOC met to work through a Structured Decision Making (SDM) process. During the first two-day session the committee developed a formalized problem statement, fundamental objectives, and measurable attributes related to the problem statement. The group identified three alternative target population objectives to be considered for a 6-year period (10% increase, no change, 10% decrease) and requested formalized spatial prescriptions for harvest with each prescription incorporating two different types of focal areas:

1) an ungulate focal area with intensified harvest to aid struggling ungulate populations in Lion Management Units 240, 250, 270, and 280 and

2) a lion focal area with reduced harvest where ungulates are over objective to increase local lion populations in Lion Management Units 210, 211, 213, 391, and 413.

The group further requested the FWP science team evaluate the effect of the new 2023-2024 commission quotas and determine population trend over the next six years.

During the second two-day session, FWP presented an overview of how the integrated population model (IPM) is used to evaluate the population objectives of interest to the committee. The presentation then described how harvest prescriptions are created and provided examples of how harvest could be allocated across the ecoregion to target areas of concern. The LEPOC continued working through the SDM process by ranking alternative population objectives and spatial alternatives relative to how well they met the LEPOC fundamental objectives. The group, through an iterative process, refined rankings of the degree to which alternatives would meet fundamental objectives. The LEPOC presented FWP a final recommendation to stabilize the current lion population for 0% change in the West-central Ecoregion lion population between 2023 and 2028, with focal areas of higher harvest in three LMUs (240, 250, and 270) and reduced harvest in six LMUs (210, 211, 213, 380, 291, and 413). FWP will use this working group recommendation as the basis for FWP season recommendations to the Fish and Wildlife Commission. Final action by the commission will be implemented for the lion hunting season beginning in fall 2024.


Photo Credit: Bob Wiesner

Introduction

Background and Committee Purpose

In 2019, The Montana Fish and Wildlife Commission adopted the Montana Mountain Lion Monitoring and Management Strategy (FWP 2019). The strategy outlines the new rigorous, scientific approach to Montana's lion monitoring, management, and conservation efforts. This new strategy incorporates previous research findings demonstrating that lion populations in western North America are well connected and are most effectively managed at large spatial scales (FWP 2019). Accordingly, the updated strategy identified four biologically meaningful lion "ecoregions" within the state (Northwest, West-central, Southwest, and Eastern). These ecoregions are large, contiguous areas of the state within which lion habitat is broadly similar and serve as the spatial framework of FWP's lion management program. The new lion management strategy also directs Montana FWP to use an adaptive harvest management process that directly engages the public in the development of harvest recommendations. Public involvement is achieved through formulation of ecoregion specific Population Objective Committees that bring a wide range of diverse, and often opposing, views on lion conservation and management to the table. By incorporating these diverse stakeholders, FWP intends to recommend lion ecoregional population harvest objectives that ensure viable lion populations while maximizing public satisfaction related to lion hunter opportunity, lion conflict, and ungulate population trends.

Lion Ecoregional Population Objective Committees (LEPOC) will be developed in each of the 3 western ecoregions: Northwest, West-Central, and Southwest. Two winters of field monitoring will be conducted in each of these ecoregions. Once completed, the data from these monitoring efforts will be integrated with harvest and demographic rates to produce an ecoregional lion population estimate, at which time the LEPOC will be established. Standardized field monitoring (FWP 2019) began in the Northwest ecoregion during winters 2019-2020 and 2020-2021, yielding the Northwest ecoregion population estimate in summer 2021 and LEPOC development during the 2021-2022 winter. Meanwhile, field monitoring efforts shifted to the West-central (WC) ecoregion. Field monitoring was conducted during winters 2021-2022 and 2022-2023, with WC ecoregion population estimates developed in summer 2023 and the LEPOC convening during late summer-early fall 2023.

The objective of each LEPOC is to work with FWP to provide a recommendation to the Commission regarding:

- Target population trend over a 6-year period (Increase, Decrease, Stable)
- Degree of ecoregional population size change (% up or % down)
- Lion Management Unit (LMU) emphases (e.g., older-age class harvest, conflict reduction, aid ungulate populations, more opportunity)

Though the LEPOC will recommend a target lion population to achieve in 6 years, they are not charged with recommending season structures, license types, or allocation of harvest among the ecoregion's lion management units to meet the ecoregional population trend objective. Upon completion, FWP will incorporate the LEPOC's recommendations into their harvest recommendations for the Montana Fish and Wildlife Commission. The commission will consider the department's recommendation through their public decision-making process and consider other input in their deliberations. The final decisions will be made within the scope of the normal commission process.

West-central LEPOC Selection


Photo Credit: Molly Parks

The West-central LEPOC consisted of 13 citizens representing a broad spectrum of lion stakeholders who reside within or close to the West-central ecoregion. On March 21, 2023, FWP Helena solicited applications from Montana citizens interested in serving on the LEPOC through a media release. The initial application period closed at 5:00 P.M on April 21, but was extended to solicit additional applications to increase the applicant pool of stakeholders. The final deadline for applicant submissions was 5:00 P.M on April 30, 2023. Applicants were asked to answer 4 supplemental questions that highlighted their interest in serving on the committee, the experience they would bring to the group, and their demonstrated ability to work in a collaborative setting. A multiple-choice survey question also allowed applicants to note which stakeholder group or groups they identified with and could represent on the committee.

Prior to soliciting applications for the LEPOC, FWP set criteria for the committee selection. With a target of 12 members, the committee would be assembled with the goal of capturing the diverse range of viewpoints surrounding lion conservation and management in Montana. Thus, the committee would include two members from each of the following stakeholder groups: hound handlers, lion outfitters, livestock producers, deer hunters, elk or sheep hunters, and the public. Due to the limited committee size of 12 members, FWP sought to incorporate the local stakeholder groups directly vested in the conservation and management of lions in the West-central Ecoregion. Applications were therefore not solicited from national constituency groups, lion researchers, or individuals living outside of the WC ecoregion.

A team of FWP staff made initial recommendations to the Director's Office regarding committee member selections from a pool of 27 applicants. This team included staff from Regions 2, 3, and 4, Game Management Bureau Chief Brian Wakeling, Carnivore Coordinator Molly Parks, and Mountain Lion Monitoring Biologist Alissa Anderson. The FWP Director's Office approved committee member selection and participants were notified of their selection on June 16, 2023. This final committee included:

John Barr	Scott Cargill	Steven Hawkes	Cody Hensen
Joshua Lisbon	Matt Lumley	John McClernan	Bill Mitchell
Josh Morris	Mark Myers	Joshua Pallister	Todd Seymanski
Trent Sullivan			

Process

Work Group Meeting Agendas

Originally, FWP planned to host four days of in-person meetings. Meetings were divided into two sets of two-day sessions (August 15-16, 2023, and October 12-13, 2023) and were held each day from 8:00 A.M. to 5:00 P.M. However, deliberations ran ahead of schedule, and the October 13 meeting was unnecessary with the meetings concluding on the evening of October 12. The meetings were recorded and live-streamed on the FWP website and YouTube, so the public could observe the deliberations at their convenience. There were also two public comment periods, open from 4:00 – 5:00 P.M. on August 15 and October 12 that allowed the public to ask questions or comment on the process. Three members of the public engaged in this part of the process during the October 12 meeting.

FWP Helena shared media releases ahead of scheduled LEPOC meetings (August 8, 2023 and October 5, 2023) to notify the public of the upcoming meeting dates, times, locations, agendas, and web links to the live streamed meetings. This information was posted on the FWP West-central Lion Ecoregional Population Objective Committee webpage (West-central Lion Ecoregional Population Objective Committee | Montana FWP (mt.gov)), along with detailed information needed to make public comment during the public comment periods. Recordings from all meetings were also posted to the website, along with the list of committee members and links to additional lion resources.

Alex McInturff and Sarah Sells facilitated the group through a Structured Decision Making (SDM) process (Runge et al. 2013) and guided the committee through the steps of developing a problem statement, identifying fundamental objectives, identifying alternative population objectives, evaluating alternatives, and making a final recommendation (Figure 1).

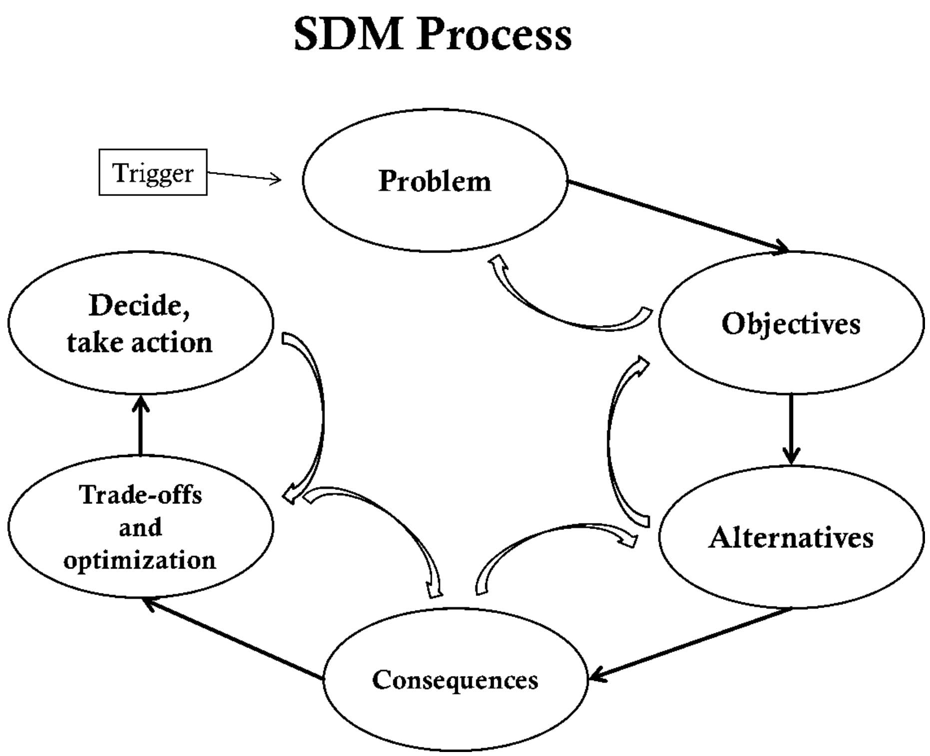


Figure 1. Structured decision making (SDM) process represented by the main steps (ovals and straight arrows). Curved arrows depict how information learned during the process can be used to revisit and revise components produced at earlier steps.

Structured Decision Making

FWP has used SDM to guide work groups through decision development on controversial wildlife management issues (e.g., 2014 Region 2 Lion Work Group meetings [FWP 2014; Mitchell et. al 2018]). Considering the challenging recommendation development process before the LEPOC, SDM was again selected to set participants up for success. Gregory and Keeney (2002) described the SDM process:

> *A structured decision making approach helps resource managers by splitting a tough decision into its parts (referred to here as "elements"). For many complex decisions, making a better choice requires that eight key elements be considered... The first five elements – Clarifying the Problem, Identifying Key Objectives, Creating Alternatives, Assessing Consequences, and Explicitly Addressing Tradeoffs (leading to the acronym PrOACT, a reminder to be proactive) – constitute the core of a structured approach to decision making (Hammond et al., 1999).*

And:

> *[We emphasize] the importance of using a structured decision process to specify and organize values, use these values to create alternatives, and assess tradeoffs to help achieve a desired balance across key objectives. Although these decision making steps are based on common sense, they are often neglected or poorly carried out as part of the complex evaluations of natural resource options…some of the benefits of using a structured, decision focused approach: new and better solutions, increased and more productive participation by stakeholders, and greater defensibility and acceptance of the resource management evaluation process and its conclusions.*

FWP began the LEPOC meetings with several presentations to give the participants relevant context and background information. These presentations started with an introduction to the SDM process (Sarah Sells), followed by context and perspective for the LEPOC and how it plays an important role in Montana's lion management (Brian Wakeling). Previous research was presented on the integrated lion-elk management program in the Bitterroot Valley (Kelly Proffitt; Proffitt et al. 2015, 2020), which highlighted findings on the effect of lion harvest on elk recruitment. This research also led to development of the spatial capture-recapture (SCR) lion monitoring method. The final FWP presentation provided a synopsis of the lion ecoregional monitoring and modeling program (Alix Godar and Alissa Anderson), including density estimates and results from the new monitoring program in the WC Ecoregion during 2021-23 (FWP 2023). Considerable discussion ensued among LEPOC members and FWP staff clarifying the high degree of uncertainty in lion population density in the ecoregion, and that a season recommendation was needed from them nonetheless.

Following these presentations, the committee worked independently with the facilitators to identify common values and objectives, and to reach a mutually agreeable decision that was based solely on the discussion and input from the diverse participants at the table. Competing social values surrounding lion conservation and management were the primary roadblock to a unanimous group decision and public consensus on lion management. Accordingly, rather than participate in the discussion, FWP sought to learn more about these diverse viewpoints from silently observing the group's discussion. However, if at any point the committee had questions, FWP biologists provide any requested information.

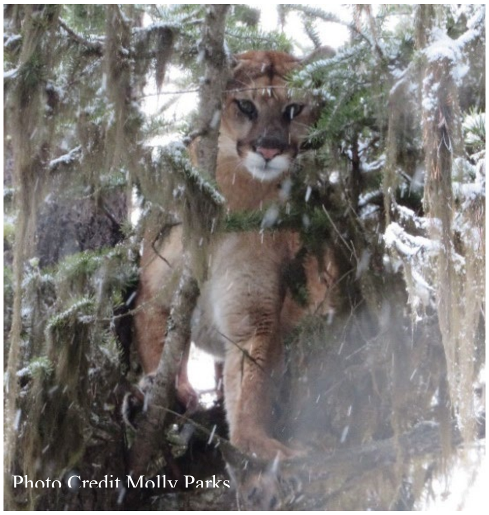


Photo Credit Molly Parks

Following are the consensus products and recommendations from the LEPOC meetings for the West-central Ecoregion. The final recommendations include a target lion population trend and degree of change, identification of focal areas for intensified lion harvest to aid struggling ungulate populations, identification of focal areas for reduced lion harvest to increase local lion populations, and a list of additional recommendations that were not a direct charge of the committee but were important topics that the committee wished to present to the Commission for further consideration. The results from each phase of the SDM process are also described below for transparency and clarity in this decision-making process.

Problem Statement

In SDM, the problem statement clearly states the challenges of the decision-making issue at hand. Without a clearly defined problem statement, decision-makers could solve the wrong problem, use the wrong tools and information, and invest in the wrong solution. The problem statement is therefore the critical first step to any SDM process. While at first glance this step may seem simple, it often takes an investment of time and effort to arrive at a statement that fully and clearly captures a group's input about the challenges at hand.

The LEPOC spent most of the first day formulating a problem statement. The day started with individuals brainstorming the relevant issues surrounding lion management in Montana and specifically the WC Ecoregion. Next, the committee was divided into small groups of 3-4 members to continue developing a list of the key issues while also beginning to establish a rapport with one another. Day one finished with group discussion and development of a draft problem statement encompassing key issues identified. Day two began with a brief discussion of the key issues and allowed the committee to refine their problem statement. The final problem statement identified by the LEPOC was:

This committee is tasked with determining the trajectory of a mountain lion population across a very large area with vast differences in ungulate populations and lion densities. We want healthy populations of both lions and ungulates, and we want to address as best we can the interplay between the two. We need to follow state law to manage all ungulate species (deer, elk, moose, sheep, antelope, goats) by managing predators. We likewise want to maintain the ecosystem services that mountain lions provide (such as selection for diseased ungulates). Different stakeholders have different concerns about mountain lion management. This includes (in no particular order), livestock owners, pet owners, general public/recreationists, lion hunters, ungulate hunters, outfitters, etc.

Overall, this is a challenging, multidimensional problem (e.g., there are effects of other carnivores, forest quality, access, available forage, ungulates that don't migrate, changing land ownerships and uses, etc.), making this a complex issue. We are asked to trust and use data that is very uncertain, and models that do not always agree with what we as hunters have observed in the field. The uncertainty leaves a very large margin for error and it's hard to make a decision based on that. We need to be careful not to implement management based on one condition that detrimentally affects lion populations in a different condition.

Despite these challenges, this committee is tasked with making a recommendation for a target population trend across the west-central lion ecoregion. We will also recommend lion density trends for geographic subsets within the greater ecoregion. These trends should reflect the desired overall ecoregion population trend (declining, stable, increasing) and specific LMU emphases to reflect differences in mountain lion populations and ungulate statuses across the ecoregion (higher quotas where ungulates are struggling, stable quotas where ungulates are at objective, lower quotas where ungulates are over objective).

After this committee provides their recommendation, the F&W Commission will make a decision on the upcoming season. Through public opinion, the public will ultimately decide if they like or will tolerate the season. The commission will consider this committee's recommendation as well as FWP staff input and public comment during the commission process.

Fundamental Objectives

In SDM, fundamental objectives define what the decision-makers truly care about. For example, if the problem could be solved perfectly, what would it accomplish? Fundamental objectives define the bottom line and what truly matters and form the basis for evaluating how well any potential solution solves the problem at hand.

Over the course of the second day, the committee worked to identify and refine specific fundamental objectives that a decision on lion population size would address. The facilitators again split the committee into small groups to identify these objectives, then brought the group together for discussion to refine the objectives. The final, consensus list of fundamental objectives is below (fundamental objectives #3 and #7 were modified during the October 12th meeting by adding parts a and b for improved clarity):

Fundamental Objectives

In no particular order:

1. Maximize sustainable, healthy populations of lions
2. Maximize hunter opportunity for ungulates
3. Maximize hunter opportunity for lions:
    a) Maximize hunter opportunity for lions by increasing the population
    b) Maximize hunter opportunity for lions by increasing quotas
4. Maximize outfitter opportunity for lions
5. Maximize sustainable, healthy populations of ungulates

6. Minimize conflict (livestock depredations and public safety e.g. habituation)
7. Maximize satisfaction over lion population by general public:
    a) Maximize satisfaction over lion population by general public who wants MORE lions
    b) Maximize satisfaction over lion population by general public who wants LESS lions

Alternatives

Alternatives are the third step of the SDM process and define possible options, solutions, and management actions that may be taken to achieve the fundamental objectives. Although we commonly first think about solutions when presented with a problem, good decisions rely on first understanding the details of the problem and the fundamental objectives that should be met.

A main goal of the LEPOC was to determine a desired change to the population (increase, decrease, or remain stable). Accordingly, the LEPOC continued the afternoon work session on the second day by completing an exercise to assign "satisfaction scores" to incremental increases and decreases to the current lion population. Using a metric of percentage change from the current population, members were asked to score how satisfied, or dissatisfied they would be across a range of population change objectives ranging from -100% (decrease) to +100% (increase) in 5% increments. Each committee member was asked to rank their perceived satisfaction for each incremental change on an ordinal scale from 1 to 5 (1 = very dissatisfied, 2 = dissatisfied, 3 = neutral, 4 = satisfied, 5 = very satisfied).

Compiling and plotting results of each participant's survey into one graph enabled visualizing areas of commonality (Figure 2). The combined output of this exercise showed the range of preferences for each group member and provided the necessary information for selecting discrete alternative population objectives. Based on this output, the group selected 4 four discrete population change scenarios for further evaluation including a population increase of 10%, maintenance of a stable population, a population decrease of 10%, and the predicted population trend in response to the newly adopted 2023-2024 commission quotas (Table 1). The group asked FWP to map the population results for

each of the 4 four scenarios to include two types of focal areas: 1) lion harvest concentrated in specific LMUs to aid struggling ungulate populations (hereafter referred to as *ungulate focal areas*); and 2) lion harvest reduced in specific LMUs to increase local lion numbers (hereafter referred to as *lion focal areas*). Four LMUs were identified as ungulate focal areas (240, 250, 270, and 280), five LMUs were identified as lion focal areas (210, 211, 213, 391, and 413), and the FWP science team identified one LMU as a limited access area where increased lion harvest would be difficult to achieve (422, Figure 3).

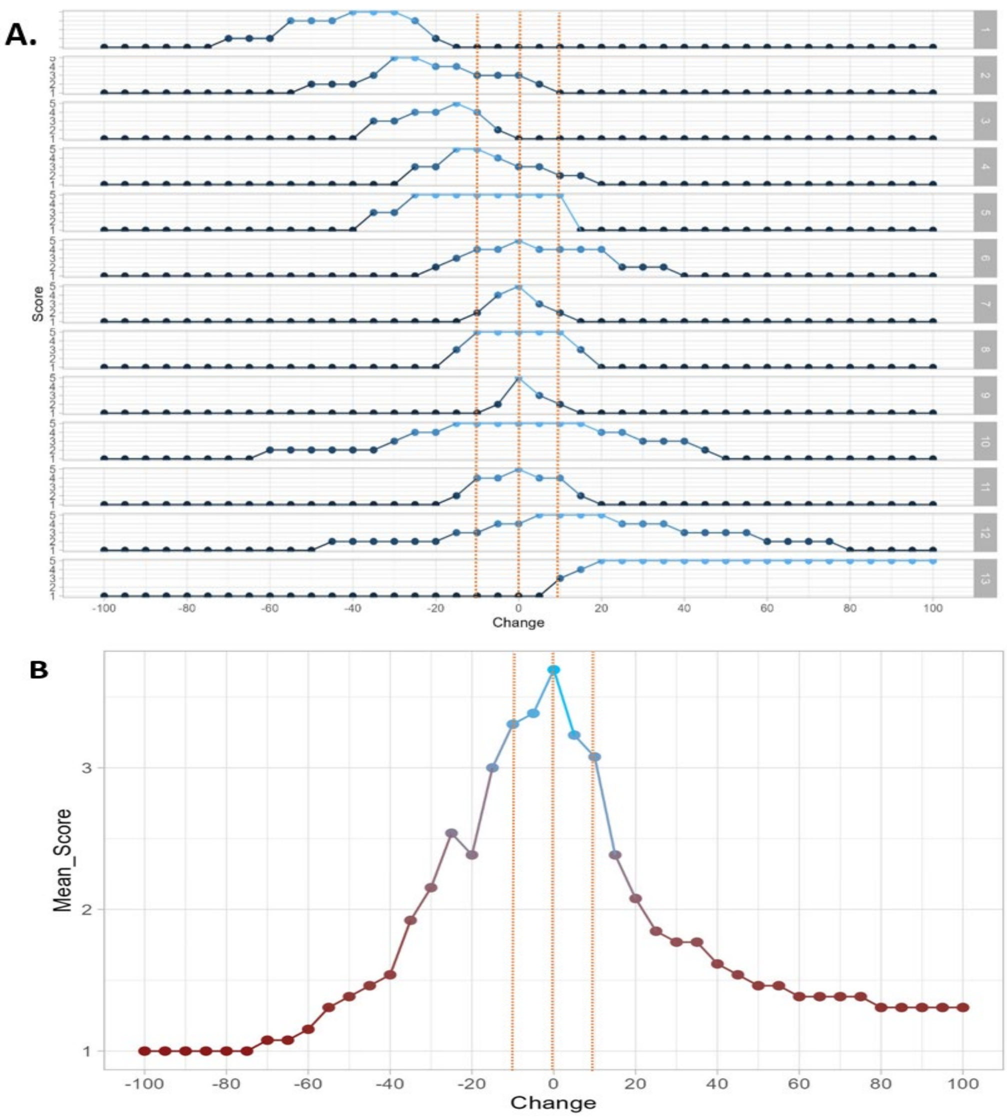


Figure 2. Satisfaction score results to possible changes to the WC Ecoregion lion population as ranked by each LEPOC group member (A), and the mean of all scores (B). Orange dashed vertical lines denote LEPOC requested population objective scenarios for modelling (-10%, 0%, +10%).

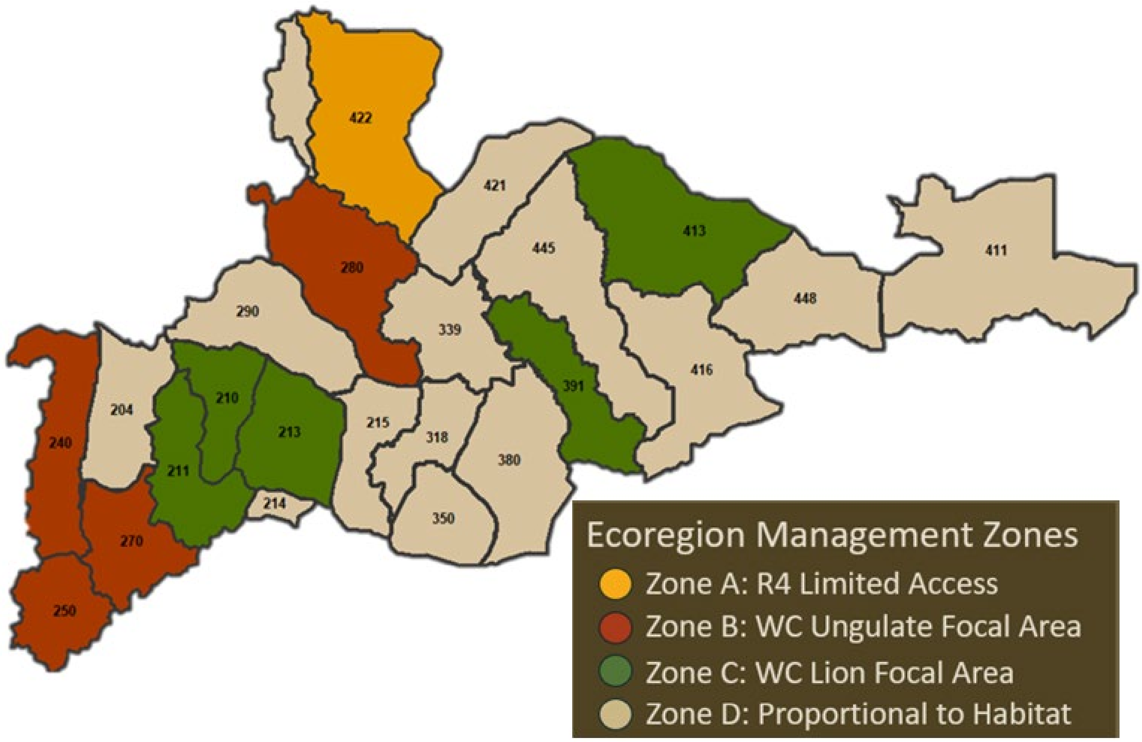


Figure 3. Focal areas identified by the LEPOC during the August 2023 meetings.

Table 1. LEPOC alternatives presented to FWP for modelling.

Population Objective Scenarios After 6 Years:
10% increase
0% change (stable)
10% decrease
Status quo (2023-2024 quotas adopted by the Fish and Wildlife Commission)

Consequence Predictions

Under the fourth step of the SDM process, consequences are predicted for each objective under each alternative. At the start of the October meeting, FWP prepared a brief presentation to review the objectives and alternatives from the previous meeting and provide context for the discussion. The presentation discussed the importance of female harvest in driving population trajectories and described the observed 5-year average harvest in the ecoregion to create a baseline for comparison to new alternatives and help committee members contextualize proposed changes. The 5-year average harvest (151 lions) was mapped with both the observed harvest levels and an alternative allocation of that same 151 lions to illustrate how management zones could be incorporated by redistributing harvest to meet local concerns. This example was not only used to illustrate how harvest prescriptions are developed and how the committee's ungulate focal areas (LMUs 240, 250, 270, and 280) and lion focal areas (LMUs 210, 211, 213, 391, and 413) could be incorporated, but also to provide comparison to the new 2023-2024 commission quotas. Reference sheets illustrating this information were developed and shared with the LEPOC (Figure 4). Due to complications described in "IPM Process for West-Central Ecoregion", FWP did not present reference sheets for the remaining committee requested scenarios (-10%, 0%, +10%) and instead informed the committee that the harvest level required to stabilize the population would be somewhere between the 5-year average of 151 (which was predicted to lead to 10% growth over the next 6 years) and the 2023-24 quotas of 280 (which was predicted to lead to 2-10% declines over the next 6 years).


Photo Credit Ryan Castle

Committee Predictions of Consequences

After the FWP presentation, the committee was asked to predict consequences for each of the alternative harvest scenarios using their personal judgement. Facilitators provided each committee member with a table listing the fundamental objectives and alternative harvest scenarios. The committee members worked independently to predict how well each alternative would meet fundamental objectives using a constructed scale of 1-5 (1=strong negative effect, 2=some negative effect, 3=no change, 4=some positive effect, 5=strong positive effect). To predict consequences for the alternatives, LEPOC members considered measurable attributes associated with each fundamental objective (Table 2). Each working group member then scored out their estimated consequences for each alternative (Table 3).

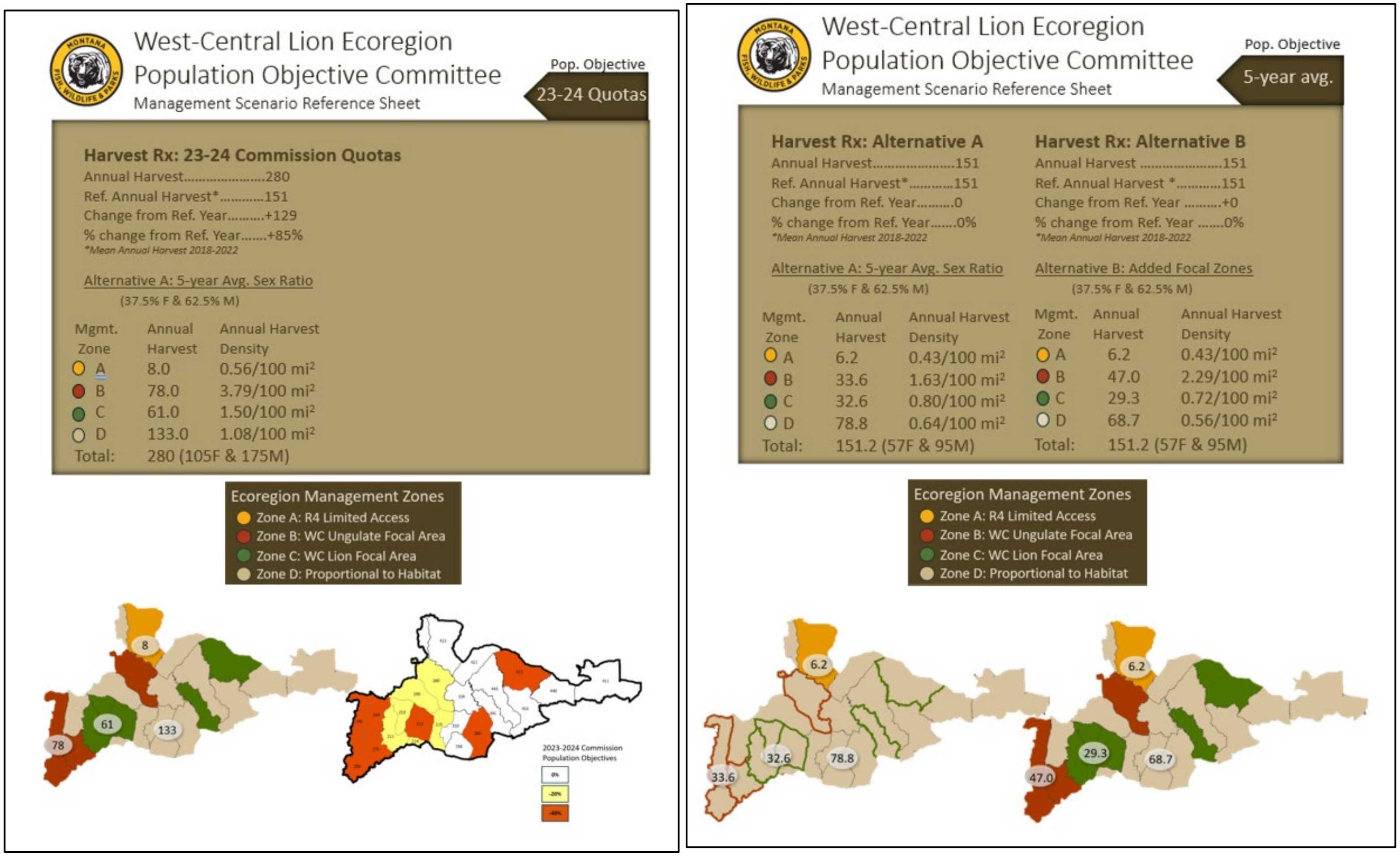


Figure 4. Reference Sheets illustrating harvest allocation for observed 5-year average lion harvest in WC ecoregion and 2023-2024 lion quotas established by Montana Fish and Wildlife Commission.

Table 2. Fundamental objectives and their associated measurable attribute.

#	*Fundamental Objective*	*Measurable Attribute*
1	Maximize sustainability of lion population	Effect on sustainability of lion population
2	Maximize hunter opportunity for ungulates	Effect on hunter opportunity for ungulates (by increasing ungulate pop)
3a	Maximize hunter opportunity for lions	Effect on hunter opportunity for lions (by increasing lion pop)
3b	Maximize hunter opportunity for lions	Effect on hunter opportunity for lions (by increasing lion quotas)
4	Maximize outfitter opportunity for lions	Effect on outfitter opportunity for lions
5	Maximize sustainable, healthy populations of ungulates	Effect on sustainable, healthy population of ungulates
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	Effect on conflict (lion depredations and public safety)
7a	Maximize satisfaction over lion population by general public	Effect on satisfaction over lion population by general public who want MORE lions
7b	Maximize satisfaction over lion population by general public	Effect on satisfaction over lion population by general public who want LESS lions

Table 3. Consequence Score Table. LEPOC scores predicting how well each alternative would meet fundamental objectives using a constructed scale of 1-5 (1=strong negative effect, 2=some negative effect, 3=no change, 4=some positive effect, 5=strong positive effect).

Consequence Table			1	2	3	4		
Obj #	Objectives	Goal of Scale	Status Quo	10% increase	Stable	10% decrease	Range: Min	Range: Max
1	Maximize sustainability of lion population	Max	2.5	3.5	3.2	2.6	2.5	3.5
2	Maximize hunter opportunity for ungulates	Max	4.0	1.9	2.6	3.8	1.9	4.0
3a	Maximize hunter opportunity for lions (lion pop)	Max	2.2	4.5	3.2	2.1	2.1	4.5
3b	Maximize hunter opportunity for lions (lion quotas)	Max	3.6	2.9	2.8	3.2	2.8	3.6
4	Maximize outfitter opportunity for lions	Max	3.1	3.5	3.2	2.5	2.5	3.5
5	Maximize sustainable, healthy populations of ungulates	Max	4.1	1.8	2.7	3.7	1.8	4.1
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	Max	3.9	1.9	2.5	3.7	1.9	3.9
7a	Maximize satisfaction over lion population by general public (who want MORE lions)	Max	1.4	4.1	3.2	1.6	1.4	4.1
7b	Maximize satisfaction over lion population by general public (who want LESS lions)	Max	4.5	1.8	2.6	4.2	1.8	4.5

Trade-offs

After predicting consequences, the next step of the SDM process entails assessment of trade-offs. This requires evaluating alternatives based on the relative consequences each has on fundamental objectives on the same scale. To facilitate these comparisons, scores were normalized and weighted, as follows.

Normalized Scores

Scores from the consequence table were next normalized onto a 0-1 scale (0 = worst case outcome comparing across the alternatives for any given objective, and 1 = best case scenario for that objective). This provided easier comparisons of consequences across alternatives and objectives. (Table 4).

Weighted Scores

Not all fundamental objectives may be equally important. Accordingly, after predicting the consequences of each alternative on the fundamental objectives and reviewing the table of normalized scores, the committee was next asked to rank the objectives in order of importance (1=most important, 7=least important). Participants also provided a 0-100 score for each objective to represent the relative importance of the objectives. For example, a participant may have believed that minimizing lion conflict with livestock and pets is the most important objective and given that objective a score of 100, while maximizing the social acceptance of lion hunting was the least important and given that objective a score of 50, meaning they felt it was exactly half as important. Through the weighting of ranked objectives, facilitators and committee members could better understand the relative importance of each objective to visualize the impacts and tradeoffs for the various alternatives. The fundamental objectives were weighted and ranked by the LEPOC to produce average ranks and scores (Table 5) Averaged across the group, objectives 1-3 and 5 were weighted the highest.

Table 4. Normalized Scores. Color shading refers to how well each alternative meets that objective (0/red = worst among alternatives for a particular objective, 1/green = best among alternatives). Accordingly, a column with more green in it and minimal red indicates that alternative is expected to perform better at meeting objectives than a column with extensive red.

NORMALIZED SCORES			1	2	3	4
Obj #	Objectives	Goal of Scale	Status Quo	10% increase	Stable	10% decrease
1	Maximize sustainability of lion population	Max	0.00	1.00	0.62	0.08
2	Maximize hunter opportunity for ungulates	Max	1.00	0.00	0.33	0.93
3a	Maximize hunter opportunity for lions (lion pop)	Max	0.03	1.00	0.48	0.00
3b	Maximize hunter opportunity for lions (lion quotas)	Max	1.00	0.18	0.00	0.55
4	Maximize outfitter opportunity for lions	Max	0.57	1.00	0.64	0.00
5	Maximize sustainable, healthy populations of ungulates	Max	1.00	0.00	0.40	0.83
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	Max	1.00	0.00	0.31	0.88
7a	Maximize satisfaction over lion population by general public (who want MORE lions)	Max	0.00	1.00	0.69	0.09
7b	Maximize satisfaction over lion population by general public (who want LESS lions)	Max	1.00	0.00	0.31	0.86

Table 5. LEPOC Fundamental Objective rankings, scores, and weights

Obj #	FUNDAMENTAL OBJECTIVE	AVG RANK	FINAL RANK	AVG SCORE	FINAL SCORE	WEIGHT
1	*Maximize sustainability of lion population*	2.2	1	85.8	85.8	0.19
2	*Maximize hunter opportunity for ungulates*	3.5	5	75.8	75.8	0.17
3a	*Maximize hunter opportunity for lions (lion pop)*	3.2	3	70.4	70.4	0.08
3b	*Maximize hunter opportunity for lions (lion quotas)*	3.2	3			0.08
4	*Maximize outfitter opportunity for lions*	5.5	6	46.2	46.2	0.10
5	*Maximize sustainable, healthy populations of ungulates*	2.7	2	82.3	82.3	0.18
6	*Minimize conflict (livestock depredations and public safety e.g. habituation)*	5.5	6	43.5	43.5	0.10
7a	*Maximize satisfaction over lion population by general public (who want MORE lions)*	5.5	6	45.8	45.8	0.05
7b	*Maximize satisfaction over lion population by general public (who want LESS lions)*	5.5	6			0.05
			Sums:	SUM=	***449.62***	***1.000***

Weighted Consequence Table

To produce the final table to depict consequences and tradeoffs, the weights on objectives (Table 5) were multiplied by the normalized scores (from Table 4) and then summed to represent the overall amount of support for each alternative (Table 6). The final table revealed decision support for each alternative.

Table 6. Weighted-Normalized Scores. The degree of green indicates which alternative best meets that objective and the degree of red shows which alternative does worst on meeting that objective. Final Scores provide a measure of overall performance for each alternative.

Obj #	Objectives	Weight	Status Quo	10% increase	Stable	10% decrease
1	Maximize sustainability of lion population	**0.19**	0.00	0.19	0.12	0.01
2	Maximize hunter opportunity for ungulates	**0.17**	0.17	0.00	0.06	0.16
3a	Maximize hunter opportunity for lions (lion pop)	**0.08**	0.00	0.08	0.04	0.00
3b	Maximize hunter opportunity for lions (lion quotas)	**0.08**	0.08	0.01	0.00	0.04
4	Maximize outfitter opportunity for lions	**0.10**	0.06	0.10	0.07	0.00
5	Maximize sustainable, healthy populations of ungulates	**0.18**	0.18	0.00	0.07	0.15
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	**0.10**	0.10	0.00	0.03	0.09
7a	Maximize satisfaction over lion population by general public (who want MORE lions)	**0.05**	0.00	0.05	0.03	0.00
7b	Maximize satisfaction over lion population by general public (who want LESS lions)	**0.05**	0.05	0.00	0.02	0.04
	Sum of Weights (for all objectives)	*1.00*				
	Final Score (sum of weighted scores/sum of weights)		0.64	0.44	0.43	0.50

Decision simplification and trade-offs

Alternative 1, the Status Quo, is the Commission 23-24 prescription, and had the highest overall score because it was predicted to meet numerous objectives best. However, it performed worst for several objectives including objective 1, which was identified as the most important objective for the LEPOC. While the other alternatives were scored lower, each was predicted to meet objectives well in different ways.

Consequences Round 2

As group discussion continued, the committee realized they may have interpreted the alternatives differently, so the alternatives were renamed for further clarity, and each person reviewed their scores and updated those they felt warranted changes (Table 7).

Objective Weights Round 2

The group also decided to review their weights on objectives to incorporate the splits of objectives #3 and #7 into two parts, and to account for the range in variation of the predicted consequences for each objective (Table 8) through the process of swing weighting, which incorporates both the overall importance of each objective as well as the difference in performance at meeting each objective among alternatives. Combining results for the group revealed objectives 1-3 and 5 remained the most important to the group, on average.

Table 7. Updated consequence table.

Consequence Table			1	2	3	4		
Obj #	Objectives	Goal of Scale	Current Season (2-10% decline)	10% increase in lion pop	Stable lion pop	10% decrease in lion pop	Range: Min	Range: Max
1	Maximize sustainability of lion population	Max	2.2	3.7	3.1	2.3	2.2	3.7
2	Maximize hunter opportunity for ungulates	Max	3.8	1.9	2.5	3.8	1.9	3.8
3a	Maximize hunter opportunity for lions (increase lion pop)	Max	1.9	4.6	3.2	2.1	1.9	4.6
3b	Maximize hunter opportunity for lions (increase lion quotas)	Max	3.6	3.0	2.8	3.2	2.8	3.6
4	Maximize outfitter opportunity for lions	Max	3.0	3.8	3.1	2.2	2.2	3.8
5	Maximize sustainable, healthy populations of ungulates	Max	4.1	1.8	2.7	3.7	1.8	4.1
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	Max	3.9	1.9	2.5	3.7	1.9	3.9
7a	Maximize satisfaction over lion population by general public (who want MORE lions)	Max	1.4	4.2	3.2	1.3	1.3	4.2
7b	Maximize satisfaction over lion population by general public (who want LESS lions)	Max	4.5	1.8	2.5	4.2	1.8	4.5

Table 8. Updated LEPOC Fundamental Objective rankings, scores, and swing weights

Obj #	FUNDAMENTAL OBJECTIVE	Difference	AVG RANK	FINAL RANK	AVG SCORE	FINAL SCORE	WEIGHT
1	*Maximize sustainability of lion population*	*1.5*	2.6	1	84.6	84.6	0.16
2	*Maximize hunter opportunity for ungulates*	*1.9*	4.0	4	70.8	70.8	0.14
3a	*Maximize hunter opportunity for lions (increase lion pop)*	*2.7*	3.8	3	65.1	65.1	0.13
3b	*Maximize hunter opportunity for lions (increase lion quotas)*	*0.8*	5.3	5	50.8	50.8	0.10
4	*Maximize outfitter opportunity for lions*	*1.6*	6.4	7	45.8	45.8	0.09
5	*Maximize sustainable, healthy populations of ungulates*	*2.3*	3.2	2	78.5	78.5	0.15
6	*Minimize conflict (livestock depredations and public safety e.g. habituation)*	*2.0*	6.0	6	44.6	44.6	0.09
7a	*Maximize satisfaction over lion population by general public (who want MORE lions)*	*2.9*	6.5	8	38.5	38.5	0.07
7b	*Maximize satisfaction over lion population by general public (who want LESS lions)*	*2.7*	6.9	9	39.2	39.2	0.08
				Sums:	SUM=	***517.85***	***1.000***

Updated Consequence Table

Combining these revised consequence predictions and weights provided updated decision support for each alternative. The results did not differ strongly from the original table, and again revealed where alternatives were predicted to meet objectives well and where they would likely fall short. (Table 9).

Table 9. The updated weighted-Normalized Scores. In each row, the dark green cell indicates which alternative best meets that objective and the red cell shows which alternative does worst on meeting that objective. Final Scores provide a measure of overall performance for each alternative.

WEIGHTED SCORES			1	2	3	4
Obj #	Objectives	Weight	Current Season (2-10% decline)	10% increase in lion pop	Stable lion pop	10% decrease in lion pop
1	Maximize sustainability of lion population	**0.16**	0.00	0.16	0.09	0.01
2	Maximize hunter opportunity for ungulates	**0.14**	0.14	0.00	0.04	0.13
3a	Maximize hunter opportunity for lions (increase lion pop)	**0.13**	0.00	0.13	0.06	0.01
3b	Maximize hunter opportunity for lions (increase lion quotas)	**0.10**	0.10	0.03	0.00	0.05
4	Maximize outfitter opportunity for lions	**0.09**	0.05	0.09	0.05	0.00
5	Maximize sustainable, healthy populations of ungulates	**0.15**	0.15	0.00	0.06	0.13
6	Minimize conflict (livestock depredations and public safety e.g. habituation)	**0.09**	0.09	0.00	0.03	0.08
7a	Maximize satisfaction over lion population by general public (who want MORE lions)	**0.07**	0.00	0.07	0.05	0.00
7b	Maximize satisfaction over lion population by general public (who want LESS lions)	**0.08**	0.08	0.00	0.02	0.06
	Sum of Weights (for all objectives)	*1.00*				
	Final Score (sum of weighted scores/sum of weights)		0.60	0.48	0.40	0.47

Deliberations continued through the afternoon portion of the October 12 meeting to consider the suite of alternatives. The prominent question raised by the group was why Alternative 1 (2023-2024 Commission Quotas) scored highest, when most of the group expressed they couldn't support it. Ultimately, facilitators pointed out this alternative may not satisfy the group because it fails to meet several fundamental objectives well, including the group's top-ranked objective (#1). Committee discussion then shifted to alternatives 2 – 4, which all included ungulate and lion focal areas, as specified by the group. The group continued to support the application of focal areas to strategically address localized concerns. With additional conversation, the group focused on Alternative 3 which would keep the population stable over the next 6 years, while requiring an increase in harvest over current levels due to current levels of ecoregional population growth. The stable population alternative was predicted to generally perform neither worst nor best on objectives but provided a compromise solution that would help meet most objectives to some degree. All but one committee member felt they could support the alternative with the LMU emphases as originally identified (above). The-non-supportive committee member asked the group to include LMU 380 in the lion focal area (decrease lion harvest by ~10%). The group agreed and reached consensus to support the revised Alternative 3.

Public Comment Period

Three attendees provided public comment. Their recommendation was that in the future, the group should have a committee member representing each LMU. They were also concerned that LMU 280 was included as an ungulate focal area, when they believed lions were overharvested there already.

Tentative Recommendation

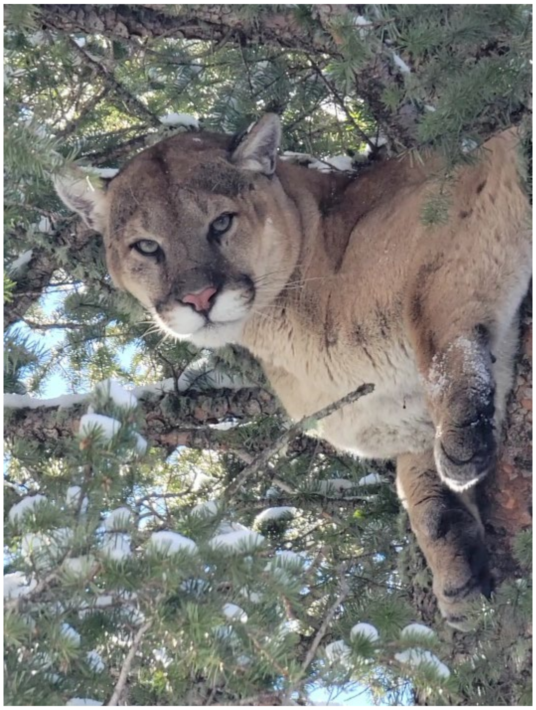
After final discussion, the LEPOC took the public's comments into account and decided to omit LMU 280 from their selected ungulate focal area, then voted on their tentative recommendation. The group conceptually reached consensus on a recommendation to manage for a stable population of lions within WC ecoregion (estimated to require between 151-280 lions harvested annually pending final modelling results). The recommended alternative would stabilize the WC ecoregional lion population at current levels over the next six years and would incorporate LMU emphases for ungulate focal areas (increased lion harvest to benefit ungulates) and lion focal areas (decreased lion harvest to grow the local lion population). The original LMU emphases were retained with slight modifications:

- Ungulate focal areas (decrease lion population): 240, 250, 270,
- Lion focal areas (increase lion population): 211, 210, 213, 380, 391, 413

Because the IPM projections weren't available at this second meeting, the group agreed to support the above recommendation but wanted to review the harvest prescriptions that would be required for this alternative, as soon as the IPM results were ready.

IPM Process for West-Central Ecoregion

The FWP science team was tasked with modelling the committee's requested alternative scenarios (Table 1) using the mountain lion IPM (FWP 2019) to evaluate the population objectives of interest to the committee, develop examples of harvest prescriptions, and provide examples of how harvest could be allocated across the ecoregion to target areas of concern. To conduct simulations, the FWP science team used the IPM structure outlined in the Montana Mountain Lion Monitoring and Management Strategy (Appendix 2 of FWP 2019), with two



modifications. First, we changed a line of code to indicate that the density estimate based on field monitoring (SCR) is the density of independent-age lions that are available for harvest, i.e., excluding kittens. Second, we added the necessary components to simulate the population into the forecast period (2023-2027). This modification made the *informed prior* (Kruschke and Liddel 2018) for harvest rates in the forecast period directly related to the proposed increase in harvest. Without this modification the model may have assumed increases in harvest were coming from a constant harvest rate on an increasing population. The complete modified code is included in Appendix A.

Ultimately, the IPM was run to determine the level of harvest needed to achieve a -10% decrease, stable (0%), and 10% increase in the WC ecoregional lion population. The IPM was also used to determine the predicted effect of the new 2023-2024 commission WC related quotas set at 280 lions, along with the impact of the 5-year ecoregional average harvest of 151 lions. While working with the IPM, the science team discovered some parts of the model were not performing up to their standards and the model needed to be updated.

Initial population size

The initial population estimate for the West-central Ecoregion conflicted with biological knowledge of lions and the harvest data for the West-central Ecoregion, confusing the model and preventing the model from working. The initial population was estimated by dividing the number of harvested lions in each age and sex class by the estimated harvest rate for the group. This calculation resulted in a small, male-dominated population, which did not make sense for lions in the West-central Ecoregion. Furthermore, this initial population could not match with the observed harvest within the biological constraints of the model. So, the FWP science team had to find an alternative way to estimate the initial population size.

Previous work estimated the number of lions in Montana for 2005 (Robinson et al. 2013, Robinson et al. 2015). The mean estimated number of independent age lions in the West-Central Ecoregion in 2005 was 606, though Robinson et al. 2015 stated this estimate was likely to be biased low based on their modeling, so we increased the estimate by adding in 30% transient lions. However, the resulting population estimate from the IPM for 2022 of ~ 2,100 independent age lions generated concerns of being too large based on results from previous lion population studies in Montana coupled with biologists' best judgments guided by harvest data, lion conflicts, and hunter observations. Ultimately, FWP decided to move forward with both estimates to account for the uncertainty around the estimates.

Confusing results

Before the start of the second LEPOC meeting in October, the IPM was giving some confusing results when the runs using the "low" initial population were compared to the runs using the "high" initial population. The runs showed that fewer lions needed to be harvested from the larger population than the smaller population to achieve the same population decline in six years. For example, a harvest of 227 lions annually resulted in a 1% increase in the low population but a 3% decrease in the high population. The science team decided to delay presenting the results to LEPOC until we could understand why the runs with different initial populations were behaving so differently.

Although the model was not performing as expected, several trends were consistent in all IPM outputs regardless of starting population size that FWP shared with LEPOC at the start of the October meeting. First, the ecoregional population has been increasing steadily since 2004. Next, should current harvest levels ~~of harvest~~ be maintained, the population will continue to grow roughly 10% over the next 6-year period. Lastly, to stabilize the population at current population levels, an increase in harvest would be needed. The new 2023-2024 quotas, if filled, also consistently resulted in a predicted decline over the next 6-year period, with different simulation runs predicting a decline between 2-10%.

The science team could not provide specific projected harvest numbers required to reach a stable population over the next 6-year period. However~~,~~ the science team estimated a harvest required to stabilize the population would be somewhere between the 5-year average of 151 and the 2023-2024 quotas of 280. The October LEPOC meeting concluded when the committee came to a tentative recommendation of a stable population, dependent on the science team's modeling results. The science team suspected the different age structures within the two initial populations may be what was impacting the model results since the high population estimate was created by adding independent aged lions to the population while holding the number of kittens constant.

The problem and the solution

The FWP science team investigated if the age structure of the initial population impacted the model results. They adjusted the number of kittens in the model and the model results changed. By only adding independently aged lions, the "high" initial population was heavily skewed towards reproductive aged individuals. The model interpreted this as lower reproductive rates for female lions and modified the vital rates in the IPM accordingly. This led to the harvest rates having a greater impact on the larger population than the smaller population.

After discussing the findings about the impact of the age structure on the model results, the core science team agreed that the age and sex distribution needed to be held constant at the rates found within the Garnet Range report (Robinson and DeSimone 2011). This meant we had to find a way to estimate our "high" initial population size without manipulating the age structure. The 2013 report (Robinson et al. 2013) provided a low, average, and high estimate of lions in Montana in 2005. In addition to the statewide estimates, estimates for small groups of hunting districts or individual hunting districts were provided which we combined to determine the estimates for each ecoregion. The average estimate from this report was used as the original "low" initial population estimate. The high estimate, 1,130 total lions, was larger than the previous "high" estimate of 1,030 lions. When the Garnet percentages (Robinson and DeSimone 2011) were used to distribute the population among the age and sex classes, the high estimate from the paper had a similar number of independent lions (789 independent lions) as the original "high" estimate that used transient lions (788 independent lions). However, the new high population had the same age structure as the "low" initial population. Using the new age distribution, the harvest required for the larger population was larger than the harvest required for the smaller population to achieve the same goal. Controlling the age distribution within the initial population made the vital rates with the different starting populations comparable and produced results that were more biologically plausible.

Final Recommendations

Confirmation of Stable Population Recommendation

After addressing concerns with the IPM performance, FWP ran the IPM using two different starting populations based on the published 2005 population estimates, with a low estimate of 602 and a high estimate of 789 lions. Based on these starting points, the IPM estimated between 1,659–2,097 independent age lions within the West-central region in 2022. Harvest projections based on these estimates indicated an annual harvest of 219–250 (average of 235) lions for the next six-year period would result in a stable population. Acknowledging a level of uncertainty surrounding population estimates, the FWP science team recommended a harvest of 235, splitting the difference between the required annual harvest for the two initial populations (Figure 5). FWP shared the updated results and illustration of harvest allocation with the committee on November 27, 2023, and after review, the LEPOC provided their final votes and came to consensus again on December 5, 2023. The LEPOC confirmed their recommendation to maintain a stable lion population with lion and ungulate focal areas (Figure 6).

Figure 5**.** The IPM results for the two initial starting populations with a harvest of 235 lions for the next 6 years show a small increase with the larger population (+3%) and a small decrease with the smaller population (-3%) from the reference 2022 population.

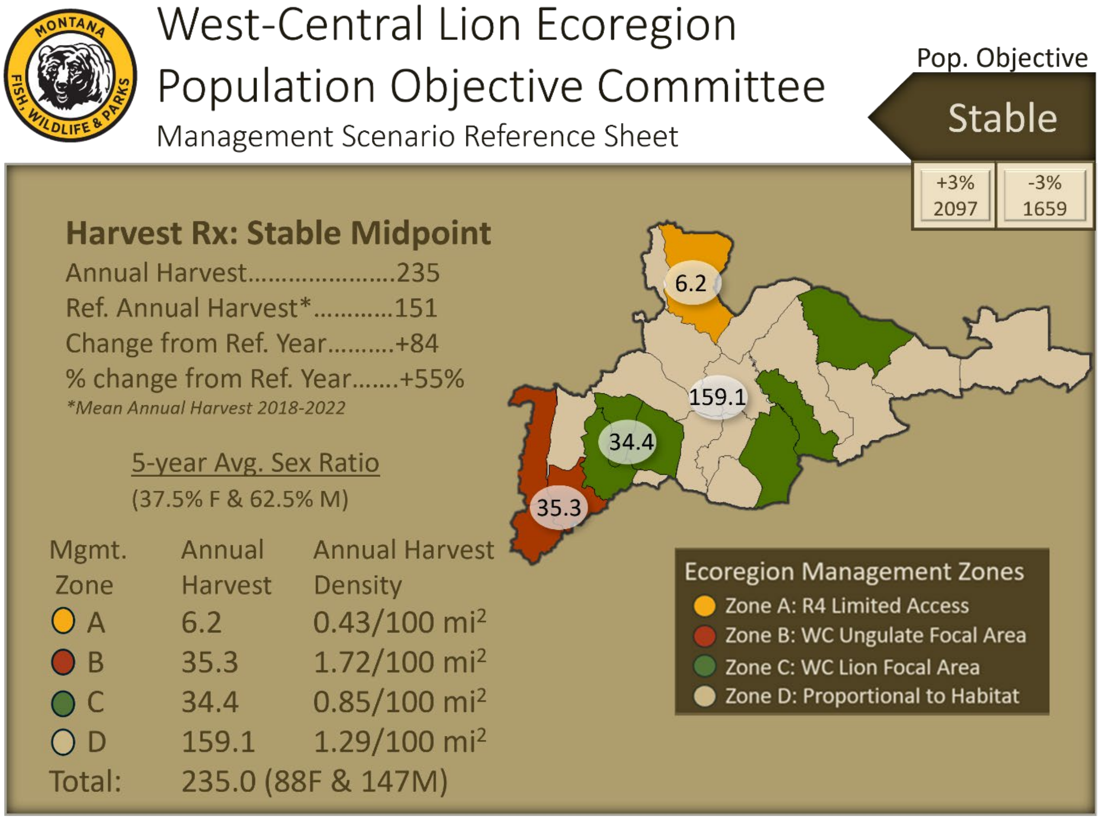


Figure 4. Final LEPOC recommendations for harvest needed to reach a stable population objective over the next 6 years.

Further Recommendations

Throughout the 3 three days of meetings, the LEPOC identified a variety of topics that they believed were important to share with the Fish and Wildlife Commission, despite falling outside of the scope of the committee's charge. These additional concerns and recommendations are as follows.

- The group would like to have a multi-faceted conversation that reflects the multi-predator system that exists in this ecoregion instead of just talking about lions. For instance, strategically target coyotes in areas where ungulates are struggling. Lions are only one of the many predators influencing ungulate populations.

- Appropriate age classes of lions should be targeted in the harvest to achieve desired goals. How do you control what age of lions hunters will harvest? Certain aspects of lion ecology make it more difficult to target harvest of age classes (e.g. lions with kittens, juveniles), which impacts social structure of cats in an area.

- The committee feels that they were tasked with making a recommendation with a very blunt tool, when what they ideally needed was something more precise. They would have preferred having more data and hope that more will be provided to the next LEPOC meeting.

- Remember that how fast a quota fills is not necessarily a good indicator of the lion population. There can be a myriad of access challenges related to filling a quotas.

- Maximize public support for lion hunting and houndsmen. Maybe consider an age/sex identification course required prior to being able to get your lion license or some other kind of required lion hunting training for hunters. If not required (due to challenges of making new requirements), at least allocate resources to more education.

- Members would like to have the ability to proactively adjust quotas each year with biologists working with all stakeholders to address specific issues.

- Along with predators, very high human hunter numbers are impacting mule deer, elk, and white-tailed deer populations.

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Appendix A: IPM JAGS code

```
model{
 #  Naming
 #  Parameter names begin with a capitalized letter
 #  Data are all lower case
 #  Indexing always follows - DAU, Year, Age, Sex
 #  There are two sexes (1 = female and 2 = male)
 #  There are four age classes, kitten, juvenile, subadult and adult
 #  If fewer indices are needed they follow the same order despite
 #   omissions

 #  Priors
 #  Pregnancy rates - [age, sex, mean:tau]
 #  Pregnancy rate for subadult females
 Preg[1] ~ dnorm(preg[3,1,1], preg[3,1,2])T(0,0.5)
 # Pregnancy rate for adult females
 Preg[2] ~ dnorm(preg[4,1,1], preg[4,1,2])T(0,0.5)
```

```
#  Fetus Counts - [age, sex, mean:tau]
#  Fetus Count for subadult females
FC[1] ~ dnorm(fc[3,1,1], fc[3,1,2])T(0,3)
#  Fetus Count for adult females
FC[2] ~ dnorm(fc[4,1,1], fc[4,1,2])T(0,3)

#  Survival
#  Priors on survival - First age class, not available for harvest, so
#   survival is the only parameter
#  Informative prior stored as probability
yS_mu ~ dnorm(means[1,1,1], means[1,1,2])T(0,1)

#  Transform probability back to real scale and use as the intercept
for(u in 1:ndau){
  for(yr in 1:nyr){
    for(s in 1:2){
      logit(S[u,yr, 1, s]) <- log(yS_mu/(1 - yS_mu))
      H[u,yr,1,s] <- 0
      O[u,yr,1,s] <- 0
    }
  }
}


################################################
#  Priors on survival - Juveniles - two sexes, cause specific mortality
for(s in 1:2){
  #  Informative priors are stored as probabilities
  jS_tmp[1,s] ~ dnorm(means[2,s,1], means[2,s,2])T(0, 1)
  jS_tmp[2,s] ~ dnorm(meanh[2,s,1], meanh[2,s,2])T(0, 1)
  jS_tmp[3,s] ~ dnorm(meano[2,s,1], meano[2,s,2])T(0, 1)

  #  Transform probability to real scale
  for(i in 1:3){
    jS_mu[i,s] <- log(jS_tmp[i,s]/jS_tmp[3,s])
  }

  tauj[s] ~ dunif(0, 20)


  #  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 1:18){
      j_yr[yr,s] ~ dnorm(0, tauj[s])
      log(jS_log[u,yr,s]) <- jS_mu[1,s] + j_yr[yr,s]
      log(jH_log[u,yr,s]) <- jS_mu[2,s]
```

```
      log(jO_log[u,yr,s]) <- 0
      jSums[u,yr,s] <- jS_log[u,yr,s] + jH_log[u,yr,s] + jO_log[u,yr,s]
      S[u,yr,2,s] <- jS_log[u,yr,s]/jSums[u,yr,s]
      H[u,yr,2,s] <- jH_log[u,yr,s]/jSums[u,yr,s]
      O[u,yr,2,s] <- jO_log[u,yr,s]/jSums[u,yr,s]
    }
  }
}


#  FORECAST: Priors on survival - Juveniles - two sexes, cause specific mortality

for(s in 1:2){
  #  Informative priors are stored as probabilities
  jS_tmp2[1,s] ~ dnorm(means[2,s,1], means[2,s,2])T(0, 1)
  jS_tmp2[2,s] ~ dnorm(meanh[2,s,1], meanh[2,s,2])T(0, 1)
  jS_tmp2[3,s] ~ dnorm(meano[2,s,1], meano[2,s,2])T(0, 1)

  #  Transform probability to real scale
  for(i in 1:3){
    jS_mu2[i,s] <- log(jS_tmp2[i,s]/jS_tmp2[3,s])
  }


#  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 19:nyr){
        log(jS_log2[u,yr,s]) <- jS_mu2[1,s]
        log(jH_log2[u,yr,s]) <- log((harv[u,yr,2,s]/ (N[u,yr,2,s]+2)) / (jS_tmp2[3,s] + .001))
        log(jO_log2[u,yr,s]) <- 0
        jSums2[u,yr,s] <- jS_log2[u,yr,s] + jH_log2[u,yr,s] + jO_log2[u,yr,s]
        S[u,yr,2,s] <- jS_log2[u,yr,s]/jSums2[u,yr,s]
        H[u,yr,2,s] <- jH_log2[u,yr,s]/jSums2[u,yr,s]
        O[u,yr,2,s] <- jO_log2[u,yr,s]/jSums2[u,yr,s]
    }
  }
}


############################################

###############################################
#  Priors on survival - SubAdults - two sexes, cause specific mortality
for(s in 1:2){
  #  Informative priors are stored as probabilities
  sS_tmp[1,s] ~ dnorm(means[3,s,1], means[3,s,2])T(0, 1)
```

```
  sS_tmp[2,s] ~ dnorm(meanh[3,s,1], meanh[3,s,2])T(0, 1)
  sS_tmp[3,s] ~ dnorm(meano[3,s,1], meano[3,s,2])T(0, 1)

  #  Transform probability to real scale
  for(i in 1:3){
    sS_mu[i,s] <- log(sS_tmp[i,s]/sS_tmp[3,s])
  }

 taus[s] ~ dunif(0, 20)

  #  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 1:18){
      s_yr[yr,s] ~ dnorm(0, taus[s])
      log(sS_log[u,yr,s]) <- sS_mu[1,s] + s_yr[yr,s]
      log(sH_log[u,yr,s]) <- sS_mu[2,s]
      log(sO_log[u,yr,s]) <- 0
      sSums[u,yr,s] <- sS_log[u,yr,s] + sH_log[u,yr,s] + sO_log[u,yr,s]
      S[u,yr,3,s] <- sS_log[u,yr,s]/sSums[u,yr,s]
      H[u,yr,3,s] <- sH_log[u,yr,s]/sSums[u,yr,s]
      O[u,yr,3,s] <- sO_log[u,yr,s]/sSums[u,yr,s]
    }
  }
}


#  FORECAST:  Priors on survival - subAdults, two sexes, cause specific mortality
for(s in 1:2){
  #  Informative priors are stored as probabilities
  sS_tmp2[1,s] ~ dnorm(means[3,s,1], means[3,s,2])T(0, 1)
  sS_tmp2[2,s] ~ dnorm(meanh[3,s,1], meanh[3,s,2])T(0, 1)
  sS_tmp2[3,s] ~ dnorm(meano[3,s,1], meano[3,s,2])T(0, 1)

  #  Transform probability to real scale
  for(i in 1:3){
    sS_mu2[i,s] <- log(sS_tmp2[i,s]/sS_tmp2[3,s])
  }

  #  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 19:nyr){
      log(sS_log2[u,yr,s]) <- sS_mu2[1,s]
      log(sH_log2[u,yr,s]) <- log((harv[u,yr,3,s]/ (N[u,yr,3,s]+2))/ (sS_tmp2[3,s] + .001))
      log(sO_log2[u,yr,s]) <- 0
      sSums2[u,yr,s] <- sS_log2[u,yr,s] + sH_log2[u,yr,s] + sO_log2[u,yr,s]
```

```
      S[u,yr,3,s] <- sS_log2[u,yr,s]/sSums2[u,yr,s]
      H[u,yr,3,s] <- sH_log2[u,yr,s]/sSums2[u,yr,s]
      O[u,yr,3,s] <- sO_log2[u,yr,s]/sSums2[u,yr,s]
    }
  }
}
#############################################################

##############################################################
#  Priors on survival - Adults, two sexes, cause specific mortality
for(s in 1:2){
  #  Informative priors are stored as probabilities
  aS_tmp[1,s] ~ dnorm(means[4,s,1], means[4,s,2])T(0, 1)
  aS_tmp[2,s] ~ dnorm(meanh[4,s,1], meanh[4,s,2])T(0, 1)
  aS_tmp[3,s] ~ dnorm(meano[4,s,1], meano[4,s,2])T(0, 1)

  #  Transform probability to real scale
  for(i in 1:3){
    aS_mu[i,s] <- log(aS_tmp[i,s]/aS_tmp[3,s])
  }

  taua[s] ~ dunif(0, 20)

  #  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 1:18){
      a_yr[yr,s] ~ dnorm(0, taua[s])
      log(aS_log[u,yr,s]) <- aS_mu[1,s] + a_yr[yr,s]
      log(aH_log[u,yr,s]) <- aS_mu[2,s]
      log(aO_log[u,yr,s]) <- 0
      aSums[u,yr,s] <- aS_log[u,yr,s] + aH_log[u,yr,s] + aO_log[u,yr,s]
      S[u,yr,4,s] <- aS_log[u,yr,s]/aSums[u,yr,s]
      H[u,yr,4,s] <- aH_log[u,yr,s]/aSums[u,yr,s]
      O[u,yr,4,s] <- aO_log[u,yr,s]/aSums[u,yr,s]
    }
  }
}


 #FORECAST:  Priors on survival - Adults, two sexes, cause specific mortality
for(s in 1:2){
  #  Informative priors are stored as probabilities
  aS_tmp2[1,s] ~ dnorm(means[4,s,1], means[4,s,2])T(0, 1)
  aS_tmp2[2,s] ~ dnorm(meanh[4,s,1], meanh[4,s,2])T(0, 1)
  aS_tmp2[3,s] ~ dnorm(meano[4,s,1], meano[4,s,2])T(0, 1)
```

```
  #  Transform probability to real scale
  for(i in 1:3){
    aS_mu2[i,s] <- log(aS_tmp2[i,s]/aS_tmp2[3,s])
  }

  #  Describe rate as function of linear predictor and define link
  #   function
  for(u in 1:ndau){
    for(yr in 19:nyr){
      log(aS_log2[u,yr,s]) <- aS_mu2[1,s]
      log(aH_log2[u,yr,s]) <- log((harv[u,yr,4,s]/ (N[u,yr,4,s]+2)) / (aS_tmp2[3,s] + .001))
      log(aO_log2[u,yr,s]) <- 0
      aSums2[u,yr,s] <- aS_log2[u,yr,s] + aH_log2[u,yr,s] + aO_log2[u,yr,s]
      S[u,yr,4,s] <- aS_log2[u,yr,s]/aSums2[u,yr,s]
      H[u,yr,4,s] <- aH_log2[u,yr,s]/aSums2[u,yr,s]
      O[u,yr,4,s] <- aO_log2[u,yr,s]/aSums2[u,yr,s]
    }
  }
}

#############################################################

###  Prior on first year population size
#  Indexing - Year, Age, Sex
#  n1 is the initial population
for(u in 1:ndau){
  N[u,1,1,1] ~ dnorm(n1[1,2], 1/n1[1,2])T(0,)
  N[u,1,1,2] <- N[u,1,1,1] # DJM: males = females

  for(a in 2:nage){
    for(s in 1:2){
      N[u,1,a,s] ~ dnorm(n1[a,s+1], 1/n1[a,s+1])T(0,)
    }
  }

  yN[u,1] <- N[u,1,1,1] + N[u,1,1,2]
  fN[u,1] <- N[u,1,2,1] + N[u,1,3,1] + N[u,1,4,1]
  mN[u,1] <- N[u,1,2,2] + N[u,1,3,2] + N[u,1,4,2]
  indN[u,1] <- fN[u,1] + mN[u,1] ##independent aged lions
  totN[u,1] <- yN[u,1] + fN[u,1] + mN[u,1]
}

###  Process model - 4 ages, 2 sex
#  Using normal approximation because it is fast and mixes well
#  Sex = 1 is a female
#  Indexing follows - DAU, Year, Age, Sex
for(u in 1:ndau){
```

```
for(yr in 2:nyr){
 #  Kittens
 #  Normal approximation of Poisson
 nMu[u,yr,1,1] <-
   ((N[u,yr,3,1] * 0.5 * FC[1] * Preg[1]) +
      (N[u,yr,4,1] * 0.5 * FC[2] * Preg[2])) *
   S[u,yr-1,1,1]
 nMu[u,yr,1,2] <- nMu[u,yr,1,1]

 N[u,yr,1,1] ~ dnorm(nMu[u,yr,1,1], 1/(nMu[u,yr,1,1]))
 N[u,yr,1,2] <- N[u,yr,1,1]

 for(s in 1:2){
   #  Juveniles
   #  Normal approximation of Binomial
   nMu[u,yr,2,s] <-
     (1 - O[u,yr-1,2,s]) * (N[u,yr-1,1,s] + 2 - min(harv[u,yr-1,2,s], N[u,yr-1,1,s]))

   nTau[u,yr,2,s] <- 1/((N[u,yr-1,1,1] + 2 - min(harv[u,yr-1,2,s], N[u,yr-1,1,s])) *
                        (O[u,yr-1,2,s]) * (1 - O[u,yr-1,2,s]))

   N[u,yr,2,s] ~ dnorm(nMu[u,yr,2,s], nTau[u,yr,2,s])

   #  SubAdults
   #  Normal approximation of Binomial
   nMu[u,yr,3,s] <-
     (1 - O[u,yr-1,3,s]) * (N[u,yr-1,2,s] + 2 - min(harv[u,yr-1,3,s], N[u,yr-1,2,s]))

   nTau[u,yr,3,s] <- 1/((N[u,yr-1,2,s] + 2 - min(harv[u,yr-1,3,s], N[u,yr-1,2,s])) *
                        (O[u,yr-1,3,s]) * (1 - O[u,yr-1,3,s]))

   N[u,yr,3,s] ~ dnorm(nMu[u,yr,3,s], nTau[u,yr,3,s])


   #  Adults
   #  Normal approximation of Binomial
   #  Female Other Mortality shared between the sexes
   nMu[u,yr,4,s] <-

     (N[u,yr-1,3,s] + N[u,yr-1,4,s] + 2 - min(harv[u,yr-1,4,s], N[u,yr-1,4,s])) *
     (1 - O[u,yr-1,4,s])

   nTau[u,yr,4,s] <-
     1/((N[u,yr-1,3,s] + N[u,yr-1,4,s] + 2 - min(harv[u,yr-1,4,s], N[u,yr-1,4,s])) *
         (O[u,yr-1,4,s]) * (1 - O[u,yr-1,4,s]))
```

```
      N[u,yr,4,s] ~ dnorm(nMu[u,yr,4,s], nTau[u,yr,4,s])

     }

     #  Totals in each year
     yN[u,yr] <- N[u,yr,1,1] + N[u,yr,1,2]
     fN[u,yr] <- N[u,yr,2,1] + N[u,yr,3,1] + N[u,yr,4,1]
     mN[u,yr] <- N[u,yr,2,2] + N[u,yr,3,2] + N[u,yr,4,2]
     indN[u,yr] <- fN[u,yr] + mN[u,yr] ##independent aged lions
     totN[u,yr] <- yN[u,yr] + fN[u,yr] + mN[u,yr]
    }
   }

   ####################  Observation Models
   #  Indexing/columns always follows
   #    1   2    3    4    5    6
   #  DAU, Year, Age, Sex, Mean, Tau

  #  Abundance Observation - [dau, yr] - (DJM: this is where SECR estimates go) - this can be
commented out to ignore
   # DJM: Can't give this NAs, so looping through ndat table won't work
   # for(i in 1:nyr){ # DJM: changed 'nn' to 'nyr'
   #   ndat[i,5] ~ dnorm(totN[1,ndat[i,2]], ndat[i,6])T(0,) #DJM: [i,5] = Mean, [i,2]=Year,
[i,6]=Tau
   # }

   # can't loop above b/c NA years - give individual values for each period with an ecoregion
estimate: e.g., 16=Year, 5=pop est Mean,
   # TotN indexing is [DAU, Year]
   ndat[19,5] ~ dnorm(indN[1,19], ndat[19,6])T(0,)

   #  OBSERVED: Harvest Observations - [dau,yr,a,s]
   for(u in 1:ndau){
    for(yr in 1:18){  #note constricted range (leaves out license year 2021 which is not
complete as of 2022-01-31)
     for(a in 1:nage){
      for(s in 1:2){
       harv[u,yr,a,s] ~ dbinom(H[u,yr,a,s], round(N[u,yr,a,s]))
      }
     }
    }
   }


   # FORECAST: Harvest forecast - [dau,yr,a,s]

    #  Survival Observations - (DJM: not aware that we have any of these)
```

```
 # for(i in 1:ns){
 #   sdat[i,5] ~ dnorm(S[1, sdat[i,2], sdat[i,3], sdat[i,4]], sdat[i,6])T(0, 1)
 # }
 # #  Harvest Mortality Rate Observations
 # for(i in 1:nhm){
 #   hmdat[i,5] ~ dnorm(H[1, hmdat[i,2], hmdat[i,3], hmdat[i,4]], hmdat[i,6])T(0, 1)
 # }
 # #  Other (Non-Harvest) Mortality Rate Observations
 # for(i in 1:nom){
 #   omdat[i,5] ~ dnorm(O[1, omdat[i,2], omdat[i,3], omdat[i,4]], omdat[i,6])T(0, 1)
 # }

 #  Derived - the constant is added to avoid division by 0
 for(u in 1:ndau){
  for(yr in 1:nyr){

    mf[u,yr] <- (mN[u,yr] + 0.001)/(fN[u,yr] + 0.001)
  }
 }

 #  Incomplete vectors cannot be monitored, so aribitrary value is given
 #  to the first year
 #  Same constant trick is used here for the division
 #  Using the log and exp handles 0 gracefully, recall that
 #  log(x) + log(y) = log(xy), so the geometric mean is calculated using
 #  an algebraic rearrangment that is more robust to 0's
 for(u in 1:ndau){
  lambda[u,1] <- 1
  for(yr in 2:nyr){
    lambda[u,yr] <- (totN[u,yr] + 0.001)/(totN[u,yr-1] + 0.001)
    logla[u,yr] <- log(lambda[u,yr])
  }
  geoLambda[u] <- exp((1/(nyr-1))*sum(logla[u,2:(nyr)]))
 }
}
```