A. TITLE Monitoring Alabama White-tailed Deer Populations to Inform Future Decision Making

B. NEED

The white-tailed deer (*Odocoileus virginianus*; WTD) is the most widespread and abundant large herbivore in North America and is the most frequently hunted big-game species across the eastern United States. In Alabama, the WTD is the highest priority wildlife species from a state management focus. Hunting for WTD in Alabama produces economic impacts of ~$1 billion in Alabama (Responsive Management 2022), and the corresponding WTD license sales drives much of the wildlife management budget of the Wildlife and Freshwater Fisheries Division (DWFF). The species is similarly important from animal damage (e.g., vehicle-deer collisions) and recreational viewing perspectives (Cook and Gray 2003, Hussain et al. 2007). With an estimated 1-2 million wild deer in Alabama, the species shapes Alabama's terrestrial ecosystems through its roles as an herbivore, prey species, and resource for scavengers (Rooney 2001, Cook and Gray 2003, Coté 2011). Given the importance of the species, a scientifically defensible, data-driven basis for Alabama WTD management decision-making by the DWFF is a fundamental expectation of stakeholders.

To date, the primary sources of data obtained by DWFF for WTD management have included the following: reported harvest numbers through state-wide hunter surveys; Game Check harvest reporting that became mandatory in fall 2016; collection of harvest data from participating private properties as part of the DWFF Deer Management Assistance (DMAP) program; check stations on select public properties such as Wildlife Management Areas (WMAs); and short-term research studies (Cook, W., ADCNR, pers. comm.) . However, these data mainly have been used either to assess population changes at property levels or as coarse indictors of zone- and state-wide trends in WTD abundance and population structure. The ability of DWFF to make data-informed decisions would be greatly enhanced if these and potentially additional data can be integrated into formal population-estimation and projection models to better monitor WTD herd size and population structure.

While a large array of monitoring options can be considered, **an important step in addressing this research problem is formalizing a WTD population model that will link monitoring and decision analyses.** Consistent with most modern population decision frameworks, a WTD population model is a fundamental part of decision analyses, ideally coupled with model modules linking deer population attributes to hunter satisfaction, economic impacts, etc. (Converse et al. 2013, Robinson et al. 2016). Large-scale statistical population models generally are forms of integrated population models (including joint-likelihood harvest models), which have at their core a population model (or equivalent relationships) that links different data sources (and underlying data-generating models) into a unified framework (Skalski et al. 2005, Schaub and Kéry 2022). Thus, an underlying population model is a core part of both statistical estimation and decision analysis. Increasingly in modern wildlife management, statistical models used for estimating parameters from monitoring data are integrated directly into population / decision-analysis models, such that statistical estimation and projection for decision analyses are tightly coupled. This ensures full propagation of statistical uncertainty and explicit accounting for correlation among parameters and estimates (Sauer et al. 2013, Raiho et at al. 2015, Andrén et al. 2019).

Feasibility and cost-effectiveness obviously are critical aspects of evaluating potential monitoring approaches. To be both useful for DWFF's decision making and scientifically defensible, a WTD monitoring approach needs to provide population estimates for routine DWFF reporting that are of acceptable precision and bias, with solid understanding of the magnitude of biases from an approach and appropriate measures of uncertainty (variance estimates) produced for all estimates. Moreover, the monitoring approach needs to meaningfully inform and scientifically support DWFF harvest-management decision making. In an expected-value-of-information (EVI) sense, the monitoring approach needs to lead to sufficiently better decisions that it justifies the cost of monitoring. EVI analyses depend on an advanced decision-analysis framework including mature specification of objectives structure, measurement attributes, etc. captured in a quantitative decision model (Runge et al. 2013, Robinson et al. 2015). One of the largest problems with past wildlife and broader ecological monitoring efforts has been the lack of strong integration of monitoring into the decision-making process, starting at the monitoring design phase (Nichols et al. 2006). Consideration of EVI and integrating monitoring development into the larger adaptive management decision framework is a critical part of ensuring the value of subsequent monitoring. Again, the link between monitoring development, a fundamental population model, and the broader decision-analysis framework is fundamental to meeting the state's needs.

A broad variety of deer population model platforms are available or can readily be developed, from deterministic spreadsheet models (Starfield 1997) to stochastic matrix models (Robinson et al. 2016) to individual-based models (agent-based models; e.g. Belsare and Stewart 2020). Regardless of the general model platform, the more fundamental considerations involve decisions about model structure (e.g. number and binning of age classes) based on WTD population dynamics and decision-making population attributes, decisions about spatial hierarchies / explicitness (e.g., whether WMA-level and zone-level analyses use the same fundamental non-spatial model, just with different population sizes, etc., or whether there's a hierarchical spatial structure to models), etc. As described above, these decisions are important in that the core population model is a critical part of the framework for developing a monitoring approach.

Similarly, there are many options for collecting WTD population data at a range of scales, from research-grade camera trapping and thermal surveys to short-term telemetry studies to state-wide pregnancy studies to citizen-science camera and observation data (e.g., Wiggers and Beckerman 1993, Keever et al. 2017, MacMahon et al. 2021, Forsyth et al. 2022). For monitoring harvested populations, harvest data are generally the most cost-effective data to collect at large spatial scales (Skalski et al. 2005, Skalski et al. 2012). However, statistical methods utilizing harvest data alone may involve low precision for zone- or WMA-level estimation, may involve violation of core assumptions that may cause problematic bias, and require supplemental information (e.g., hunter-effort data) to even be feasible (Millspaugh et al. 2010, Clawson et al. 2013, Murphy et al. 2021, Ferreira 2022). In Alabama, numerous types of WTD population data at a variety of spatial scales are currently being collected (or have been collected in shorter-term studies) and might form the basis for beginning to assess trade-offs among different monitoring approaches and cost effectiveness. These include trail camera sightings, deer-vehicle collision histories, and citizen science observations. For wildlife population monitoring in general, there has been a dramatic increase in development of integrated population models (IPMs) leverage leveraging multiple types of data to estimate demographic parameters at scales previously considered unfeasible (Schaub and Kéry 2022). By integrating data from diverse sources, we may be able to improve precision of deer population parameters which will scale up to improve efficiency and defensibility of harvest decisions.

C. OBJECTIVES

In this project, DWFF staff and AU CFWE researchers will collaborate to determine a feasible, informative monitoring approach for informing DWFF's understanding of status and trends in WTD abundance and herd composition / population structure and for informing WTD harvest-management decision making at both larger (zone-level) and property-level (e.g., WMA) spatial scales. To accomplish this, we have broken the task down into more specific objectives.

Objective 1. Develop modeling, monitoring, and decision-analysis frameworks in preparation for subsequent project objectives. This involves developing a general WTD biological model structure, alternative population models, and decision-analysis scenarios in the context of DWFF WTD decision-making needs.

Objective 2. Summarize and evaluate value of existing Alabama WTD harvest information. At present, harvest data and hunter surveys are the primary large-scale information being collected for Alabama WTD. For this objective, we will analyze currently available information related to Alabama WTD harvest (harvest reports, hunter surveys, etc.) and evaluate the utility and limitations of using harvest data as the primary approach for monitoring key biological parameters of Alabama WTD populations. Although there is a bewildering array of potential ways of monitoring WTD populations, use of harvest data (e.g., harvest numbers, hunter effort) is likely to be a core part of any cost-effective approach that can be used at large spatial scales. In addition, there are numerous existing applications and evaluations of harvest-based monitoring (e.g., Statistical Population Reconstruction, SPR models) for monitoring harvested species at state- or zone-level scales, such that this project can efficiently build on such prior or ongoing work from other states.

Objective 3. Identify, evaluate, and compare integrated WTD monitoring alternatives. Although harvest data are likely to be a key component of Alabama WTD monitoring, it is not a panacea, and models such as SPR come with assumptions and sample size needs that may not be feasible to meet. Moreover, the most effective and efficient large-scale approaches for demographic monitoring involve integrating multiple data sources. This could include integrating multiple data types that are being collected or could be feasible to collect at large scales (e.g., harvest data, citizen-science camera surveys, and state-wide roadkill reports), and/or integration of large-scale, lower-resolution extensive data with more intensive localized sampling (e.g., in a double-sampling approach).

Objective 4. Evaluate trade-offs of alternative decision-modeling approaches. For all options examined in Objectives 2 and 3, a basic assumption is that a) the major conclusions are robust with respect to the population-modeling frameworks used, or b) we understand the differences in conclusions among model types, why they arise, and what the implications are with respect to evaluations of monitoring strategies. An additional outcome of this project will be to guide DWFF managers in the trade-offs of using matrix-type models vs. spatially explicit ABMs as population decision-modeling frameworks in future decision-making situations. Finally, comparisons between models that use different methodologies will help us better understand mechanisms that underpin deer population dynamics, thereby informing defensible harvest-management decision making. Work towards this objective will be woven within all previous objectives, rather than representing additional stand-alone work.

Future Objectives: Human-dimensions considerations. The DWFF manages Alabama wildlife populations for sustainable benefit to the people of the state. The needs and preferences of those who participate in Alabama WTD hunting clearly are a critical aspect of decision making, as maximizing satisfaction of hunters and other stakeholders is a fundamental objective of management. While the work above focuses on WTD populations, there is a clear need to make explicit the links between WTD population characteristics and stakeholder satisfaction. In addition, communication of technical monitoring information and decision analyses to public stakeholders as well as within the agency is a challenge in its own right. While the first year of the overall DWFF-AU WTD research collaboration will concentrate on WTD populations and monitoring, objectives focused on human dimensions of Alabama WTD management that tie tightly into population-focused objectives above will be developed and integrated into the effort during or after the first year of this project. This will integrate essential social-scientist expertise into the overall effort.

D. EXPECTED RESULTS OR BENEFITS

At completion of the project, we expect to provide DWFF with a tool that uses the best available data to estimate WTD population sizes and trajectories. The tool will be versatile and allow DWFF to evaluate how interventions (e.g., altered harvest regulations) impact populations and trends. Most importantly, it will be data-driven and user-friendly allowing managers to explore the impacts of different harvest scenarios without need for a coding background or a robust education in statistical modeling.

The benefits of this project to DWFF are manifold. At its core, this project is designed to help the agency manage one of their most valuable resources in a sustainable way while maximizing benefits to the community. Harvest rates established using the tools we produce will be scientifically defensible to all stakeholders, and if interested, DWFF could make these tools available to the public so they could "see for themselves" how different management approaches impact deer populations. The scientific basis for decisions, coupled with increased transparency is likely to improve hunter satisfaction while setting the bar for deer management in state agencies around the country.

E. APPROACH

Personnel and responsibilities

Auburn University's research team will consist of Dr. Robert Gitzen, Dr. Jonathon Valente, Dr. Aniruddha Belsare, Dr. Stephen Ditchkoff, one PhD student, and two MS students. The first objective will be worked on collaboratively by the entire project team, as it will set the stage for the remainder of the work. Meeting the other outlined objectives will be the responsibility of one or more of the graduate students as a component of their thesis or dissertation project (although completion of all objectives will be the ultimate responsibility of the Principal Investigators). Dr. Gitzen (and Dr. Ditchkoff, TBD) will supervise two sequential MS students to meet the second objective while Dr. Valente and Dr. Belsare will co-advise a PhD student to focus on the third and fourth objectives. Given that Dr. Ditchkoff has decades of experience studying deer biology in the southeastern United States, he will serve as an expert advisor for development of all aspects of the project.

Objective 1

We will first outline spatial, temporal, and demographic resolutions and scales needed to be relevant to DWFF WTD decision making. This will involve working closely with DWFF personnel to outline the types of decision problems that may be faced by DWFF [e.g., WMA- vs. zone-level decisions; potential demographic resolution relevant to future harvest decisions (e.g., antlerless, yearling bucks, post-yearling bucks, vs. finer age resolution, vs. antler point / size regulations)], to ensure that we develop relevant and useful population. Through these discussions we will determine the specific primary biological outputs (in terms of spatial scale and resolution and in terms of demographic parameters, e.g., abundance, sex and age ratios, etc.) relevant to DWFF WTD decision-making needs. These discussions will both inform and be informed by consideration of biological parameters most likely to be feasible as targets of operational monitoring. Next, we will develop initial working draft biological models for use in addressing subsequent objectives. For operational decision making, there are trade-offs among potential underlying population-modeling approaches (e.g., simplicity/ease of communicating the model structure to stakeholders vs. flexibility for dealing with spatially explicit multi-scale decision scenarios). In the shorter term, for meeting Objectives 2 and 3, population simulation models will be a critical engine involved in comparing candidate monitoring approaches, including assessing the robustness of results to alternative population model structures. Therefore, model building will start with simple deterministic spreadsheet models and expand to matrix-type non-spatial or spatially implicit stochastic models ("matrix models"); we simultaneously will incorporate spatially explicit agent-based models ("ABMs"), adapting existing WTD ABMs being used by wildlife agencies in several other states.

Third, we will develop a transparent, explicit objectives hierarchy / hierarchical ranking system for evaluating the strengths and trade-offs of alternative monitoring approaches. The choice among monitoring approaches is a decision problem in its own right, with considerations such as scope/scale, cost, statistical considerations (precision, bias, sensitivity to assumptions) for the multiple parameters of interest, public and agency engagement and acceptance, etc. To guide subsequent evaluations and comparisons, we will work with DWFF team members to develop a set of explicit ranking/ratings criteria and associated ratings scales for evaluating WTD monitoring strategies in subsequent objectives.

Lastly, we will develop a suite of current, past, or expected future focal decision scenarios and prototype decision structures (e.g., model objectives hierarchies and utility scales) for use in expected value of information (EVI) analyses in subsequent project objectives. Modern wildlife management recognizes that in decision-focused contexts, the value of a particular modeling and monitoring approach is determined by the extent to which it enables managers to make better decisions – i.e., by the extent to which that approach increases the managers' ability to identify alternatives with greater expected overall utility (overall satisfaction in achieving management objectives). For example, will greater investment in monitoring (i.e., higher intensity resulting in increased precision) pay off, compared to lower-precision monitoring, in supporting better future management decisions? To explore the comparative value of candidate monitoring approaches for future decision making, we will work with DWFF staff to develop 1-3 decision problem scenarios, each with a clear objectives hierarchy and set of alternative management choices. These scenarios will be used for test-driving alternative model structures and potential monitoring approaches to examine their comparative value for informing DWFF WTD decision making (Box 1).

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Box 1. Population, monitoring, and decision simulation steps to assess and compare candidate Alabama WTD monitoring strategies.

1. Simulate 5-25 years of deer population dynamics from each population model, based on team-specified population scenarios such as a simulated declining trend in overall abundance, relative proportion of adult bucks, decreased fawn survival, etc.

2. Simulate alternative deer population monitoring with alternative methods and intensities, during the simulation years and assess bias and precision of the alternative monitoring strategies.

3. Simulate the decision situation, with a simplified set of fundamental objectives and alternatives, and a state-dependent decision needed in the face of the simulated uncertainty about the population status/dynamics from the simulated monitoring.

4. Simulate prediction of consequences using the imperfect understanding of deer dynamics and assess expected utility of the decision under the various monitoring approaches to assess comparative value of information produced by each approach for the simulated decision scenario. Embedded in this step will be the need to develop analysis tools for integrating model outcomes into a decision-making framework.

Objective 2: MS student 1

We will first compile and summarize existing state-wide hunter survey harvest reports, Game Check data, WMA check-station data, DMAP data from participating partners, and other partner-provided data that could be available (e.g., Westervelt property harvest data). We will then assess patterns and trends estimable with this information, assess potential sampling and reporting biases, and recommend initial steps for improvement. An important focus of this and subsequent aspects of this objective (as well as Objective 3) will be considering stand-alone and integrated values of data from more intensive property-level harvest monitoring (DMAP) and data from broad scale harvest reporting and surveys for monitoring WTD. This includes examining to what degree DMAP properties are representative of the broader state, in terms of deer management intensity, hunting pressure, habitat, and geographical distribution, and in terms of how well DMAP harvest information is representative of broader harvest-reporting data. Depending on representativeness, these evaluations may lead to a range of general monitoring strategies for consideration (e.g., monitoring primarily based on DMAP data collection vs. various degrees of integration of DMAP and statewide data.

Next, we will evaluate the potential utility of SPR models for monitoring zone-level and property-level WTD abundance and harvest rates. This includes a) determining the extent to which existing data, combined with auxiliary estimates from the literature, can support SPR-based approaches, and b) determine what would be needed, in terms of years of data, accuracy and thoroughness of reporting, and intensity of auxiliary studies, to support SPR-based monitoring. This latter task may involve consideration of whether expanding current data collection by asking additional questions from Game Check or working with partners to collect age data comparable to DMAP data collection would enable or enhance more informative harvest-model approaches.

Objective 2: MS student 2

Finally, using simulation modeling, we will evaluate the expected value of information for alternative intensities of potential harvest-focused monitoring in the context of the portfolio of decision problems discussed above. Results from this effort will provide baseline information on if and when additional data will be useful for improving population estimates and decision-making. Importantly, the results will also feed into work being conducted by the PhD student as part of Objectives 3 and 4 to better understand what kinds of additional information are most valuable to collect. Thus, this second MS student will work closely with the PhD student towards the end of the project.

Objective 3

We will first identify and explore existing relevant data sources. These may include public trail camera information, deer-vehicle collision information from insurance companies, citizen-science observations, or addition of more intensive or extensive deer harvest data. Once these have been identified, we can develop a set of candidate integrated monitoring and modeling approaches and summarize the level of effort required for each. Understanding what data are available and costs of aggregating new datasets will help articulate what avenues are worth pursuing.

Next, we will conduct simulation modeling using ABM- and matrix-based approaches to evaluate potential biases and precision that can be gained from alternative monitoring approaches. We will work with DWFF to develop a suite of realistic simulation scenarios to examine how these novel approaches perform under realistic variability in WTD population conditions. We will then simulate sampling of these WTD populations and fit our newly designed models to those data to examine how well they perform for recovering the true mechanisms driving the population.

Objective 4

Using results from our data-finding, modeling, and simulation efforts, we will develop a comprehensive monitoring and modeling strategy for DWFF. This will involve combining bias and precision information for the various approaches with estimated costs to evaluate the EVI of alternative monitoring strategies in simulated decision situations (Box 1). Ultimately, the goal of any such monitoring effort is to develop precise and unbiased estimates of the population parameters of interest, but greater accuracy tends to come with higher costs. By integrating the results from the above objectives, we can work with DWFF to determine one or more recommended monitoring approaches and a pathway to implementation.

We will also work with DWFF to identify the most straightforward way to implement the selected approach going forward. We will work with DWFF personnel to help them understand the potential tools and algorithms through which our modeling approach could be implemented (e.g., ArcGIS, Excel spreadsheets, R Shiny apps). Through this collaboration we will identify the path most likely to be utilized by DWFF biologists in the future and examine alternatives for providing the tool to community stakeholders.

F. LOCATION

Core researchers on this project will be headquartered in the College of Forestry, Wildlife and Environment at Auburn University. That said, we will collaborate closely with DWFF biologists in Montgomery, Alabama, along with wildlife managers located on WMAs across the state (Figure 1).

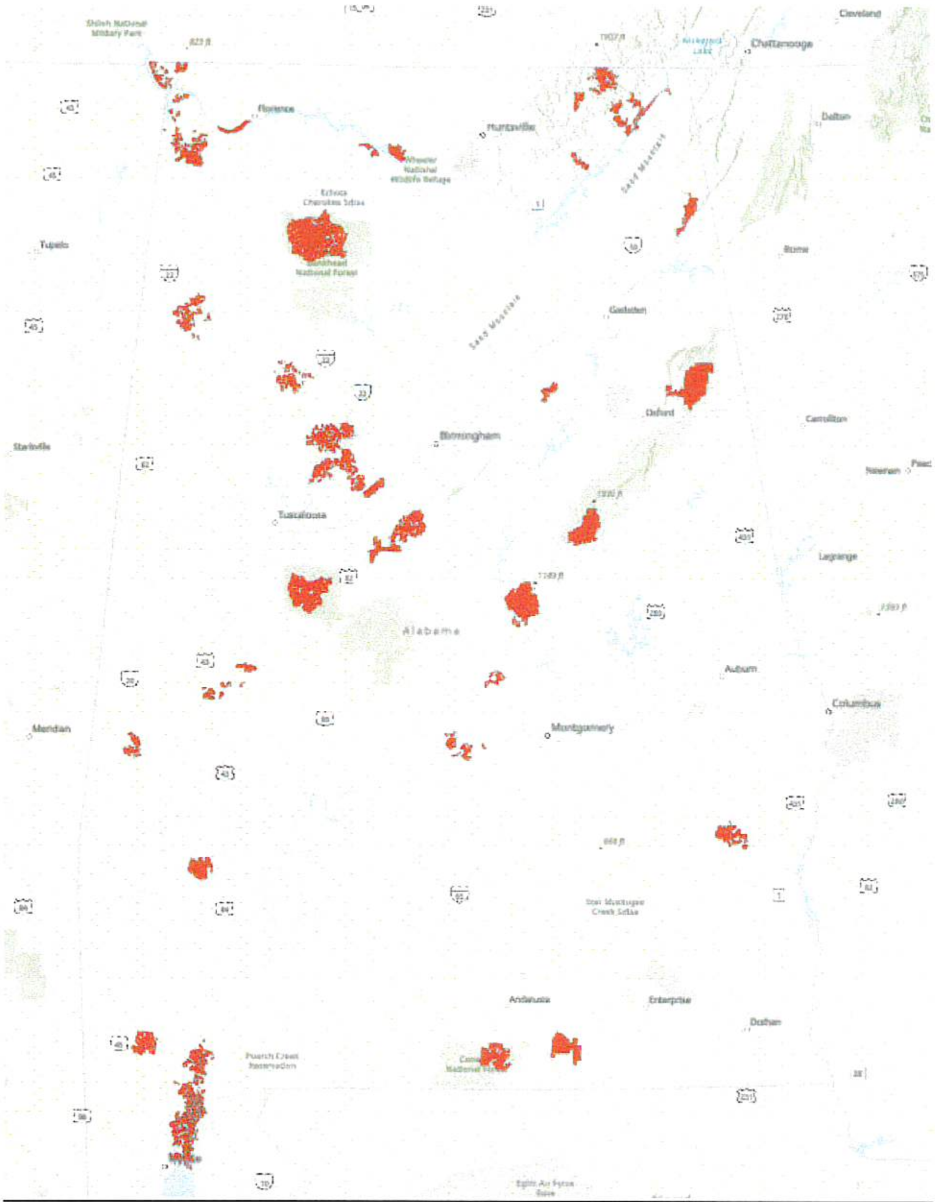

Figure 1. Locations of all wildlife management areas (WMAs) in the state of Alabama.

G. LITERATURE CITED

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J. DELIVERABLES

1. Annual reports summarizing efforts from the previous fiscal year.
2. A report summarizing the general WTD biological model we develop, the suite of population models we will test, and the decision-analysis scenarios (developed in partnership with DWFF) for assessing those models.
3. A tidy database containing all existing DWFF WTD information and data gathered from private cooperators.
4. A report and/or peer-reviewed manuscript outlining the steps for developing decision analysis scenarios and validating any proposed population model.
5. A report and/or peer-reviewed publication that evaluates the suitability, precision, and bias sources of existing harvest models (SPR).
6. A report and/or peer-reviewed manuscript evaluating the potential to improve the quality of or augment the utility of currently collected data.
7. A report and/or peer-reviewed manuscript evaluating the empirically assessed utility of alternative data sources for improving WTD monitoring and modeling, including an assessment of the logistical feasibility of acquiring such data.
8. A report and/or peer-reviewed manuscript comparing the bias, precision, cost, and EVI for traditional and alternative WTD population modeling approaches.

9. A user-friendly application for implementing the selected modeling approach that can be used by biologists and community members to evaluate decision scenarios.
10. An informational workshop with DWFF biologists and/or members of the public that demonstrates how to use the decision support tool.

K. TIMELINE

	2024			2025				2026				2027				2028				2029		
	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4
Personnel																						
Advertising/hiring	■	■					■	■														
PhD student 1		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
MS student 1		■	■	■	■	■	■	■	■	■	■	■	■									
MS student 2										■	■	■	■	■	■	■	■	■	■	■	■	
Objective 1																						
Develop general WTD model structure		■	■	■	■																	
Formulate alternative population models		■	■	■	■	■	■															
Develop decision-analysis scenarios		■	■	■	■	■	■															
Objective 2																						
Compile existing data					■	■	■	■	■	■												
Assess sampling and reporting biases					■	■	■	■														
Develop SPR models								■	■	■	■											
Evaluate limitations of SPR models										■	■	■	■	■	■							
Assess performance of SPR in agreed-upon scenarios												■	■	■	■	■	■	■	■			
Develop recommendations for improving data collection																		■	■	■	■	
Objective 3																						
Examine availability and accessibility of alternative data sources					■	■	■	■	■	■	■	■	■	■	■							
Compile alternative monitoring data					■	■	■	■	■	■	■	■	■	■	■							
Develop candidate models that integrate these data sources								■	■	■	■											
Evaluate limitations of alternative models												■	■	■	■							
Assess performance of alternative models in agreed-upon scenarios												■	■	■	■							
Develop recommendations for use of such alternative data																■	■					
Objective 4																						
Compare performance and EVI of traditional and alternative models														■	■	■	■					
Develop recommendations and consult with DWFF																		■	■			
Create tool for implementation																			■	■		
Refine tool based on DWFF feedback																				■	■	

Deliverables

	2024			2025				2026				2027				2028				2029		
	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4	FY Q1	FY Q2	FY Q3	FY Q4
Deliverable #1																						
Deliverable #2																						
Deliverable #3 (database will be maintained throughout project)																						
Deliverable #4																						
Deliverable #5																						
Deliverable #6																						
Deliverable #7																						
Deliverable #8																						
Deliverable #9																						
Deliverable #10																						

L. COMPLIANCE STATEMENT

We certify that this proposed research effort will comply with applicable state and federal laws and regulations including, but not limited to, NEPA requirements, Endangered Species Act Requirements, National Historic Preservation Act, and state and federal collection permit requirements.