Statistical review of Future Roadkill Estimation Method (FREM) used by US FWS South Florida Ecological Services Field Office staff

Technical Memorandum

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Executive Summary

This Technical Memorandum documents an independent statistical review of the "Future Roadkill Estimation Method (FREM)" developed and used by staff since 2018 at the U.S. Fish and Wildlife Service (US FWS) South Florida Ecological Services Field Office in Vero Beach. This review specifically addresses the use of the FREM approach to predict an annual average PVM for 2060 in the context of FWS analysis related to potential development within the Eastern Collier Multiple Species Habitat Conservation Plan (ECMSHCP). This review is conducted as a scientific peer review based on my expertise as a PhD statistician with two decades of experience in research, teaching, and scientific collaboration. This review considers the US FWS Information Quality Guidelines and other best practices for documenting and evaluating quantitative predictive methods.

This review covers three general tasks related to the development and application of the Vero Beach Ecological Services Field Office FREM approach: (Task 1) assess the quality of existing documentation and transparency, (Task 2) evaluate assumptions, decisions, and sources of uncertainty, and (Task 3) provide a professional opinion regarding the scientific justification for using the FREM approach to obtain predictions of PVM in 2060 for use to support decision-making. Development of an alternative approach is beyond the scope of this review.

Task 1 Summary. *The documentation describing the development and application of the FREM approach does not meet the standards described in the US FWS Information Quality Guidelines, for "objectivity" and "transparency."*

Documentation supporting method description, method development, and evaluation of predictive ability is lacking. Standards for "objectivity" issued by the US FWS in their *Information Quality Guidelines* are meant to ensure information is presented "accurately, clearly, and completely, and in an unbiased manner." The guidelines further state "we [the US FWS] will explicitly state assumptions, limitations or biases related to the information" and that "we will generally require sufficient transparency about data and methods that a qualified member of the public could undertake independent reanalysis." The lack of supporting documentation is not consistent with the standards outlined in the US FWS guidelines and limits effective evaluation and justification for decision-making. For example,

- Existing documentation does not include a mathematically rigorous description of the FREM algorithm and associated definitions and assumptions.
- Details of how the method was developed are omitted and discussions of sources of uncertainty are missing.
- Violations of assumptions and potential limitations of the FREM approach, along with implications of these on potential decisions informed by FREM predictions, are not adequately described.

- Two examples provided to demonstrate predictive ability are missing details about how the areas and time periods were chosen and if the information was used in both method development *and* assessment of predictive ability.

Task 2 Summary *The evaluation of key assumptions, decisions, and sources of uncertainty underlying the FREM approach reveals multiple concerns with its use for predicting PVM in 2060. The method ignores important factors related to panther movement across the landscape and ignores sensitivity of predictions to choice of baseline time interval and known sources of uncertainty.*

This review raises substantial concerns about use of the FREM approach. The main concerns are related to justification for assumptions and decisions in method development, lack of acknowledgement of uncertainty in predictions, and lack of adequate justification of the method's predictive ability.

- Predicting increases in PVM counts based only on one measure of traffic volume, Average Annual Daily Traffic (AADT), ignores important factors such as diurnal and seasonal changes in traffic volume, changes in panther population size, landscape characteristics, and panther access to roadways (fencing, wildlife crossings).
- Data analysis reveals evidence for a strong, positive association between annual panther counts and annual PVM counts in the region. Using the natural log scale for both variables, the estimated correlation coefficient is 0.94 (see Section 3.3.5).
- Exploratory analysis reveals weak associations between 5-year PVM counts (or averages) and midpoint year AADT values. The associations range from negative to positive depending on the road segment and are generally not consistent with the mathematical relationship specified in the FREM formula.
- The FREM approach ignores all uncertainty in AADT estimates and projections used as inputs to the formula, as well as uncertainty due to extrapolation beyond observed AADT values. This review demonstrates that FREM PVM predictions can be sensitive to realistic levels of uncertainty in the AADT inputs, as expected mathematically. Investigation into the range of potential predictions given known sources of uncertainty should be a prerequisite to using the FREM predictions to inform decision-making.
- PVM predictions based on FREM can also be sensitive to the choice of 5-year baseline time period – both due to the recorded PVM count and the AADT value associated with the midpoint year.

Task 3 Summary: *Statistical review of the FREM approach reveals limitations with the method that are serious enough to question its current use in predicting year 2060 PVM. The use of FREM is not adequately justified and predictions are not deemed trustworthy enough to inform decisions.*

Scientific review identifies substantial limitations in transparency, extent of documentation, and underlying methodology for predicting future PVM using the FREM approach. Use of three roadway data inputs (PVM over a past five-year period, a past single year AADT, and a projected future year AADT) to produce a single number representing predicted PVM 40 years in the future without acknowledging any uncertainty in the FREM predictions is not adequate for use as a basis for decision-making regarding potential impacts of future development within the ECMSHCP area on panthers. Exploratory data analysis suggests the range in predictions due to sources of variability and uncertainty unaccounted for in FREM is large enough to potentially impact decision-making related to the ECMSHCP. Additionally, dissemination of the information regarding FREM does not meet the standards of transparency, utility and objectivity as defined and issued by the US FWS in its *Information Quality Guidelines and Peer Review* document.

1. Introduction

This Technical Memorandum documents an independent statistical review of the Future Roadkill Estimation Method (FREM) adopted in 2018 to predict future panther vehicle mortalities (PVM) by staff at the U.S. Fish and Wildlife Service (US FWS) South Florida Ecological Services Field Office in Vero Beach. The FREM approach is being considered for use to predict PVM in 2060 for a collection of road segments identified by FDOT traffic analysis to be relevant to potential future development within the Eastern Collier Multiple Species Habitat Conservation Plan (ECMSHCP) area. The prediction of 2060 PVM for the identified road segments identified provides a specific context for parts of this review.

This review accomplishes the following: (1) assesses the available documentation of the method and justification provided by FWS staff in support of the method; (2) provides detailed description the approach based on available information, including primary underlying assumptions, decisions, and sources of uncertainty; (3) evaluates the reasonableness of the underlying assumptions and decisions; (4) investigates sensitivity of predictions to sources of uncertainty; and (5) provides my professional opinion as a statistician regarding the scientific justification of the method for use in predicting PVM for year 2060. Development of an alternative method to FREM is beyond the scope of this review, though information is provided throughout the review that will be useful for any future predictive modeling work.

1.1 Sources of information used in the review

Information obtained for this review came primarily through verbal communication with Bruce Johnson, Ph.D. Senior Scientist at Stantec Consulting Services Inc.; a written description of the FREM method provided by USFWS to Dr. Johnson and forwarded to me; and formulas contained in an Excel spreadsheet developed by the staff at the US FWS South Florida Ecological Services Field Office containing the PVM predictions for road segments relevant to the ECMSHCP. Together, the FWS staff and Dr. Johnson cross-checked the AADT and PVM data inputs for specific road segments as a quality control procedure. The written description provided to Dr. Johnson by staff at the US FWS South Florida Ecological Services Field Office consisted of a two-paragraph document attached to an email on July 8, 2020. The document briefly described the FREM formula and an “evaluation of the appropriateness of the FREM method for estimating risk to panthers from increasing traffic volumes” consisting of two examples of FREM predictions associated with small prediction errors. The two examples used 2009 – 2013 PVM data and 2011 AADT values for selected road segments to predict PVM for 2013 – 2017 using AADT values for 2015 (see Section 3.5.3 for more detail).

The available documentation does not contain an adequate amount of information or associated data to fully describe the approach, understand how it was developed, or understand the scope of the assessment of predictive accuracy. The limits of the information are discussed in detail in Section 2 (Task 1) with reference to the standards issues by the US FWS in its Information Quality Guidelines and Peer Review (US FWS 2012).

1.2 Challenges in extrapolating to predict future PVM

Predicting future PVM in a changing system is difficult. Predictions farther into the future require greater extrapolation beyond available data, thus making the task even more challenging. In the case of the ECMSHCP, the desired prediction is 40 years into the future – a substantial extrapolation. The trustworthiness of the extrapolation rests on assumptions that are impossible to check, making arguments in favor of their justification a crucial part of the process of deciding to use such predictions in a decision-making context.

It is not realistic or productive to expect there is a single best method for prediction; different approaches will have different pros and cons, and all will require substantial extrapolation to predict PVM forty years into the future. Because extrapolations are heavily dependent on underlying assumptions, it is crucial to follow best practices in transparency for predictive model development to facilitate open critique, comparison, and discussion of methods.

Use of model predictions to inform decision-making should be accompanied by adequate justification. Requirements for adequate justification generally include mathematically rigorous documentation of the model, explicit statement of underlying assumptions and sources of uncertainty, acknowledgement of potentially arbitrary decisions made in the development of the approach, and a detailed description and justification of how it was "tested." The prerequisite to adopting any approach should be adequate documentation to facilitate rigorous scientific evaluation before a method is adopted for decision making; and if it is adopted, that its limitations are communicated to stakeholders and factored into any decisions informed by its outputs.

As described in the previous sub-section, based on available information, the use of best practices is not evident, and this conclusion is supported by consideration of the standards described in the US *FWS Information Quality Guidelines and Peer Review* (US FWS 2012). The definitions, wording, and standards provided in the US FWS information quality guidelines document provide a relevant and useful context against which to review aspects of the FREM approach. The most relevant parts of the guidelines for this review are provided in the next section.

1.3 US FWS Information Quality and Peer Review Guidelines

The US Fish and Wildlife Service's Information Quality Guidelines and Peer Review document (US FWS 2012) was issued "for ensuring the quality, objectivity, and integrity of information disseminated by the FWS." Given that these guidelines are issued by US FWS and provide reasonable expectations for sharing of information, the guidelines are used to inform this review of the FREM approach.

> *Quality is defined as "an encompassing term that includes the terms utility, objectivity, and integrity" (III-6). Utility is defined as referring "to the usefulness of the information to its intended users, including the public" (III-7). The most relevant definition for this review is that for Objectivity (III-8):*

> *Objectivity includes whether the disseminated information is presented accurately, clearly, and completely, and in an unbiased manner. Objectivity involves two distinct elements: presentation and substance: a) Information disseminated by the FWS will be presented accurately, clearly, and completely. b) Information disseminated by the FWS will be treated in an unbiased fashion. In a scientific, financial, or statistical context, we will analyze the original and supporting data and develop our results using sound statistical and research methods to ensure, to the best of our knowledge that our results are not subject to bias. Where a potential for bias is identified, the FWS will address it. c) The limitations of the information disseminated by FWS will be explicitly stated.*

The term reproducible is also relevant to this review, defined as "information is capable of being substantially reproduced, subject to an acceptable degree of precision" (III-11). Additional detail is presented in Section IV of the document regarding *how* the FWS will determine utility (IV-1), integrity (IV-2), and objectivity (IV-3). The FWS standards for objectivity found in Section IV-3 are most relevant to this review and quoted directly below, as they are relied on for parts of this review and resulting opinions.

> *The FWS definition of objectivity includes whether the disseminated information is presented accurately, clearly, and completely, and in an unbiased manner. To achieve this end, FWS will subject information to review by persons qualified to judge objectivity (as defined by the type of information and the circumstances in which it will be used). Such a "peer review" will be conducted before decision making, unless legal deadlines or other constraints prevent such a timely review. In such cases, the peer review may have to be post hoc. To the extent they are understood, we will explicitly state assumptions, limitations or biases related to the information. Sometimes, supporting documentation must also be disseminated in order to ensure a more clear, complete, and unbiased presentation. In those cases, FWS will identify the sources of supporting information.*
>
> *Transparency about research design and methods is pivotal to reproducibility. With regard to analytical results, we will generally require sufficient transparency about data and methods that a qualified member of the public could undertake an independent reanalysis. These transparency standards apply to our analysis of data from a single study as well as to analyses that combine information from multiple studies. However, the objectivity standard does not override other compelling interests such as privacy, trade secrets, intellectual property, and other confidentiality protections.*
>
> *In situations where public access to data and methods will not occur due to other compelling interests, we will apply especially rigorous checks to analytical results and documents. We will, however, disclose the specific data sources used and the specific quantitative methods and assumptions we employed. We will define the*

type of checks, and the level of detail for documentation, given the nature and complexity of the issues.

Section IV-4 explains how FWS will describe strengths and weaknesses of the data used in influential scientific information and highly influential scientific assessments:

The preparer of a highly influential assessment or of influential information will document the strengths and weaknesses of the data underlying the assessment/information so that the reader will understand the context for the FWS decision.

1.4 Positive aspects of the FREM approach

The majority of this report focuses on concerns and limitations identified with the FREM approach. This section provides positive aspects of the approach that could have contributed to its adoption.

FREM is easily implementable with readily available historic traffic volume data for individual road segments and a Florida Department of Transportation (FDOT) projected AADT for the future year of interest (more details provided in next section). All that is needed (for each road segment of interest) is PVM over a five-year period, a past AADT value from the midpoint of that five-year period, and the predicted AADT.

The approach is not designed to thoroughly model factors thought to affect PVM (e.g., panther population size, habitat surrounding the road segment, locations of migration corridors, panther access to roadways, time of day differences in traffic volume, etc.). Instead, the goal is to use a simple formula with readily available inputs to approximate a complex process. In general, the predictive accuracy of a model need not be tied to a model's ability to represent causal aspects of the system; as even a spurious relationship can be effectively used for prediction.

The simplicity of the mathematical formula allows it to be carried out quickly and easily in a spreadsheet and calculations can easily be checked. The lack of quantification or consideration of sources of uncertainty contributes to the ease of use; it is a simple formula that takes three numbers as inputs and outputs a single number as the predicted PVM.

1.5 Summary

This review addresses the two elements of "objectivity" as defined by the US FWS: presentation and substance. Task 1 addresses presentation of information regarding the FREM approach, Task 2 addresses substance of the approach, and Task 3 draws upon both presentation and substance to substantiate an opinion about the use of the approach for decision-making. The US FWS information quality guidelines are referenced for convenience, language, and context; they are in-line with scientific best practices in general.

2. Documentation of the FREM approach (Task 1)

This section evaluates the quality of information provided to support the FREM approach according to the standards provided by the US FWS *Information Quality Guidelines and Peer Review*. The full extent of information understood to be available about the FREM includes a written description of the FREM method provided via email by USFWS to Dr. Johnson and forwarded to me, and formulas contained in an Excel spreadsheet developed by the USFWS Vero Beach staff containing PVM predictions for road segments relevant to ECMSHCP analysis.

This section also describes my understanding of the approach at the time of this review based on the information provided, with the goal of improving transparency around the FREM approach to better facilitate critical evaluation of the method before it is used to inform decisions. In the words of the Information Quality Guidelines, this section provides a review of the "presentation" (Task 1) and Section 3 presents a review of the "substance" (Task 2).

2.1 Assessment of Information Quality

The amount of publicly available information regarding the FREM approach is limited in terms of utility (*FWS Information Quality Guideline and Peer Review* IV-1) and objectivity (IV-3), and strengths and weaknesses of the data used are not described (IV-4).

Several standards of Information Quality conveyed in the US FWS guidelines that are *not* met mainly due to lack of documentation and justification are provided in the following quotes:

- "disseminated information is presented accurately, clearly, and completely, and in an unbiased manner"
- "To the extent they are understood, we will explicitly state assumptions, limitations or biases related to the information. Sometimes, supporting documentation must also be disseminated in order to ensure a more clear, complete, and unbiased presentation. In those cases, FWS will identify the sources of supporting information."
- "information is capable of being substantially reproduced, subject to an acceptable degree of precision"
- "With regard to analytical results, we will generally require sufficient transparency about data and methods that a qualified member of the public could undertake an independent reanalysis."
- "The preparer of a highly influential assessment or of influential information will document the strengths and weaknesses of the data underlying the assessment/information so that the reader will understand the context for the FWS decision."

2.2 Overview Description of FREM

Given the lack of documentation, this section provides a brief written description of the approach to accompany the mathematical description referred to in Section 2.3 and provided in Appendix A.

Summary Description of FREM*: FREM is a simple mathematical formula used to predict a future 5-year PVM for a single road segment based on three readily available inputs: a baseline 5-year PVM total for the road segment, an estimate of AADT for the midpoint year of the baseline 5-year period, and a projected AADT for the midpoint year of the future 5-year period of interest. FREM proceeds by setting the ratio of the baseline to future 5-year PVM equal to the ratio of past (estimated) to future (projected) AADT, and then solving for the future PVM. In other words, a future 5-year PVM is predicted by adjusting a past 5-year PVM by a factor equal to the ratio of the past to projected AADT values obtained from the midpoint years. The total for a collection of road segments is obtained by summing all predicted PVM for the individual road segments.*

In the context of the ESCMHCP, the baseline 5-year period is from the beginning of March 2014 through the end of February 2019, with 2017 used as the midpoint year to obtain the AADT value. The future midpoint year of interest is 2060; the associated 5-year period runs from beginning of March 2057 through the end of February 2062. For example, for Church Road from State Road 82 to State Road 29, the 2014-2019 5-year average PVM is 0.20 (5-year count = 1 PVM), the 2017 estimated AADT is 450, and the projected 2060 AADT is 10,287; this leads to a predicted 5-year average PVM for that road segment of 4.57 (5-year count of 22 or 23 PVM). The large increase in PVM is predicted because the AADT ratio is large (10,287/450 = 22.86), even though the past observed number of PVM is small (1.0). This case illustrates a primary assumption of the model; it assumes the only reason the past PVM is small is because of low past traffic volumes. The application of the FREM equation is carried out for each road segment included by the FDOT regional traffic model for the ECMSHCP area analysis and then the predictions are summed to obtain the total prediction for the area (90 segments total).

The FDOT regional traffic model attributes a proportion of the future AADT to potential development associated with the ECMSHCP; this estimated proportion of AADT is then also applied to the total future FREM-predicted PVM to attribute a proportion of the predicted PVM to future predicted development within the ECMSHCP.

2.3 Mathematical Notation and Definitions

Notation and definitions describing my current understanding of FREM are provided using mathematical notation and definitions in Appendix A. Any quantitative method used for predicting PVM should be presented in a mathematically rigorous way to support reproducibility and review of the method. To my knowledge, such documentation was not produced by FWS staff and thus was not available before created as part of this review.

2.4 Sources of Uncertainty Ignored

In the FREM approach, there is no explicit acknowledgement, discussion, or incorporation of sources of uncertainty, either quantitatively or qualitatively. As this greatly affects the quality of information provided about the predictions, it is briefly discussed here.

Using point predictions from a simple model to inform decisions without considering sources of uncertainty is not meaningful or scientifically defensible. Basing decisions on single numbers is a simple and easy way to proceed, but it promotes a false sense of confidence in the single number and thus the decision being made; such an approach is misleading and omits an important part of justifying a decision. Methodology that fails to account for sources of uncertainty does not align with best scientific practices. At the very least, a thorough qualitative evaluation of sources of uncertainty and their potential magnitude relative to the predictions should be undertaken.

Propagating sources of uncertainty through to predictions can be challenging, but efforts to do so are valuable for providing information about the potential variability in predictions stemming from uncertainty in inputs. While it is unrealistic to assume that all uncertainty can be quantified, investigating the range of predictions resulting from at least some known sources is useful "reality-check" exercise, with the understanding that incorporating any additional sources would lead to an even greater range in predictions. This type of exercise in propagating uncertainty is especially important when predictions are meant to be a substantial basis for making practical (e.g., permitting or regulatory) decisions.

In calculations performed for the ECMSHCP analysis, FREM predictions for each road segment are provided as a 5-year average PVM out to two decimal places and then aggregated over many road segments to obtain a point prediction (single number) for the future year of interest (e.g. 2060). In general, a point prediction should be interpreted and used differently for decision- making depending on the level of uncertainty associated with it. For example, suppose a point prediction is 29.32 PVM/year. Compare the interpretation of the 29.32 in the context of two different prediction intervals: (wide) 15.4 to 45.3 and (narrow) 27.1 to 32.1. Discussion of the prediction and how it should inform decisions should depend on which interval was reported. With current application of FREM, the stakeholder has no knowledge of magnitude of uncertainty in the prediction and thus may be lured into using the point prediction as if it has no associated uncertainty.

Section 3.3.4 briefly discusses the potential effects of extrapolation beyond observed ranges of AADT values for a segment. Section 3.6 investigates effects of propagating reasonable levels of uncertainty in inputs (estimated and projected values for AADT) through to FREM predictions to investigate the range of predictions that could be obtained just due to uncertainty or natural variability in the key inputs. The exercise relies on sampling from probability distributions to account for uncertainty in AADT values, where the variance (spread) of the distributions can be adjusted based on the road segment of interest or scenarios assuming different levels of uncertainty.

2.5 Documentation of Assumptions, Decisions, and Sources of Uncertainty

The first step in making a quantitative method transparent and open for evaluation is explicit statement of assumptions underlying development and application of the method; decisions (implicit and explicit) involved in its development; and acknowledgement of identified sources of uncertainty. As described in Section 2.1, documentation of assumptions, decisions, and sources of uncertainty is lacking and not up to the standards described in the *US FWS Information Quality Guidelines and Peer Review*. Therefore, a substantial part of this review is explicitly identifying, documenting, and assessing assumptions, decisions, and sources of uncertainty (hereafter just referred to as assumptions) underlying the FREM approach. The collection of assumptions included is not exhaustive, but it is meant to be sufficient to identify concerns that should be evaluated and discussed before the approach is adopted for decision-making.

The following topics are addressed in Section 3 (Task 2):

- Assumptions related to AADT
- Measurement of traffic volume using estimates of average annual daily traffic (AADT)
- Relationship between AADT and PVM (over time for individual segments and across a collection of segments for a given time)
- Decision to use 5-year intervals and midpoint AADT values
- Investigating sensitivity of predictions and prediction errors to choice of baseline 5-year interval
- Investigating sensitivity of predictions to uncertainty in inputs and extrapolation beyond observed ranges of AADT

3 Evaluation of Assumptions and Limitations (Task 2)

For this task, many of the primary assumptions are explicitly stated and assessed based on available information about the FREM approach, available data, and statistical expertise. The list of assumptions is not exhaustive, but it is intended to be thorough enough to form an opinion regarding whether use of the FREM method for predicting PVM in 2060 is adequately justified to inform decision-making relevant to projected future development within the ECMSHCP area. This section also serves to describe assumptions not otherwise known to be documented.

When evaluation of an assumption involves data or analysis, a brief description of the analysis, results, and conclusions are described, with additional details provided in supplementary files referenced in Appendix B.

3.1 Assumptions related to AADT

For the FREM approach, traffic volume is summarized for a given year using estimates or predictions of Annual Average Daily Traffic (AADT). Primary assumptions related to the use of AADT in predicting PVM using the FREM approach are provided in this section (there is some repetition in ideas among stated assumptions).

Assumption: An increase in AADT (as a measure of traffic volume) on a road segment is associated with an increase in 5-year PVM by the same multiplicative factor - in a deterministic fashion with no uncertainty.

Relevant considerations:

- This is a strong and fundamental assumption to the method. Adequate justification for the development is not provided.
- The relationship between 5-year PVM and AADT is assessed in several ways in this review to help in evaluation of the assumption, including assessment of the assumed 1:1 relationship relative to the associations observed in data from five individual road segments.

Assumption: Annual changes in traffic volume, as measured by estimated, calculated, and/or projected AADT, contain sufficient information to predict changes in PVM *with adequate accuracy and precision to support decision making*.

Relevant considerations:

- Judging adequate accuracy and precision is difficult, but it is part of scientific best practices before relying on model output for decision-making.
- This assumption is assessed in different ways throughout the report through investigations of relationships between AADT and PVM and direct assessments of predictive behavior.

- Documentation provided by Vero Beach FWS staff does not adequately justify accuracy and precision of FREM (see Section 3.5.3).

Assumption: Panther ecology related to panther road crossings (the number of times panthers will cross a given road segment) does not need to be accounted for in predictions. Implied in this assumption may be that the number of panther road crossings is constant over the road segments of interest and over the relevant time period; meaning traffic volume is the only component needing to be accounted for when predicting.

Relevant considerations:

- There is convincing evidence that the number of panthers has increased over time, seriously calling into question this assumption. Such evidence is based on Southwest Florida region level, yearly data and results are presented later in Section 3.3.5.
- FREM assumes it is not necessary to account for other changes in the system (e.g., changes in panther population size); smaller scale changes in traffic volume (hourly, daily, seasonal); or characteristics of the road segments (e.g., surrounding habitat, location relative to migration corridors, or changes in mitigation efforts such as increases in fencing and wildlife underpasses, etc.).

Assumption: PVM and AADT can continue to increase with no upper limit.

Relevant considerations:

- Given there is a limit as to the traffic a road can reasonably accommodate and a limit for the number of panthers in the system, realistic ranges should be considered as part of the interpretation and prediction process.
- Traffic increases beyond the planned capacity of a road segment may not have the effect of increasing PVM risk. For example, traffic increases could result in traffic congestion during periods of highest traffic volume, thereby reducing vehicle speeds to the point PVM risk may actually decrease during those periods.
- The range of 2060 projections for PVM and AADT may be well within the range of realistic future values such that the upper limit is not a concern, but at some point practical constraints on the upper limits will come into play and discussions of those constraints can provide a useful reality check for the method and its predictions.

Other observations and considerations:

- While it is not necessary for a predictive model to describe a causal relationship between the two variables, in the case of PVM and traffic volume, there is a clear causal implication that increased traffic *causes* increased PVM through increasing the risk of a physical collisions between vehicle and panther.
- In this system, there are two components contributing to risk of a PVM: (1) traffic characteristics and (2) panther road crossing behavior. The FREM assumes the risk of PVM increases if the traffic volume along the road segment increases, regardless of the

potential for panther road crossing. Assuming PVM counts can be predicted only from an annual measure of traffic volume does not account for other traffic characteristics (such as driver behavior, lighting, vehicle speeds, etc.) and implicitly assumes the panther-crossing component of the system (the ability and frequency of panther entry onto a roadway) is relatively constant over the road segments and the time periods of interest.

- While related, predicting PVM counts for a segment over a time period is not equivalent to predicting risk (or probability) of a PVM and they generally require different modeling approaches. When making statements about risk, it is also important to be clear about what is being implicitly assumed about the state of the system. For example, we may talk about the risk of a PVM *given* ("conditional on") there being a fixed number of panthers crossing the road in a given time period, or we may talk about risk of a PVM *given* a fixed traffic volume in a given time period. If both traffic volume *and* number of panther crossings are changing, then risk of a PVM (or count of PVM) depends on changes in both variables.
- Applying the FREM algorithm to individual road segments helps account for heterogeneity among road segments within the system in terms of expected number of panthers crossing, but it still does assume road segment conditions related to panthers stay stable except for changes in AADT.

3.2 Average Annual Daily Traffic (AADT): measurement and uncertainty

Traffic volume is one factor necessarily related to PVM in the sense that there must be traffic for a PVM to occur. Theoretically, an increase in traffic volume at a location during a time period when a constant number of panthers are attempting to cross a road segment (an unrealistic assumption) is expected to increase the risk of a PVM. However, the clear connection between traffic volume and risk of PVM does not imply a simple proportional relationship between increases in one measurement of traffic volume (AADT) and PVM given the complexity of the system, even if panther crossing effort were constant. Measurement of traffic volume using AADT is subject to errors and the aggregation to an annual summary masks potentially important diurnal and seasonal information in traffic volume potentially relevant to predicting PVM risk (given that panther behavior is not expected to be constant over the course of a day or year).

The FREM approach does not acknowledge or account for any sources of uncertainty, including the obvious source of uncertainty and variability in estimated and projected AADT values. The information provided by the FWS Vero Beach staff does not provide justification for ignoring these known sources of uncertainty. Presumably, the FREM methodology assumes (1) the uncertainty is small enough to ignore, and/or (2) that the uncertainty will not, or should not, impact decisions made based on the method. These assumptions are assessed later in Section 3.6.

3.2.1 Measurement of traffic volume using AADT

Assumption Average annual daily traffic (AADT), as estimated, calculated, or predicted by traffic models, captures the characteristics of traffic volume relevant to predicting PVM.

Relevant considerations:

- The FREM approach uses available values for AADT as if they capture aspects of traffic volume most relevant to PVM. There are multiple concerns with this:
  - AADT does not capture diurnal differences in traffic volume which are relevant if panthers tend to move across roads more at dusk or dark than during daylight hours.
  - AADT does not capture seasonal differences in traffic volume which are relevant if panthers tend to migrate through the area more at certain times of the year. Segments with quarterly counts available contain seasonal information that could be used.
  - Discrepancies between FDOT calculated AADT values and estimates obtained as averages from Collier County quarterly data collection counts (e.g., CC-MS2 vs. FDOT data for SR-29) demonstrate one source of lack of accuracy and precision associated with reported AADT values. This contributes to uncertainty in the values used, as addressed later in the review.
- An unquantifiable source of uncertainty is the degree to which AADT reflects the aspects of traffic volume actually relevant to predicting future PVM.

3.2.2 Variability and uncertainty in recorded AADT values

There are two assumptions addressed together for this section:

Assumption Uncertainty in calculated or estimated AADT for a year in the past can be ignored in predictions.

Assumption Uncertainty in projected AADT, even 40 years into the future, can be ignored in predictions.

Primary sources of variability or uncertainty in AADT:

- Measurement error in using AADT to broadly capture traffic volume
- Estimation error when AADT is based on the average of a number of counts (e.g, 4 quarterly counts).
- Calculation or model projection error when AADT is calculated using information from FDOT traffic models and analysis. Uncertainty is expected to increase as the distance from monitoring stations increases, and degree of uncertainty (and size of errors) will

depend on the traffic and road segment characteristics between the monitoring station and the segment of interest.

- Natural temporal variability in AADT values for the same segment.
- Prediction error in projecting future AADT (includes yearly variability in AADT, measurement and estimation error, as well as prediction errors due to modeling assumptions, and all yet-unknown changes to the system involved in extrapolating into the future).

Relevant considerations:

- Propagation of some uncertainty in AADT through to FDOT predictions is demonstrated in a later section using computer simulation from specified probability distributions to incorporate variability in AADT values.
- Using variability of AADT values within the 5-year baseline interval (if available) may be a reasonable lower bound for specifying a level of uncertainty.
- The uncertainty in projected AADT values is expected to far surpass the variability in observed AADTs within the 5-year baseline period.
- Larger magnitude AADTs are expected to have greater uncertainty given numerical properties (variance tends to increase as the mean increases).

3.3 Relationship between PVM counts and AADT values

This section investigates the relationship between PVM counts and AADT values for: (1) data available for 90 road segments evaluated for the ECMSHCP analysis traffic modeling (assessing relationship over space for a given time period), and (2) for data from five individual segments (assessing relationship over time for a given road segment) described in Section 3.3.2.

Assumption: The FREM equation is relevant to be applied broadly to any road segment and any time periods. That is, the assumed 1:1 relationship between change in AADT and change in 5-year PVM is assumed to hold for any pair of past and future time periods, regardless of the magnitudes of AADT or PVM or any other considerations, and for any road segment with a previously recorded PVM.

Relevant considerations and observations:

- FREM relies on a direct 1:1 relationship between changes in AADT and changes in 5 year average PVM for a defined road segment over time. It is not clear what the basis or justification for this assumption is.
- One reason for adopting the approach may be ease of obtaining inputs from already available historic PVM data, AADT data, and FDOT traffic modeling projections for future years.
- Care should be taken in assessing the relationship between AADT and PVM to avoid conflating a relationship over space for a given time with a relationship over time within a single road segment.

- The FREM algorithm is implemented at the level of individual road segments before predictions are summed to obtain a total over a collection of segments. The aggregation equally weights all road segments (regardless of length, previous PVM, magnitude of AADT, surrounding habitat, etc.).
- The algorithm does not account for heterogeneity among road segments, including characteristics recognized as important for panther ecology (cover along road, location relative to migration corridors, etc.). It assumes the algorithm can be used on any individual segment, regardless of such characteristics. Alternative approaches to prediction in the future may be more successful if able account for individual road segment characteristics when making predictions.
- Application of FREM typically assumes all segments that will have a PVM in the future have already had a PVM in the past. In other words, road segments without a recorded PVM in the past are not considered for predictions. Similarly, segments with predictions of zero have been excluded in applications of FREM because they cannot contribute to the total PVM given the equation (regardless of change in AADT, the prediction will be zero).

3.3.1 AADT and PVM over space for 2014-2019 data

Summary PVM and AADT data used for the 2060 PVM predictions for 90 road segments are shown graphically (Figures 1 through 4); the PVM data are 5-year counts (or averages) for the period from March 2014 through February 2019 and the AADT data are from 2017. There is no indication that road segments with larger estimated 2017 AADT values tend to have larger 5-year PVM counts. In particular, small PVM counts (1 or 2; average of 0.2 or 0.4) are generally associated with the range of observed AADT values (Figure 1). In general, exploratory data analysis reveals very weak, if any, association between 2017 AADT and 5-year average PVM for the relevant collection of road segments.

Exploratory Data Analysis
Data for 90 road segments used in the ECMSHCP FREM predictions are included in this exploratory analysis. These are road segments in the region of interest with at least one PVM in 5-year baseline period and at least one source of AADT data available. The recorded PVM are from the 5-years defined by beginning of March 2014 through end of February 2019. PVM and AADT counts are displayed on the original scale (Figure 1) and on the natural log scale (Figure 2) for easier visualization (due to the restriction of both variables to be non-negative). Points may also be jittered (their position moved) by a small random amount to allow for visualization of overlapping points. Each point represents an individual road segment and they are grouped into facets (panels) by road or region.

Formal statistical modeling is not undertaken, as the lack of association is clear and assumptions for even common regression methods are clearly violated. The plots contain more information needed to assess the association than summary statistics calculated under additional questionable assumptions.

Note that the FREM approach does not assume a relationship between AADT and PVM should hold *over space* for a heterogeneous collection of road segments, but if the relationship between AADT and PVM is strong in general, it is expected to show up to some degree over space for a given time. Comparing the scatterplot of the baseline AADT (2017) vs. baseline 5-year annual average PVM (Figure 3) to a scatterplot of the projected AADT (2060) vs. the FREM predicted annual average PVM (Figure 4) demonstrates how FREM forces this general relationship over space in predictions.

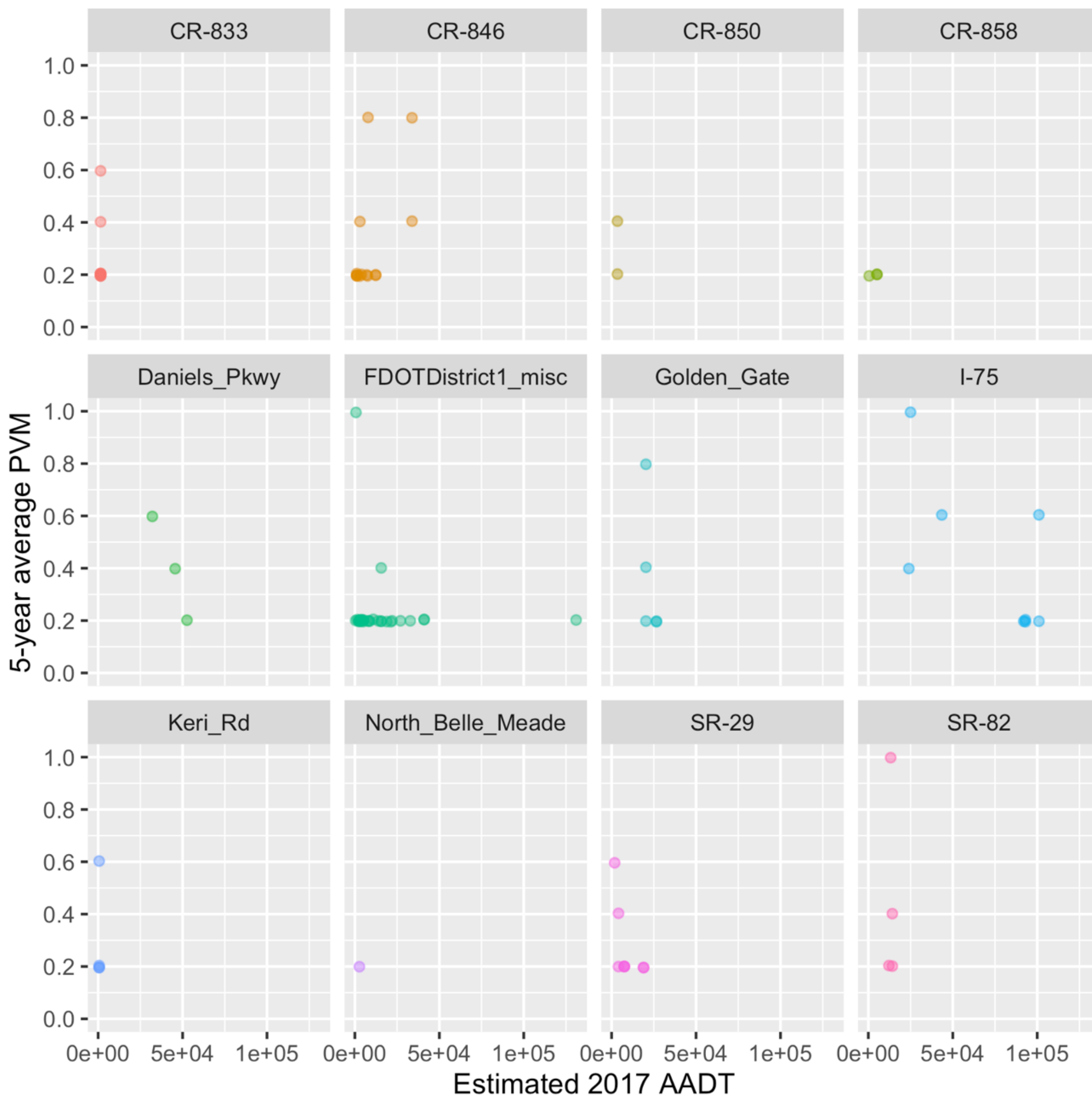

Figure 1 *Estimated AADT from 2017 and 5-year average PVM for 90 road segments used in the FREM predictions for 2060 PVM, faceted by the associated road or region. The 5-year period is start of March 2014 through February 2019.*

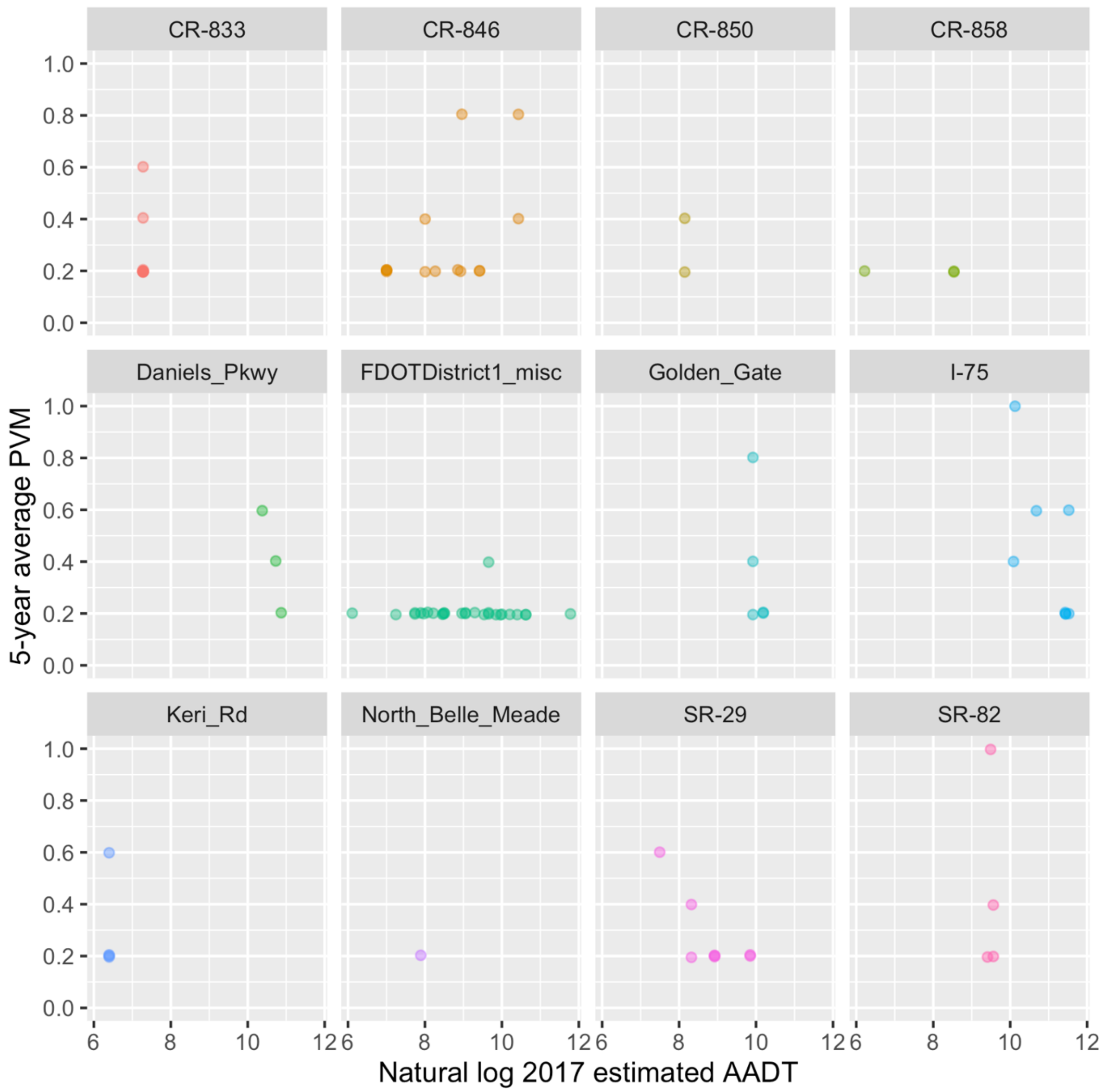

Figure 2 *Natural log transformed 2017 estimated AADT and 5-year average PVM for 90 road segments used in the FREM predictions for 2060 PVM, faceted by the associated road or region. The 5-year interval is start of March 2014 through February 2019.*

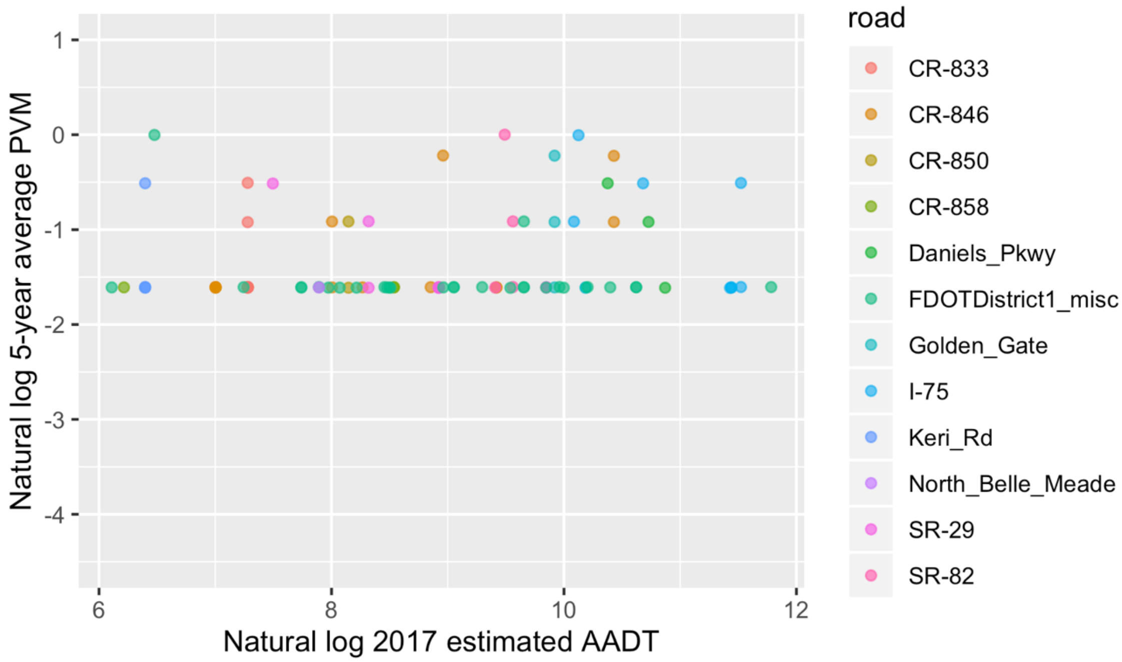

Figure 3 *Natural log 2017 AADT and 5-year average PVM (3/2014 - 2/201) for all road segments without faceting. Compare this plot to Figure 4.*

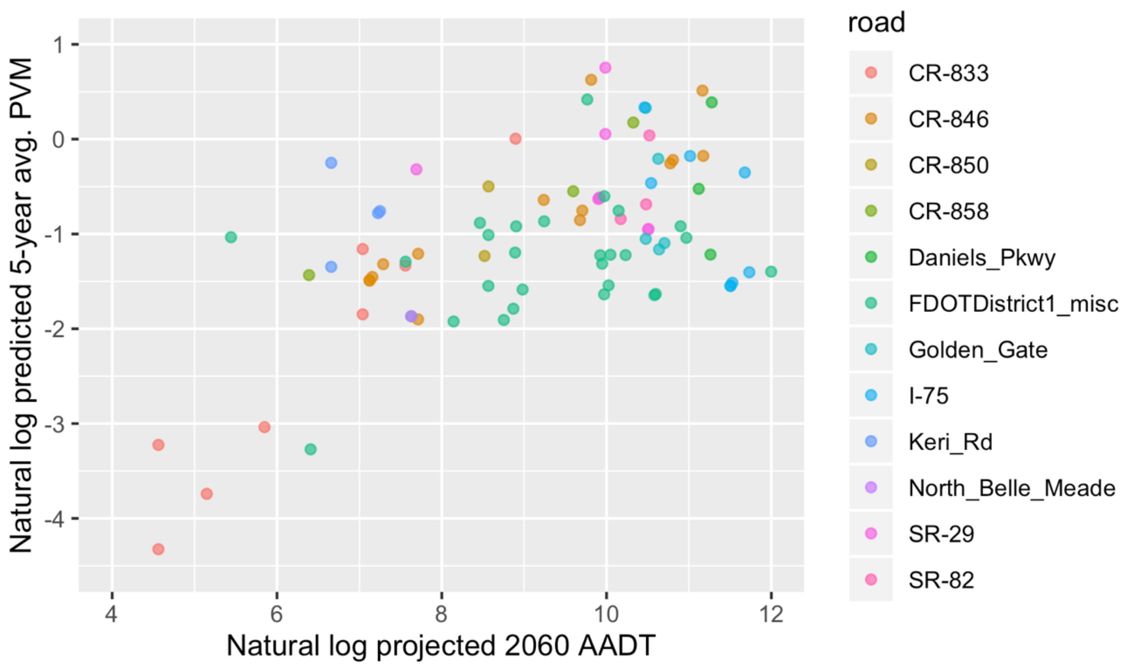

Figure 4 *Projected 2060 AADT values and the FREM predicted 5-year average PVM values. Note the relationship forced by the FREM algorithm that is not apparent in the observed data from the baseline period shown in Figure 3.*

3.3.2 Five road segments used for exploratory analysis

Summary Five road segments are used for exploratory analysis of the relationship between PVM and AADT over time within a road segment. Two of the segments chosen were previously labeled as PVM "hotspots" (US-41 and CR-846) and three of the segments contribute most to the total 2060 PVM prediction by FREM. The five segments are not meant to be representative of all segments, but because they contribute substantially to final predictions, decision-making is expected to be sensitive to the algorithm's performance for such road segments. Data from the five segments are used in Section 3.3.3 to investigate the relationship between AADT and PVM over time, and again in Section 3.6 to evaluate predictive ability of FREM.

Two of the segments were identified by FDOT identified as PVM "hotspots" (FPRIT Transportation Sub-Team report, 2018), had historic PVM and AADT data available, had little or no fencing, and had limited ingress/egress near counting stations so that AADT counts are considered representative of the entire road segment.

- *CR-41 between Forty Mile Bend and Collier Seminole State Park (CR-41):* This segment is 30 miles long, has 26 years of AADT data available and had 17 reported PVM from 1994-2019. AADT fluctuates between 2280 and 3056 from the 1994 – 2009 period used in investigations.
- *CR-846 2.8 miles east of SR-29 (CR-846):* This segment is 7.2 miles long, has 14 years of AADT data, and 10 reported PVM between 2006 and 2019. It had a wildlife crossing and 1.1 mile of fencing installed in 2011.

The remaining three segments were chosen because their predictions make up a relatively large proportion of the total predicted 2060 PVM using the FREM algorithm for the ECMSHCP analysis. The three segments, making up 3.3% of the 90 total segments, account for 19% (9.54) of the total 50.48 predicted 2060 5-year average PVM and therefore provide a useful starting point for assessing sensitivity to the FREM assumptions and investigating the relationship between AADT and PVM over time within segments. The segments differ in the magnitudes of their associated AADT values, which adds to their usefulness in investigating the FREM algorithm.

- *SR-29:* The 2060 PVM predicted by FREM for a 2.5-mile unfenced road segment of SR-29 north of the FPNWR is 2.12 (predicted 5-year PVM of about 10). The AADT ratio is 21,717/4,104 = 5.29 and the 2015-2019 average PVM was 0.4. This 2.5-mile segment (FID 63077) has no major ingress or egress points, making it reasonable to assume that AADT values represent the entire 10-mile length of segments on SR-29 between CR 858 and I-75. The exploratory data analysis presented in this review for SR-29 uses PVM from the 10-mile segment between CR-858 and I-75. The most southern third of the length was fenced in 1997 and the middle third in 2007; the northern third is not fenced. There were 13 total PVM reported in the 25-years from 1992-2019 and no PVM reported in the period from 2007 to 2012. Total PVM for 2014-2019 is 3 with 2 in

2016 and 1 reported after the end of Feb 2019 cutoff used for the 2060 predictions for the ECMSHCP analysis. Estimated AADT values from FDOT range from 900 in 1994-1995 to 3300 in 2019. Collier Country MS2 (CC-MS2) AADT data are available from 2008 To 2019; these are averages of (almost) quarterly traffic counts and based on data of higher quality. The CC-MS2 data are treated as a separate data set in the plots and results. The 2017 FDOT AADT value is 3000 and the CC-MS2 AADT value is 4104.

- *SR-82 from Hendry County Line to Corkscrew Blvd (SR-82):* The predicted 2060 PVM for this section is 2.85 (5-year total of 14-15 PVM), coming from a 5-year average of 1 PVM multiplied by the AADT ratio 37,726/13,233 = 2.85. This 1.89-mile road segment has a total of 7 PVM from 1992 to 2019, with 6 of those recorded in 2015-2019 (3 in 2016 alone). Estimated AADT increased from 4400 in 1992 to about 12,800 in 2005 and during this period of increasing AADT no PVM were recorded. Between 2006 and 2019, AADT fluctuated from about 9500 (low in 2008) to 13,200 in 2019.
- *Church Road from SR-82 to SR-29 (Church Rd)*: This segment contributed the largest predicted PVM to the 2060 total PVM in the ECMSHCP analysis: a 5-year annual average of 4.57. This prediction comes from multiplying the 2015-2019 average PVM (0.2) by the ratio of the 2060 projected AADT to the 2017 estimated AADT (10,287/450 = 22.86). This AADT ratio is substantially higher than the ratios for all other road segments and deserves more scrutiny as part of the overall prediction. This corresponds to about 22 PVM expected over a 5-year period just for that segment. The segment has length 3.06 miles and only has available AADT and PVM data from 2011 to 2019. AADT values available from FDOT have only two values: 650 (2011-2013, 2018-2019) and 450 (2014-2017). There is limited ingress and egress along this segment, so AADT values are assumed to represent the entire length. There are 3 reported PVM: 1 in 2012, 1 in 2018, and 1 in 2019 (after the end of February used as the cutoff for the ECMSHCP predictions). Too few years are available to use this segment in moving 5-year window predictions in Section 3.6.

3.3.3 AADT and PVM over time within a road segment

Summary Investigation into the relationship between AADT and 5-year moving average PVM for the five road segments does reveals weak, if any, association between the two variables. The results do not support the bold assumption built into FREM of a strong relationship with a fixed slope for all road segments and no method of accounting for statistical uncertainty. Even if there were evidence for an association that may be useful for prediction, the AADT values projected for 2060 using the FDOT traffic model will often be well beyond the range of AADT values observed, necessitating extrapolation. In other words, the predictions contributing the most PVM will usually be based on substantial extrapolation beyond the range of observed data for most segments, resulting in large, unquantified statistical uncertainty. This substantial source of uncertainty is not accounted for in the investigation included in Section 3.6, but is briefly discussed in the results for this section.

For the five road segments described in Section 3.3.2, associations between AADT and PVM over time are explored to assess the foundational assumption of the FREM equation. The investigation is mainly graphical using plots over time and the scatter plots of AADT and PVM values. Summaries of results are included after the figures on the following pages.

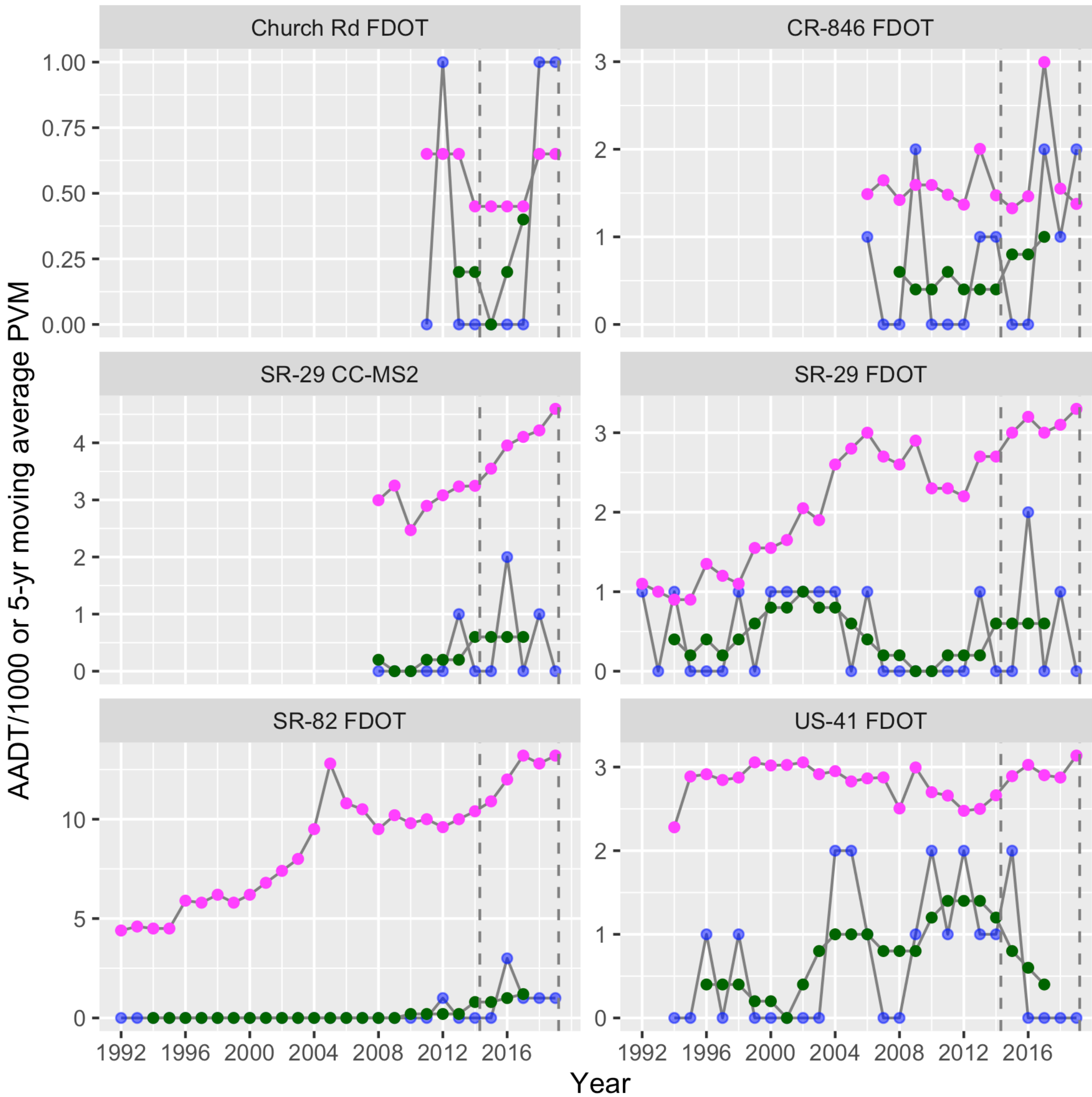

***Figure 5-year**ly AADT divided by 1000 are in pink, yearly PVM are in blue, and the 5-year moving averages plotted at the midpoint year are dark green. SR-29 has AADT data from Collier County (CC-MS2) and FDOT starting in 2008 and these are shown in two different panels. Note the y-axis scales differ across panels.*

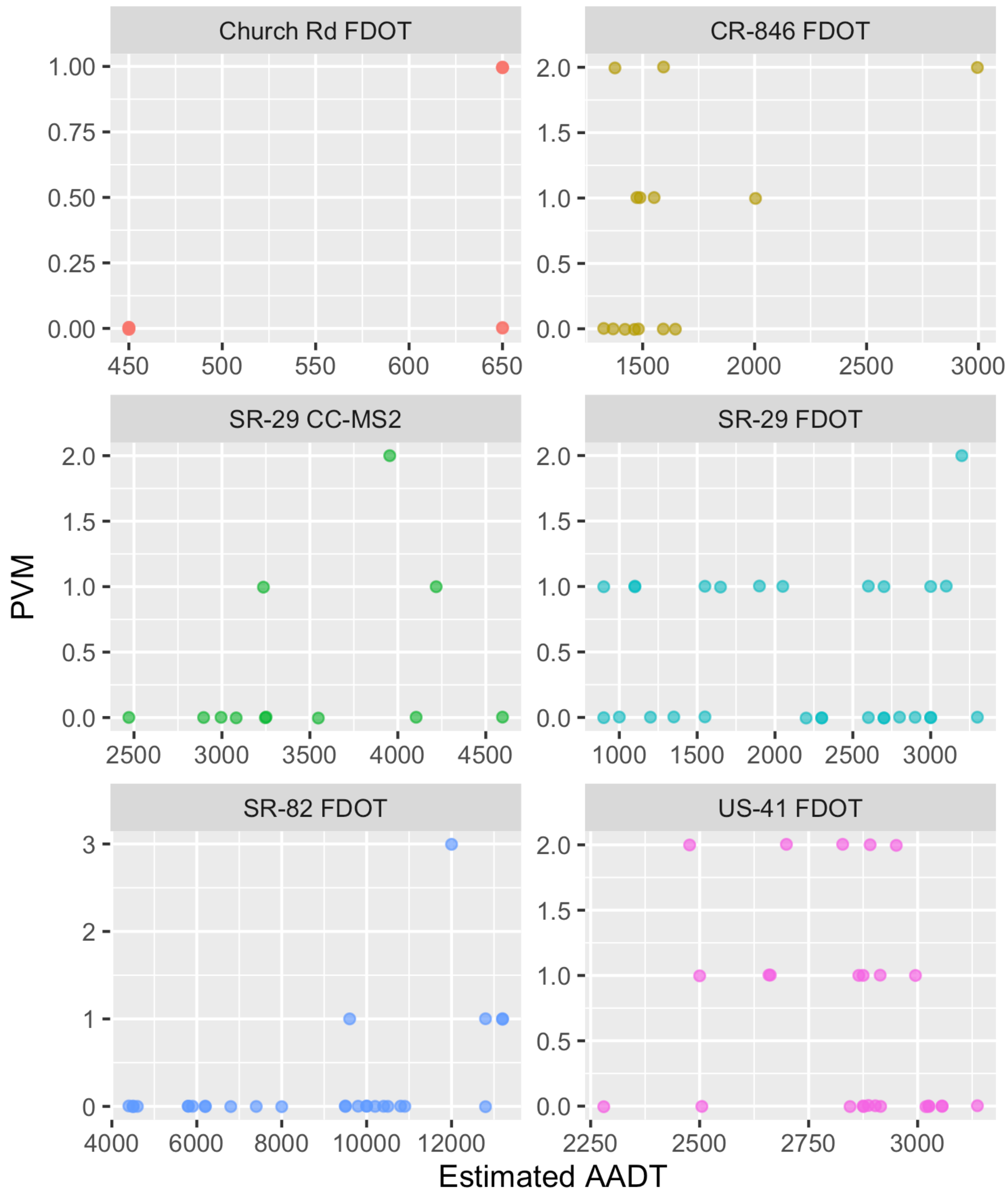

***Figure 5** Scatterplots of yearly estimated AADT values and yearly recorded PVM on their original scales. Points are jittered by a small amount to help with visualization of overlapping points. These are annual data for PVM, not data aggregated over 5-years as are used in FREM.*

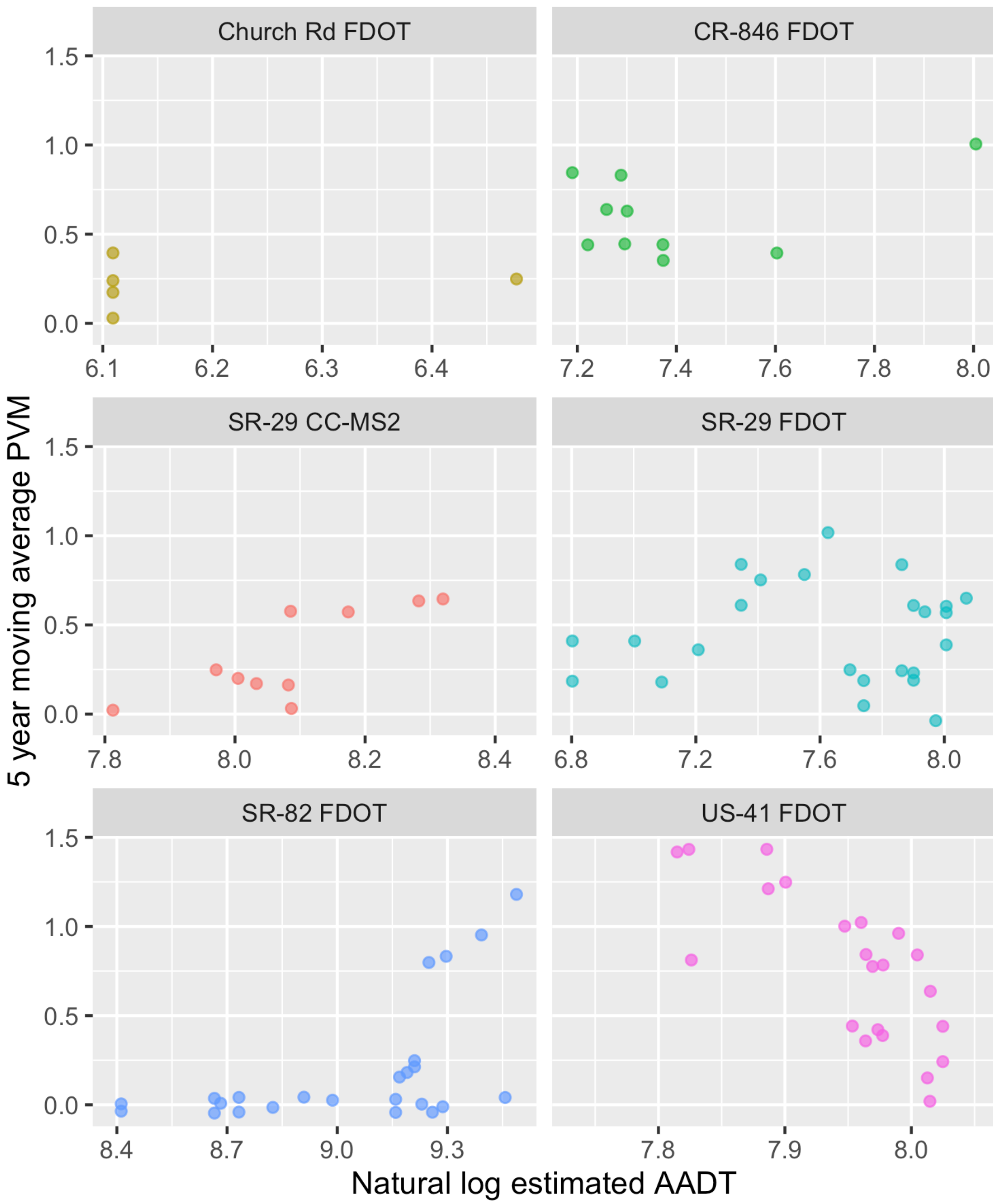

Figure 6*: Scatterplots of the natural log of 5-year moving average PVM plotted against the midpoint years' estimated AADT values. PVM values are restricted to 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, or 1.4 – points are jittered vertically to avoid overlap.*

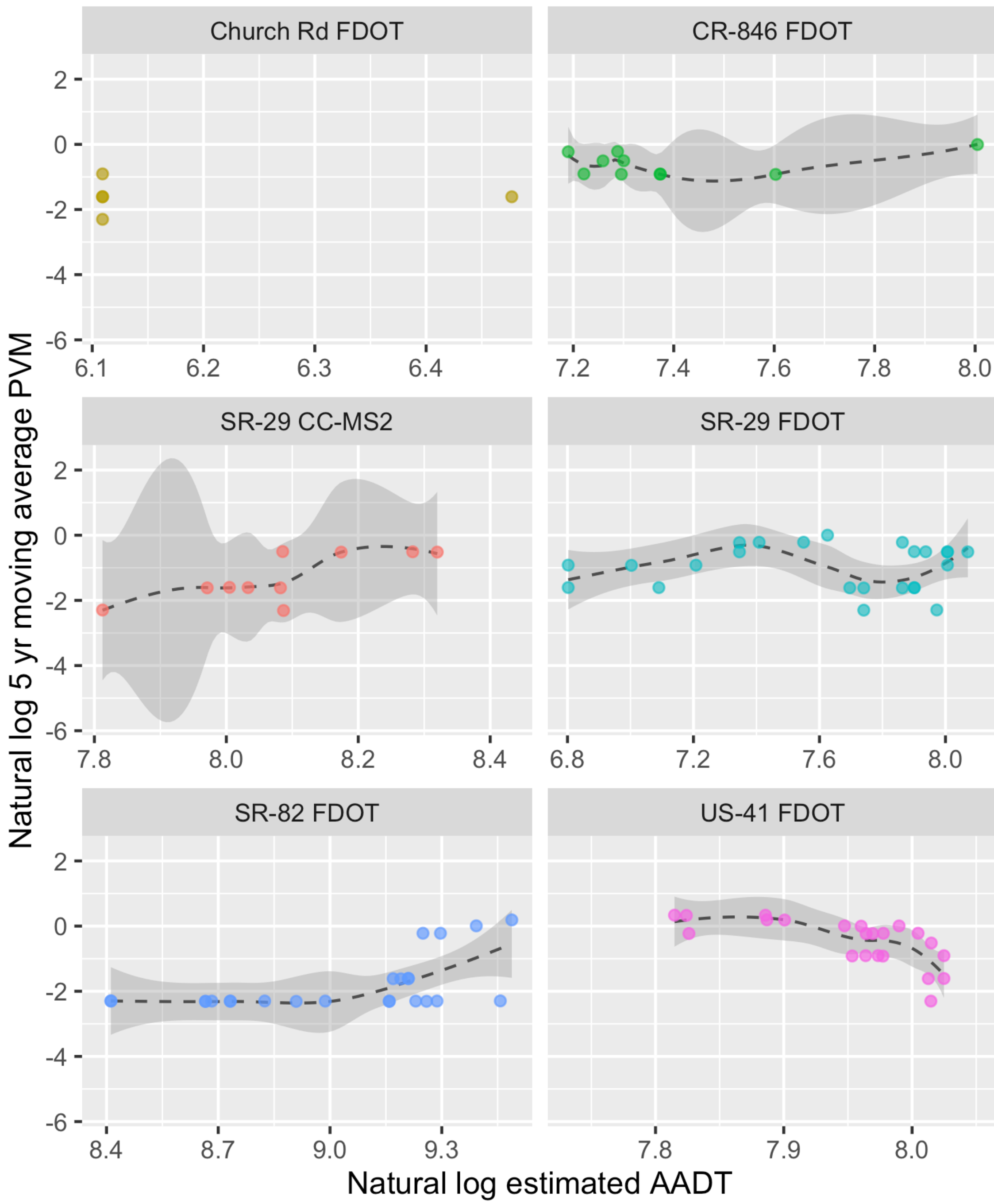

Figure 7 *Scatterplots with smoothed fitted lines (loess method) and 95% pointwise confidence bands investigating the relationship between the natural log estimated 2017 AADT values and natural log of the 5-year moving averages for PVM (0.1 was added to moving averages of 0 before log transforming so points associated with zeroes are plotted at -2.3). The FREM algorithm assumes linearity on this log-log scale. Note x- and y-axis scales differ and there is severe positive autocorrelation due to the use of overlapping moving averages.*

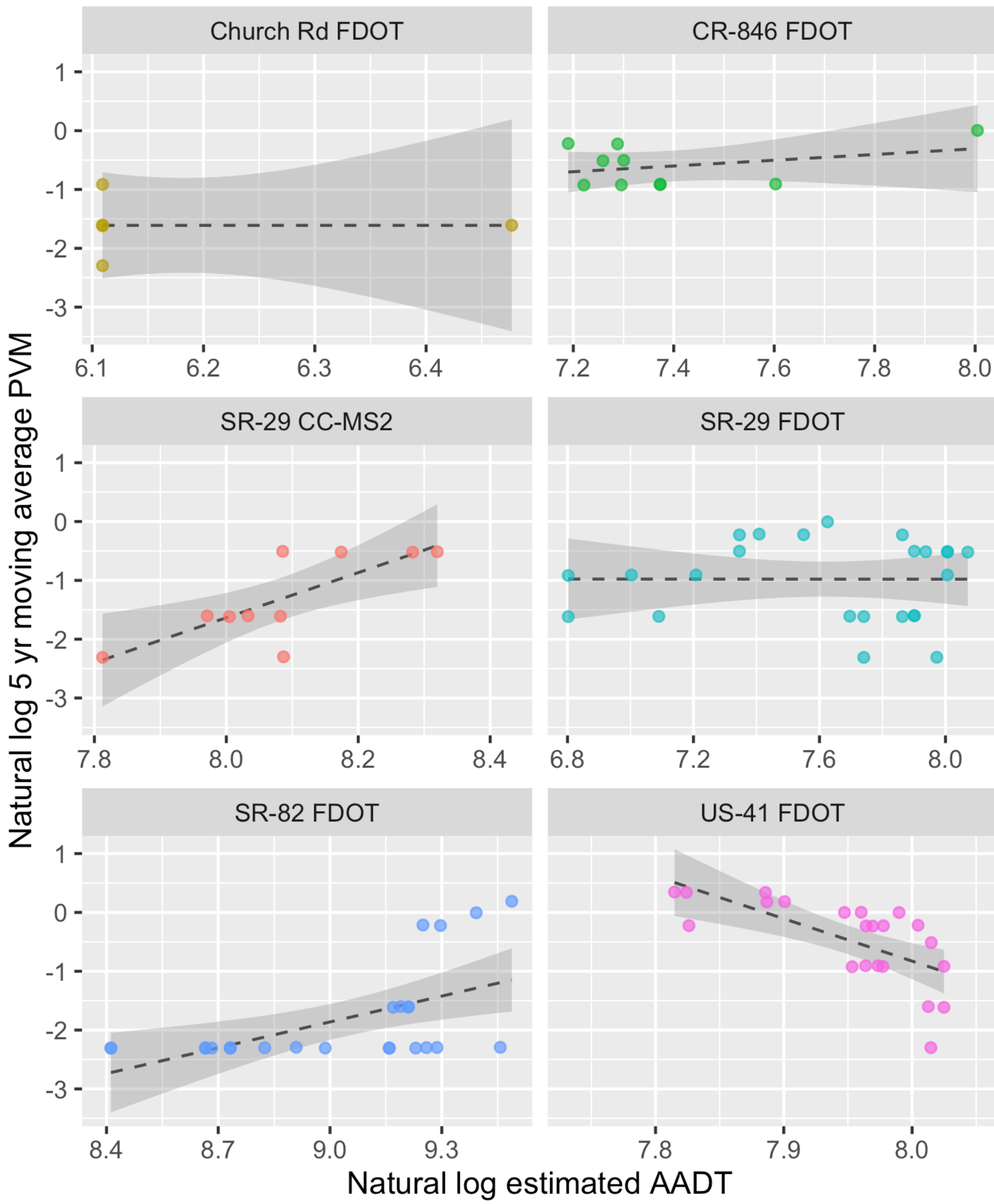

Figure 8 *Scatterplots, simple linear regression fitted lines, and 95% pointwise confidence bands investigating the relationship between the natural log estimated AADT and the natural log of the 5-year moving average PVM (0.1 was added to moving average PVM of 0 before log transforming so points associated with zeroes are plotted at -2.3). Note x- and y-axis scales differ by panel (see Figure 9 for common scales). Assumptions of linear regression are violated by use of moving averages and confidence bands should be interpreted as understating the statistical uncertainty in the relationships.*

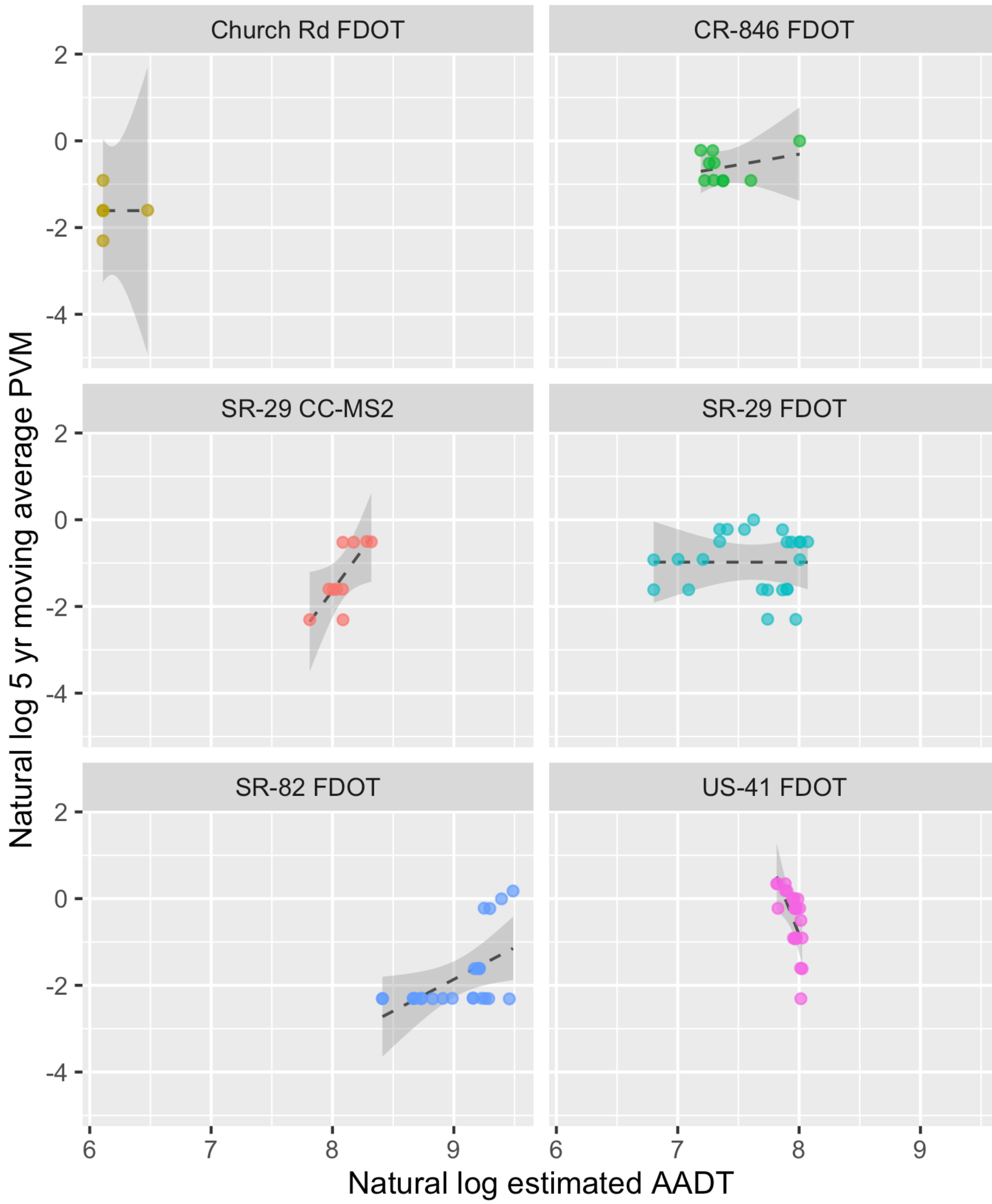

Figure 9 *Information in Figure 8 plotted with same x- and y-axis scales for all panels to avoid masking the relatively small restricted AADT ranges covered within each segment clear.*

Summary of Results and Observations:

- The data reveal weak, if any, associations between PVM and AADT depending on the road segment, with direction of the association depending on the segment. For example, SR-29 CC-MS2 and US-41 reveal associations of about the same strength, but that for SR-29 CC-MS2 data is positive and for US-41 it is negative.
- The range of observed (estimated) AADT values within each segment is small relative to the range across the segments combined (Figure 9) and relative to projected AADT values for 2060. If the 2060 projected AADT is outside the observed range for any segment, then the prediction is based on extrapolation. Extrapolation is an important source of uncertainty in predictions if predictions are based on an association quantified statistically. For example, the range of observed AADT values for Church road are 450 – 650 and the projected AADT for 2060 is 10,287 – well beyond the range of past reported values.
- Given the FREM formula, the largest PVM predictions will typically be the result of substantial extrapolations, with no observed data to support any association in that range. Even if the assumptions of FREM were deemed reasonable within the observed range of AADT (which they are not for the road segments assessed), the extrapolation adds additional uncertainty that increases the further the 2060 AADT value is from the range of observed values from the past. That is, the greater the extrapolation, the greater the statistical uncertainty (e.g., picture the confidence bands in Figures 8 and 9 continuing to widen as the range is extended to the projected 2060 AADT value). The extent of the extrapolations is expected to result in extremely wide prediction intervals from a statistical perspective, and these are not quantified or acknowledged in the FREM approach. As a rough illustration of the potential unreasonableness of predictions and magnitudes of uncertainty coming from the extrapolation, we can use the linear regression model fits (despite the violations of assumptions) to predict the 5-year average PVM at the projected 2060 AADT value and assess the prediction intervals. The point predictions from the six model fits (including both sources of data for SR-29) range from 0.2 for Church Road to 392 PVM/year for SR-29 CC-MS2, and the approximate 95% prediction intervals are wide enough to not be useful other than as an illustration of the statistical uncertainty due to extrapolation. The intervals, in units of PVM/year are: SR-29 CC-MS2 (2.6, 59614); SR-29 FDOT (0.04, 3.9); SR-82 (0.18, 12.2); Church Rd (9.6×10^{-9}, 4.1×10^{6}); CR-846 (0.25, 1.68); and US-41 (0.7, 11.6). The only reasonable interval is from CR-846 where the projected 2060 AADT (2300) is actually less than the recorded 2017 value (2995).
- The assumptions for linear regression are violated due to the use of moving averages from overlapping time periods. The 95% confidence bands included in Figures 7, 8, and 9 should be interpreted loosely and with caution; they are expected to under-represent uncertainty due to violations in assumptions and are provided only as an illustration of the general magnitude of statistical uncertainty even under a best-case scenario of no violations of assumptions and within the range of observed AADT values.

- Even with statistical uncertainty under-stated, the 95% pointwise confidence intervals conveyed through the bands in Figures 7 through 9 are wide. For some segments, the bands appear consistent with a slope of 1.0 on the log-log scale assumed by the FREM formula; however, the bands are also consistent with a wide range of other values not consistent with the FREM formula. The slope of 1.0 translates to mean an m-fold increase in baseline AADT is associated with an m-fold increase in median 5-year PVM; the 'm' is the same number in both parts of the statement. Four of the segments even have confidence intervals that contain a range of negative values, suggesting decreases (rather than increases) in AADT are associated with increases in PVM. The results (data and model used) should not be taken as evidence *for* a slope of 1.0.

3.3.4 Relationship between annual panther counts and PVM

Summary There is convincing evidence of a relationship between panther annual counts and annual PVM for Southwest Florida. The strength of the observed relationship makes it difficult to ignore panther population size as a potentially important component to predicting PVM risk and occurrence.

In this section, a summary of the estimated relationship between annual panther counts and PVM counts using data from McBride & McBride (2015), where annual counts are taken as minimum population sizes and assumed to reasonably track population size changes over time.

The FREM approach does not consider information about potential changes in population size – another aspect in addition to traffic on the roadways that physically affects risk of a PVM. Ignoring population size implicitly assumes the population size will stay constant during the period in question (e.g., March 2014 through February 2062), or at least that it is relatively constant during and across the two 5-year intervals used (3/2014 – 2/2019 and 3/2057 – 2/2062 for the ECMSHCP analysis). Exploratory analysis using the annual panther counts and yearly region-level PVM counts is used to assess the observed relationship as part of assessing the decision to ignore potential population size changes in the prediction of future PVM.

Analysis

Simple linear regression (SLR) was used to describe the linear part of the relationship between the natural log of annual panther counts and the mean natural log of yearly reported PVM.

- SLR assumes continuous variables, rather than discrete counts. However, it can perform reasonably well if counts are non-zero and log transformed, as done for this analysis.
- The linearity assumption is clearly adequate on the log-log scale (Figure 12).
- SLR assumes independence among residuals (vertical distances between the observed value and the fitted regression line). A severe violation of this assumption was expected because of temporal (serial) autocorrelation due to the fact the data are from a time

series. However, checking observed autocorrelation in the residuals revealed little concern (i.e. points do not tend to be clustered in runs below or above the regression line). If positive autocorrelation exists and is ignored, standard errors are expected to be under-reported. Even keeping this in mind does not change the conclusions given the strength of the linear relationship observed.

- SLR assumes normality of the residuals. The violations of this assumption are not severe enough to call into question the conclusions based on the results, particularly given the robustness of SLR methods to departures from normality.
- The assumption of constant variance of residuals across the range of AADT values is also not violated to an extent that would call into question conclusions based on the results.

Poisson log-linear regression is a generalized linear model that can be used to more appropriately model response variables that are counts, like total PVM over a specified time period and road segment. This is in contrast to SLR that assumes the log transformed count can be modeled as a continuous random variable, rather than a count restricted to integers. The Poisson model relates the log annual counts to the mean PVM per year (annual PVM rate).

- As for SLR, the linearity assumption appears reasonable and the violation of the independence assumption due to temporal autocorrelation is assumed not to be so severe as to change conclusions and therefore was not corrected for in this model for the same reason as the SLR model.
- The variance expected in the PVM counts, based on the mean, is less than expected under the Poisson model, but the departure is not severe. Standard errors are expected to be larger than if the observed variance more closely matched that assumed under the Poisson model.
- The results are very similar to those from the SLR model based on the log transformed data, though wording of results differs slightly to match assumptions of the models.

Plots of the data used in further exploratory analyses are provided in Figures 10, 11, and 12, followed by a brief summary of results and some relevant conclusions.

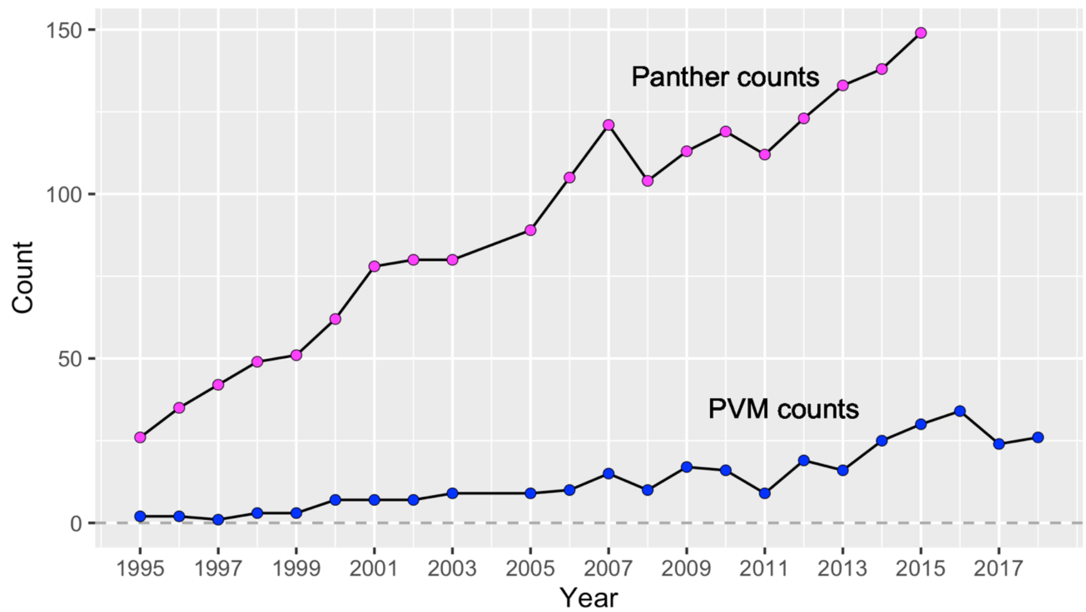

Figure 10 *Yearly PVM counts for the state plotted along with annual panther counts (McBride & McBride, 2015), on the original scale.*

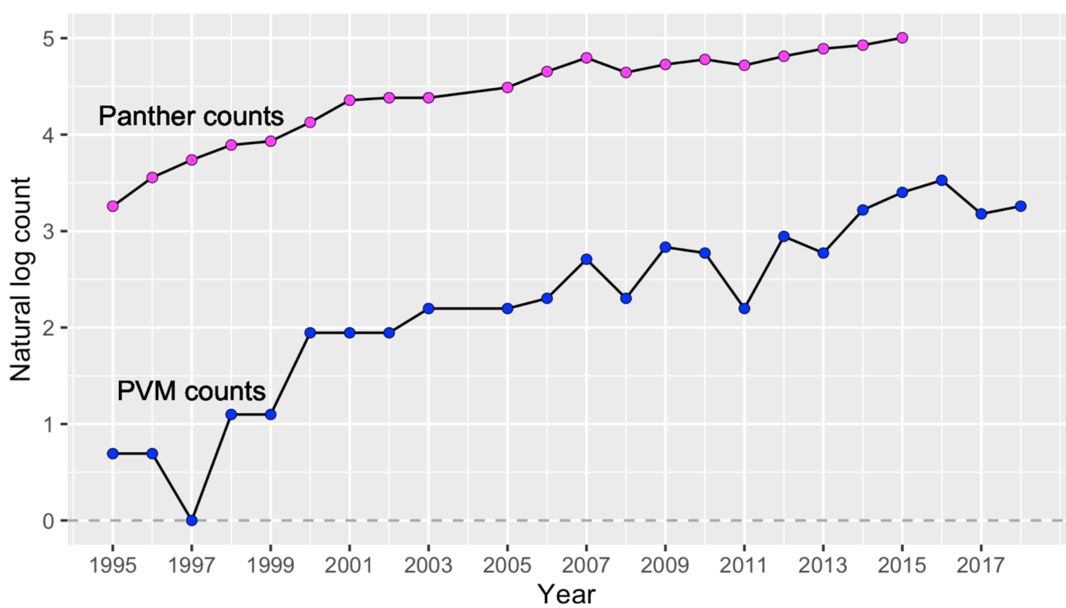

Figure 11 *Yearly PVM counts for the Southwest Florida region plotted along with annual panther counts (McBride & McBride, 2015). Both variables are plotted on the natural log scale as it is used for further data analysis due to better meeting the assumptions of the regression model used (linearity is improved compared to Figure 12).*

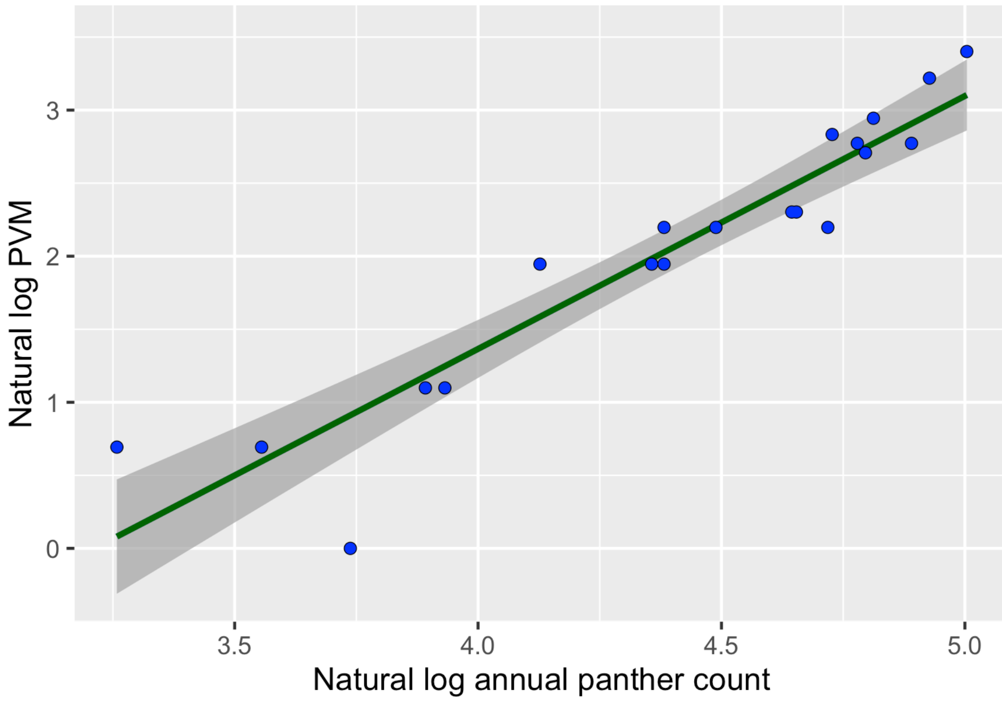

Figure 12 *The data displayed in Figures 10 and 11 are shown here in a scatter plot used to assess assumptions for simple linear regression. There is clearly a strong linear relationship on the log-log scale; the observed correlation coefficient is 0.94. The bands around the regression line are 95% point-wise confidence bands.*

Summary and conclusions:

- There is a strong, positive association between the annual panther counts and the mean or median annual PVM (see Figure 12). The observed correlation between the two count variables after natural log transformation is 0.94 (R-squared based on a simple linear regression model is 0.88).
- Based on the results of two reasonable models (simple linear regression and Poisson log-linear regression), *a doubling of panther annual count is associated with an estimated 3-fold increase in central tendency of yearly PVM counts, with an associated 95% confidence interval from about 2.5 to 5 times*.
- The brief exploratory analysis suggests increases in panther population size cannot be ignored as a potential contributor to increased PVM. The analysis is based on annual counts of panthers from McBride & McBride (2015), assuming changes in annual counts reasonably track changes in population size, and yearly state counts of recorded PVM and recorded PVM.
- The analysis alone does not establish that increases in population size *cause* increases in PVM, but it provides clear evidence of an association between the two variables at the temporal and spatial scales available. This information should be used in conjunction with ecological reasoning and explanations.

- Evidence for such an association between panther population size and annual PVM does not imply there is no relationship between AADT and PVM, particularly at the level of individual segments. However, it is important to acknowledge the panther contribution to PVM risk has changed over time, and it may continue to change. This calls into question the decision to rely only on AADT for predictions, as if the panther system is fixed (or close enough to fixed) to be ignored.
- It is still be possible for AADT to be an effective predictor for PVM, even if population size is the main driver of PVM *if* there is also a strong association between AADT values and annual counts, or AADT and PVM at smaller spatial scales (road segment level). Such an association is not observed in the analyses undertaken as part of this review.

3.4 Decision to use 5-year PVM and single year AADT

A fundamental aspect of FREM deserving attention is its reliance on 5-year summaries of PVM (sum or average) and use of AADT from the midpoint year of the 5-year period. There is no documentation explaining or justifying these choices and associated assumptions. It is assumed PVM are summarized over a number of years to decrease variability and avoid baseline values of zero. A single year AADT value also lessens the requirement for more years of AADT data (historic and projected). Summarizing AADT over 5-years would likely require additional traffic modeling.

3.4.1 Constant PVM rate within 5-year periods

Assumption The underlying mean PVM (or rate) is constant over the two 5-year periods used (i.e., it was constant over the baseline period and will be constant over the projected period). This assumes there are no changes to the underlying system that would affect the PVM rate (included changes in traffic volume and/or panther population size).

Related considerations:

- There should be recommendations for how to assess and justifying this assumption for the chosen 5-year intervals as part of FREM documentation
- This assumption should reasonably hold for every road segment used in the predictions.

3.4.2 Single year AADT representative of 5-year period

Assumption: AADT is stable enough over any 5-year period that the AADT for a year at or near the midpoint of the period is representative of AADT over the period. “Stable enough” assumes variability within the chosen 5-year intervals is small relative to variability over time that reflects changes in the underlying traffic volume of the system. Likewise, predictions in a 5-year period are stable enough to be represented by the midpoint year’s value.

Related considerations:

- Assumes that meaningful changes in the traffic volume relevant to predicting future PVM happen at a much longer time scale than 5-years so that it is still reasonable to assume a constant AADT within each 5-year interval.
- The decision to use the AADT from a single year, rather than a summary over the 5-years (like a 5-year average AADT) simplifies prediction because AADT must only be projected for a single year in the future.
- More investigation into observed variability in AADT within 5-year periods is suggested given larger than expected standard deviations for segments investigated, particularly if AADT is based on quarterly traffic counts. Values based on FDOT models tend to be less variable, but are also assumed to be less accurate and less precise. For example, for SR-29 the standard deviation within the baseline 5-year period is 130 for FDOT data and 427 for the Collier Country MS2 data. The midpoint year value is 4104 for CC-MS2; three standard deviations from this value results in an interval from 2823 to 5385.
- There is also uncertainty in the AADT values presented, separate from the year-to-year variability that should be considered. The standard error of the average for the estimated AADT (4104) from SR-29 CC MS-2 quarterly data is 57.4, corresponding to an approximate 95% confidence interval from 3990 to 4218.
- If the FREM approach is meant to be applied broadly in time, then it is worth considering the conflict that AADT and PVM are assumed to be steady within any 5-year period, but allowed to change over time to obtain predictions. At the very least, justification for why PVM rates are assumed to be constant within the two 5-year periods of interest should be included with any use of FREM.

3.4.3 Choice of baseline 5-year interval

The choice of baseline 5-year interval is only addressed through describing it as “the last” five years - assumed to be the most recent 5-years before making the predictions. However, decisions will stand for coming years and time is needed to assess methods. Ideally, shifting the baseline period by one year would have little effect on the prediction, but this is something that should be assessed on a case by case basis. For this review, sensitivity of predictions to a moving five-year baseline window is evaluated for five individual segments with AADT and PVM data available over time in Section 3.6.2.

Related considerations:

- Based on the formula, if a historical 5-year average PVM is 0, then the predicted future 5-year average PVM will always be zero, regardless of any changes in AADT. Therefore, for a segment, the traffic volume can increase substantially, but an increase in PVMs would never be predicted. If there is indeed a relationship between traffic volume and PVMs (as assumed by the approach), then this is a clear limitation inconsistent the equation’s underlying theory. Practically, it appears this issue results in restricting the collection of segments to those with at least one PVM within the 5-year period chosen for the baseline. More generally, this means that inclusion criteria depend on a necessary input for predictions, which should be acknowledged.

- For the five segments specifically investigated within this review, there were multiple 5-year periods with 0 PVM, even though the segments were classified as “hot spots” or associated with large predictions in the context of the ECMSHCP. Risk of PVM is clearly not zero for these segments, yet they could be excluded from predictions based on baseline period.
- Sensitivity of the predictions to the length of interval is beyond the scope of this review, but that is future work that could be done and is expected to show results similar to using different baseline years (the AADT ratios would be the same, but the PVM will be more or less variable depending on if a shorter or longer intervals is chosen, respectively). Assumptions regarding a stable system over the period should be considered, as previously mentioned.

3.5 Assessing predictive accuracy and precision

The decision to base decision-making strategies on quantitative predictions of PVM should include an assessment of prediction errors and variability in predictions. This information can be incorporated into decision-making and used to inform stakeholders of the range of potential predictions based on the FREM approach.

As necessary background, Section 3.5.1 discusses rough guidelines, or reference values, for assessing adequacy of accuracy and precision of predictions; Section 3.5.2 discusses the difference between predictions for individual segments vs. in aggregation for a region; and Section 3.5.3 then provides an overview of the information provided by FWS staff regarding predictive accuracy (how close predictions are to the true value). No information was provided about predictive precision (variability in predictions due to sources of uncertainty). Section 3.6 provides a description of investigations into the implications of uncertainty in AADT inputs on the rage of predictions of PVM obtained using FREM.

3.5.1 Judging adequacy of accuracy and precision

Summary: For predictions to be the basis of decision-making, adequate accuracy and precision of the predictions relative to decision-making context should be justified. For this report, reference points are specified to aid in judging magnitudes of predictions, prediction errors, and predictive variability relative to the decision context. Other logic and justification may be used to support different reference points based on other criteria for judging adequacy; this should be an on ongoing conversation among stakeholders. The reference points provided here are meant to be rough thresholds for calling into question accuracy or precision relative to a context: (1) *predictions greater than 0.8 PVM/year; (2) prediction errors greater than 0.8 PVM/year; and (3) standard deviations of predictions (or prediction errors) of 0.4 or greater.*

A thorough evaluation and report of the accuracy and precision associated with the FREM approach is beyond the scope of this review. Instead, the goal of this review is to provide enough information to decide if serious concerns exist about accuracy and precision regarding the use of FREM predictions for year 2060 relative to the decisions they may inform. The question asked is whether, based on analyses on initial investigation, there are enough questions about the adequacy of the accuracy and precision to raise concerns about relying on use of the method to inform decisions. This scientific review identifies potential areas of concern and reasons for them.

The goal of *adequate* accuracy and precision is taken relative to the range of predictions that may change practical decisions informed by the approach. In other words, if the prediction errors are large enough that a "wrong" decision may be made, or the range of predictions is large enough to be associated with different decisions, then the accuracy and/or precision are not considered adequate for the context.

To define *adequate* as a reference for this review, summaries of past PVM and the 2060 projected PVM for road segments relevant to prediction for the ECHSHCP analysis are provided for reference to aid in judging magnitudes of predictions, prediction errors, and variability in predictions. Reference points, or guides, at the level of the individual road segment (see next subsection for more on this) are provided to facilitate interpretations of later results. The reference points are meant as rough starting points, not hard thresholds, and certainly open for discussion and more in-depth justification by stake-holders with a better understanding of how the decision-making process may be affected by changes in the predictions.

Characteristics of the segments included for ECMSHCP analysis:

- 90 road segments with inclusion criteria: (1) traffic volume may be affected by the proposed HCP development, (2) at least one PVM recorded between beginning of March, 2014 and end of February, 2019, and (3) estimated 2017 AADT value and a projected 2060 AADT values are available.
- The midpoint of the 5-year interval considered is given as 2017. The midpoint year associated with the PMV count should be beginning of March 2016 through end of February 2017, including more of 2016 than 2017. It is assumed the AADT values associated with 2017 are connected with the calendar year, rather than the March – February year associated with the PVM counts. Data are not readily available for all segments to assess the difference in the overall prediction between using 2016 and 2017 AADT data.
- Total of 133 reported PVM (5-year average of 26.6 PVM/year)
- Of the 90 segments, 68 had 1 recorded PVM, 10 had 2 PVM, 6 had 3 PVM, 3 had 4 PVM, and 3 had 5 reported PVM. For predictions, these are reported and used as 5-year

averages: 0.2, 0.4, 0.6, 0.8, and 1.0. No segments had reported PVM greater than 5 (i.e., 1.0 is the maximum observed 5-year average PVM).

- The three segments (3.3% of all segments) with 5 reported PVM contributed 11% (15/133 = 0.11) to the total reported PVM. The six segments (6.7% of all segments) with 4 or 5 PVM contributed 20% ((12+15)/133 = 0.20) percent to the total.
- The aggregated predicted average PVM based on applying FREM to individual segments and then summing over the 90 segments is 50.5 PVM/year, corresponding to 252 or 253 PVM over five years (March 2057 – Feb. 2062).
    - The 50.5 represents an increase of 23.9 average PVM between 2014-2019 and 2057-2062, or an almost doubling of annual average PVM in the next 40 years.
    - Based on FDOT traffic models, 14.8 of the 50.5 5-year average PVM, are attributed by the traffic model to changes associated with potential ECMSHCP development, corresponding to over half of the potential regional increase in average PVM (14.8/23.9 = 0.62).

The reference values provided in the summary to aid in judging size of prediction errors and variability in predictions are discussed here relative to the summaries of available data. It may be reasonable to expect future PVM to increase above observed levels, or at least to have more segments with “large” observed PVM, but the available distribution provides a useful reference. Again, the reference points are only meant to be guides and can and should be adapted based on different justifications and connections to decision-making.

- Given only 6.7 percent of segments reported 4 or more PVM, a 5-year average PVM greater than or equal to 0.8 may be considered “large” relative to historically observed values.
- The total annual average PVM attributed to the HCP by FDOT traffic models to potential development within the ECMSHCP is 14.8. While not all segments contributed equally, this corresponds to an average contribution of about 0.16. By this scale, a prediction of 0.8 may also be considered large in this context. It would take only about 18-19 of the segments to have a prediction of 0.8 (with the rest near zero) to obtain the 14.8. This logic is somewhat complicated by the % attribution of AADT to particular developments by the FDOT model, but it is still useful for reference.
- Errors close to the magnitude considered “large” for predictions is generally cause for concern (i.e., absolute values of errors are as large as the “large” predictions). Therefore, the 0.8 PVM/yr (4 PVM in 5-years) is again provided as a reference point. It is assumed such errors in even 10% of segments could combine to potentially change a decision made on the predictions.
- For judging variability in predictions, a reference point is provided for the standard deviation of predictions (or equivalently standard deviation of prediction errors). Assuming a mean prediction of 0.5, a standard deviation of 0.5 would be considered very large (given the constraint to that average PVM be positive, this also places constraints on the standard deviation and makes it more difficult to interpret). However, a standard deviation of 0.4 would also be considered large (corresponding to

predictions out to nearly 1.7). Even assuming a mean prediction of 0.8, a standard deviation of 0.4 would be considered large. As with AADT, the quantitative properties of average PVM result in assuming that the standard deviation should increase with increasing mean (reason for using the natural log scale in some analysis in this review). The reference point of 0.4 is provided as a rough guide (or flag) for judging standard deviations of predictions.

3.5.2 Level of prediction: road segment or collection of segments

Summary*:* It is important to first assess predictive ability for individual road segments, rather than only in aggregate over a collection of road segments. There is no theoretical justification to trust that errors across road segments will "balance out" for any collection of road segments (that is that the average error will be close to zero). Errors of over-prediction are expected to be larger due to the mathematical properties of PVM and AADT and prediction errors are constrained by the discreteness of observed values. And, variability in predictions over road segments is also an important part of the overall picture, not only the sum.

It is important to distinguish the two phases of FREM: (1) predict PVM individually for each road segment, and (2) aggregate (sum) the predicted values for annual average PVM over all road segments with equal weights. As described in the next subsection, the only justification of predictive accuracy provided by FWS is given by description of two examples of aggregate predictions with low prediction errors over two different collections of potentially overlapping road segments.

It is important to acknowledge that it is possible for the method to perform well in aggregate for particular collections of road segments, even if it performs poorly for individual road segments within the collection. An aggregate prediction will have a small prediction error if the sum of the magnitudes is close to the observed, even if the predictions for every segment are "far" from the future observed value. That is, predictive accuracy and precision may be poor for individual road segments, while the aggregate prediction exhibits a small overall prediction error.

Reliance on adequate behavior in aggregation can be misleadingly attractive, particularly when uncertainty in inputs is ignored. In general, "balancing out" of errors should not be relied upon as a justification for the approach as there is no theoretical justification for the assumption that FREM is statistically unbiased over any collection of segments. Therefore, if adequate predictive ability is not demonstrated at the individual road segment level at which the FREM equation is carried, then the aggregate approach should at least rest on theoretical justification and/or other evidence (beyond the extent provided as justification for FREM – see Section 3.5.3).

In the context of this system, there are (at least) two properties that raise serious concerns about relying on a "balancing out" logic: (1) predictions are restricted to be positive, (2) road segments included in the collection are very heterogeneous with their own characteristics related to risk and occurrence of PVM, making it hard to imagine them as a collection of random segments from a single population.

Some considerations regarding properties of the observed counts and predictions are:

- Observed 5-year averages of PVM are discrete (they take on values of 0/5, 1/5, 2/5, 3/5, 4/5, 5/5, …) In available data there were only five unique values observed (min 1/5 and maximum 5/5). In the future, larger counts may be observed for some segments, but associated constraints on the range predictions errors (observed minus predicted) are still expected.
- Overprediction errors are expected to be larger than underprediction errors. Predictions of 5-year average PVM have no theoretical upper bound mathematically, but they must be non-negative (they are defined be between 0 (inclusive) and infinity). This translates to predictions *errors* having a maximum of the actual observed AADT value and no theoretical lower bound. That is, the errors are defined between negative infinity and the reported AADT value (inclusive of the reported value if PVM predictions of zero are possible and exclusive if road segments with a PVM of zero are excluded from predictions).
    - For example, if the observed 5-year annual average PVM is 0.4, then the largest the underprediction can be is 0.4 (if segments with 0 counts are included), while an overprediction has no theoretical maximum.
    - Modeling strategies can be implemented in the future that take into account the numeric properties of the variables.
    - This discussion and related analysis defines a predictions error using the observed/reported AADT value and does not take into account the measurement error associated with that observed value.
- Related to the previous bullet, the distribution of prediction errors across road segments is expected to be left skewed (some large negative errors), corresponding to a right skewed distribution of predictions; it is not expected to be symmetric or centered at zero.
- There is no reason to believe the collection of road segments behave as a random sample of independent segments from a common distribution. Therefore, the collective error will depend on the specific collection of segments.

To understand the FREM approach and when it may work well or not so well, it is important to start with the fundamental part of the model that is developed and applied at the road segment level. It is designed to predict future PVM for an individual road segment based on its current PVM and current AADT and the projected future PVM and this is based on the practical theory that increasing traffic volume on a road segment increases risk of a PVM on that road segment. Adoption of the approach should first rest on evidence that predictions for individual road segments are adequately accurate and precise before moving directly to assessing aggregate predictions with no justification for why success in aggregate for a collection of road segments should generalize to another collection of segments and a different time in the future.

3.5.3 Evidence of predictive accuracy provided by FWS staff

Summary The lack of documentation provided for FREM makes it difficult to assess its predictive accuracy and precision. Limited information provided, along with two examples of successful aggregate predictions, raise questions about method development and testing. Specific concerns are provided in this section, providing more details about the 2 paragraph written description of the method provided by Vero Beach FWS staff.

Documentation from FWS staff states that "To evaluate the appropriateness of the FREM method for estimating risk to panthers from increasing traffic volumes, the Service compared actual roadkill data to roadkill estimates derived by the FREM using historic roadkill and traffic volume data." The comparisons come from two examples comparing aggregate FREM predictions to observed PVM for two collections of road segments, where both predictions (rounding to nearest integer) differ from the reported 2017 counts by only 1 PVM. The description of the evaluation leaves questions unanswered about the development of the approach and the assessment of predictive accuracy.

- It is not clear if other predictive comparisons were also undertaken and just not reported, or if these two examples were the only scenarios investigated. In general, there is no justification for why these examples should be taken as evidence that FREM will have small prediction errors for different prediction scenarios and not enough information for others to judge this.
- The examples report surprisingly small prediction errors for ecological predictions such as these (predicted 5-year average PVM of 29.85 compared to an observed value of 29; and a predicted 5-year average of 72.4 compared to an observed value of 71). The small prediction errors reported without adequate information, begs questions about how FREM was developed and tested relative to these scenarios. Was FREM developed using theory independent of the data used for "testing" or using different data? Or, were the data used to develop, or "train", FREM also used to evaluate its predictive ability? Use of the same data to develop and test a predictive method provides a misleading picture of predictive accuracy. It is not clear if this was the case for FREM, but there is not enough information available to rule out this possibility.
- For the two examples, the periods used as the baseline (2009 – 2013) and future (2013 – 2017) overlap by one year for unexplained reasons. It is possible that the cutoff separating them is in 2013, but that information is not provided. The overlap, or even the proximity of the two intervals in time, would be expected to increase predictive ability beyond intervals separated by many years (such as the 40 years used for the predictions related to ECMSHCP development). It is questionable to assume that the apparent success in prediction for this example should generalize to use of any baseline and future periods.

- The predictions are presented at the aggregate level (after summing over predictions from a collection of road segments). There is no information about how accurate predictions were for individual segments, though that information should be available.
- In assessing predictive ability of FREM, there is an important distinction in terms of what can be used for "future" AADT values in the calculations. Lack of documentation makes it challenging to assess this for the examples reported. If past years' AADT values are being used as if they are future years, then it is possible to use the reported (past) AADT values *or* to use projected values if FDOT model projections were obtained. From the wording provided, it appears projected AADTs for 2017 were used for prediction for the collection of "affected roadway segments" (leading to the prediction of 29.85), but it is not clear if historic observed AADTs from 2017 may have been used when assessing the "Plan's Action Area" (obtaining a predicted value of 72.4). This distinction is important because there is expected to be greater uncertainty in projected AADT than in observed (reported) AADT; predictions are expected to be closer to observed values if observed AADT values are used instead of projections. Note that using "observed" rather than projected AADTs to assess predictive accuracy is still useful, but it represents an optimistic scenario in terms of uncertainty.
- Road segments were included if they "had sufficient traffic volume and roadkill data;" though the criteria defining "sufficient" are not provided. In one of the examples ("Plan's Action Area" related to the Phase 1 of Ave Maria University DRI in Collier County), there were 22 road segments included because they had "documented roadkills dating from 2009 – 2017, and historic FDOT traffic volume data from 2013 – 2017." The 2013 AADT data were used for baseline and 2017 AADT observed data or projections were used for "future."
    - Given the description, it is assumed there the 22 road segments used for one of the example predictions were also used in the second reported prediction covering a larger number of segments (i.e. it is assumed the "affected roadway segments" are included within the 22 road segments in the "Plan's Action Area" meeting the inclusion criteria).
    - Road segments are restricted to those with documented road kills during the 5-year period because the only possible prediction from a 0 observed PVM count is a prediction of zero. It is not stated how many road segments were excluded based on the criteria – due to zero counts or no data. These same inclusion criteria are likely applied to other FREM prediction contexts (such as that related to the analysis related to ECMSHCP development).
    - There are about 90 segments included in the ECMSHCP analysis, as compared to 22 for example provided. There is no justification as to how the FREM approach may perform for a greater number of segments, and potentially a more heterogenous collection of segments.
- Alternative explanations for the increase in reported PVM (e.g., increases in panther population size) between the two time periods are not provided, but should be an important part of a thorough evaluation of the method and its ability to predict farther into the future.

3.6 Assessing predictive ability

Predictive behavior is assessed through use of historic data for five road segments and computer simulation used to propagate assumed levels of uncertainty in AADT in the FREM predictions. The goal of the investigations is to assess whether the degree of sensitivity of the predictions to assumptions or unacknowledged uncertainty is substantial enough to potentially affect decision-making based on FREM predictions for 2060. Specific summaries and conclusions are provided within the subsections.

For this review, prediction errors and variability in predictions at the level of individual road segments were investigated in two general ways for a small subset of road segments: (1) sensitivity of predictions and prediction errors to choice of baseline time period are evaluated using historic data, and (2) variability in predictions for 2060 due to assumed uncertainty in AADT values is assessed for several scenarios using computer simulation to propagate uncertainty through the FREM equation.

The investigations undertaken for this report are limited in terms of the number of road segments and scenarios used. That is, they are not exhaustive demonstrations of predictive ability. From the perspective of a scientific review, the investigations are meant to provide an initial look at the reasonableness of the approach in the context it is planned to be used.

3.6.1 Five road segments for investigations

The five road segments described in Section 3.3.2 are again used here to assess predictive ability. If reasonableness of the FREM approach is not demonstrated for these five road segments, then the method's performance for other segments is called into question. While other segments included may have some "balancing out" effect, there is no direct evidence or theoretical justification for this without more in depth analysis of all road segments included in a prediction. An investigation involving all road segments related to the ECMSHCP analysis would involve compilation of data for all segments and is beyond the scope of this review.

3.6.2 Prediction errors using moving 5-year intervals

Using available historic yearly data for estimated AADT and reported PVM for the road segments, FREM prediction errors can be calculated using all possible non-overlapping 5-year intervals for pairs of baseline and future intervals. For this exercise, the "future" AADT values are actually observed (estimated or calculated) values for road segments. These values are expected to be closer to true traffic volume than if projections of AADT forty years before had been used based on traffic models. Therefore, the *size of the prediction errors reported here are taken as a best-case scenario (smallest possible)*; that is, they are expected to be smaller than errors would be based on projected future AADT values that are not based on observed data, , and still only account for one source of uncertainty among many.

Data and Methods For the five road segments described in Section 3.3.2, the FREM approach was applied to all possible non-overlapping 5-year intervals to assess prediction errors and sensitivity of predictions to choice of baseline and future interval. For example, if data are available from 1996 to 2019, the first set of predictions uses the period from 1996 – 2000 to predict for every 5-year interval after that (2001-2005, 2002-2006, 2003-2007, … , 2014-2019); the second set of predictions uses 1997-2001 as the baseline period, and so-on. Because these are time periods over which PVM are recorded, predictions can be compared to the observed value of PVM. Note that it is expected that some actual PVM are missed and therefore recorded PVM are observed, but not the true PVM count.

The results are displayed in the following two figures, one of the raw predictions (Figure 13) and one of prediction errors (Figure 14). In Figure 13, each set of points connected by a line represents the set of future predictions based on a single baseline 5-year interval. The first future interval is the closest non-overlapping interval and the most distant is the interval with midpoint 2017. Figure 14 is organized in the same way as in Figure 13, but with prediction error on the y-axis instead of raw prediction scale.

There are *two important ways to interpret the information* in Figures 13 and 14: (1) look at variability over time (horizontally within the set of points connected by a line to learn about variability in predictions based on changes in future AADT values (sensitivity to future year), and (2) look at variability vertically within a year to learn about variability in predictions for a given future year using different baseline years (sensitivity to baseline year). The gray points and gray line are the 5-year average actually reported for the data.

As noted previously, *less uncertainty is expected in the AADT values used for "future" in this exercise because they are actually past reported values and not future projections* based on FDOT models. The use of past years as hypothetical future values allows comparison of predicted to observed PVM, leading to the ability to learn from the prediction errors (Figure 14).

As previously described, these results should only be taken to apply to the individual road segments included. However, given the potential sensitivity of overall conclusions for the ECMSHCP analysis to the prediction results for these road segments, they represent a reasonable starting place. If magnitudes and variability of predictions are large enough to question the adequacy of the approach in terms of accuracy and precision for these segments, then more work is needed to justify using the FREM approach predictions as information for decision-making.

Summary of results (Figures 13 and 14 appear after this summary):

- Predicted 5-year average PVM can range from near 0 to close to about 1.6 for the same year based on different baseline intervals. This corresponds to a difference of up to 8 PVM over a 5-year period. This was observed for both US-41 and SR-29 where longer time series' of FDOT data were available. This range surpasses the reference values serving as flags for questioning predictive accuracy and precision (see Section 3.5.1).

- For most years and segments with a reasonable amount of data, the proportion of predictions greater than the 0.8 deemed to be large relative to historically observed values as discussed in Section 3.5.1, ranged from about 20% to close to 50%. Therefore, these predictions are large enough to affect potential decisions when aggregated with other segments. In the year with the largest predictions for US-29 FDOT, 64% of the predictions were greater than or equal to 1.0 and for US-41, the year with the largest predictions had 31% over 1.0. A prediction of greater than 1.5 is considered extreme in its potential to affect decisions, and there were several predictions in many years that reached this threshold using two different baseline years FDOT data for US-29 and US-41.
- Even for segments with few years of data available predictions vary by at least 0.25, corresponding to a difference of 1-2 PVM over a 5-year period.
- Prediction errors are generally large relative to the context described in Section 3.5.1 unless the baseline PVM is 0 (meaning the prediction will also be zero and the prediction error is then zero). The year with the largest prediction errors for US-41 has 67% of the prediction errors greater than or equal to 0.8; for US-29 FDOT the proportion is 82%; and SR-82 has a year with all predictions over 0.8.
- Prediction errors do not tend to be centered around zero for a particular year. Average predictions errors, excluding predictions based on years with 0 baseline PVM, ranged from -1.1 to 0.42 for SR-29 FDOT; from 0.6 to 0.9 for SR-82; from -0.5 to 0.4 for CR-846; and from -0.4 to 0.9 for US-41.
- The standard deviation for predictions (and prediction errors) for a given year for which there were at least four predictions ranged about 0.1 to 0.55, with a median close to 0.3. As discussed in Section 3.5.1, a standard deviation of 0.4 is flagged as "large" relative to ultimate decision-making.
- Variability over future intervals for a given baseline year is expected as future AADT changes (points connected by a line). However, it is worth noting the fluctuations over time in predictions come from the yearly changes in estimated AADT over time. The variability in AADT over time, even within 5-year intervals, is sometimes enough to change predictions by a meaningful amount. This calls into question the use of the midpoint year's AADT as representative of the 5-year periods, as if AADT values tend to be constant enough over five years that use of the midpoint is sufficient, which is something that could be explored in more detail in future investigations of FREM.

Conclusions

- Predictions are judged to be sensitive to the 5-year intervals – for both the baseline period and the future period. The variability in predictions observed is large enough to elicit concerns, and prediction error magnitudes are also large enough for concern relative to the context in which FREM predictions may inform decision-making. Based on this limited investigation, there are concerns about the adequacy of the FREM algorithm in predicting for individual segments.

- It is assumed that for any prediction far into the future, there will be unforeseen changes to road segments and the system in general. Therefore, no known changes to road segments (like fences) are accounted for in this analysis. The FREM algorithm is being applied to non-stationary systems and therefore should be demonstrated to work adequately in such systems.
- This exercise represents an optimistic scenario compared to that needed for predictions for the ECMSHCP analysis. The longest time period between baseline and prediction in this exercise is 23-years, using 1994 (1992-1996) as the baseline to predict for 2017 (2015-2019). This is compared to the 43 years (2017-2060) needed for the ECMSHCP analysis. There are still other sources of uncertainty ignored.
- Based on the 5 segments investigated over time, variability in predictions due to different baseline years, the size of prediction errors, and variability in prediction errors all raise concerns about the adequacy of the current FREM approach for predicted PVM. The ranges in predictions and sizes of prediction errors are large enough to potentially change decisions informed by predictions obtained using the FREM approach.

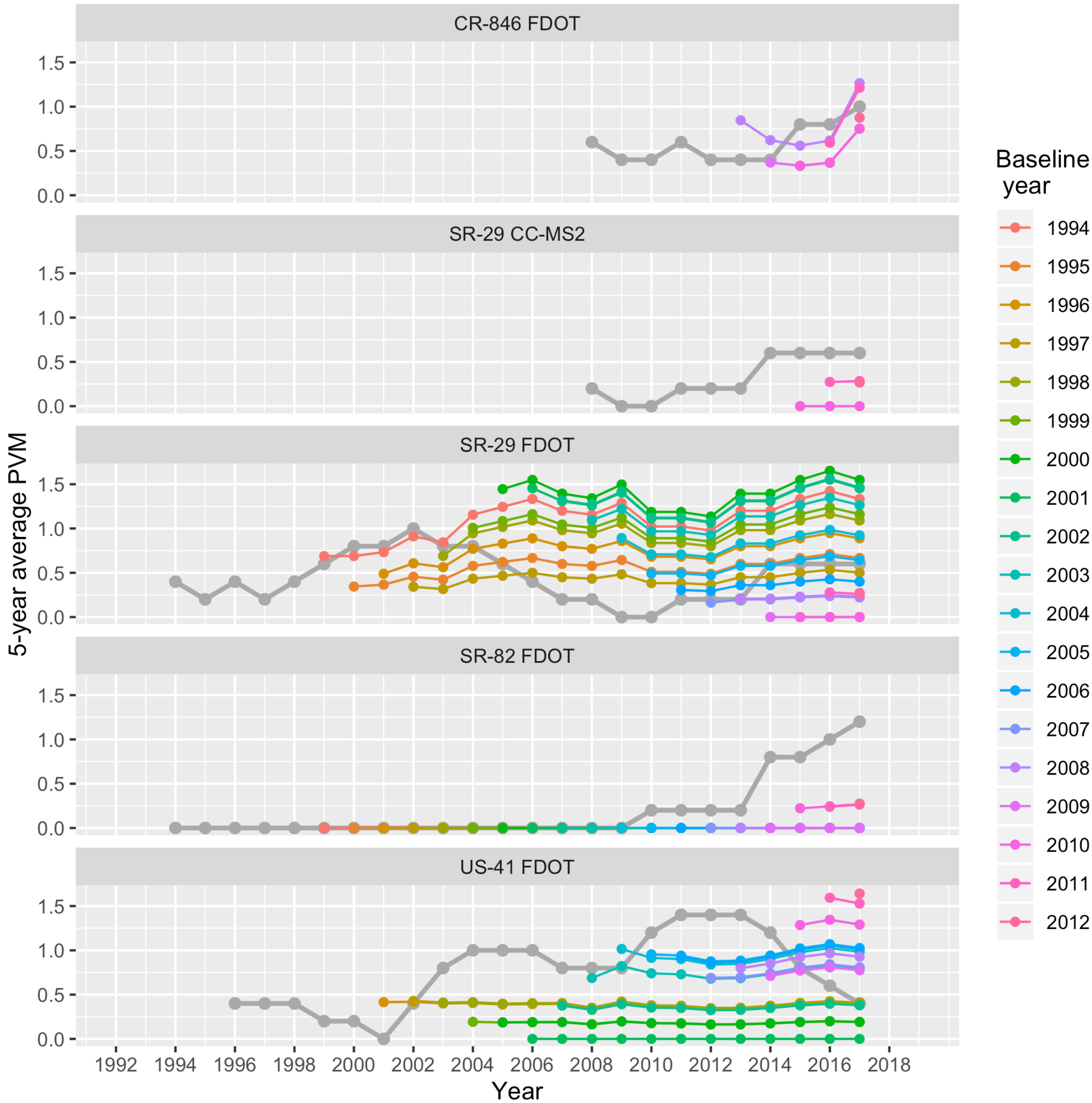

Figure 13 *Predictions of average PVM for moving 5-year windows based on a single baseline period are plotted at the midpoint of each window and connected by lines. There is one line for each baseline period (midpoint year shown in the legend) and the actual observed 5-year average PVM values are shown in gray. Baseline periods are the seven to two years before the first point appears. The first year with PVM data is 1992 for SR-29 FDOT and SR-82 FDOT, so the first 5-year average is plotted at 1994 (midpoint of 1992-1996) and the first prediction is plotted at 1999 (midpoint of 1997-2001).*

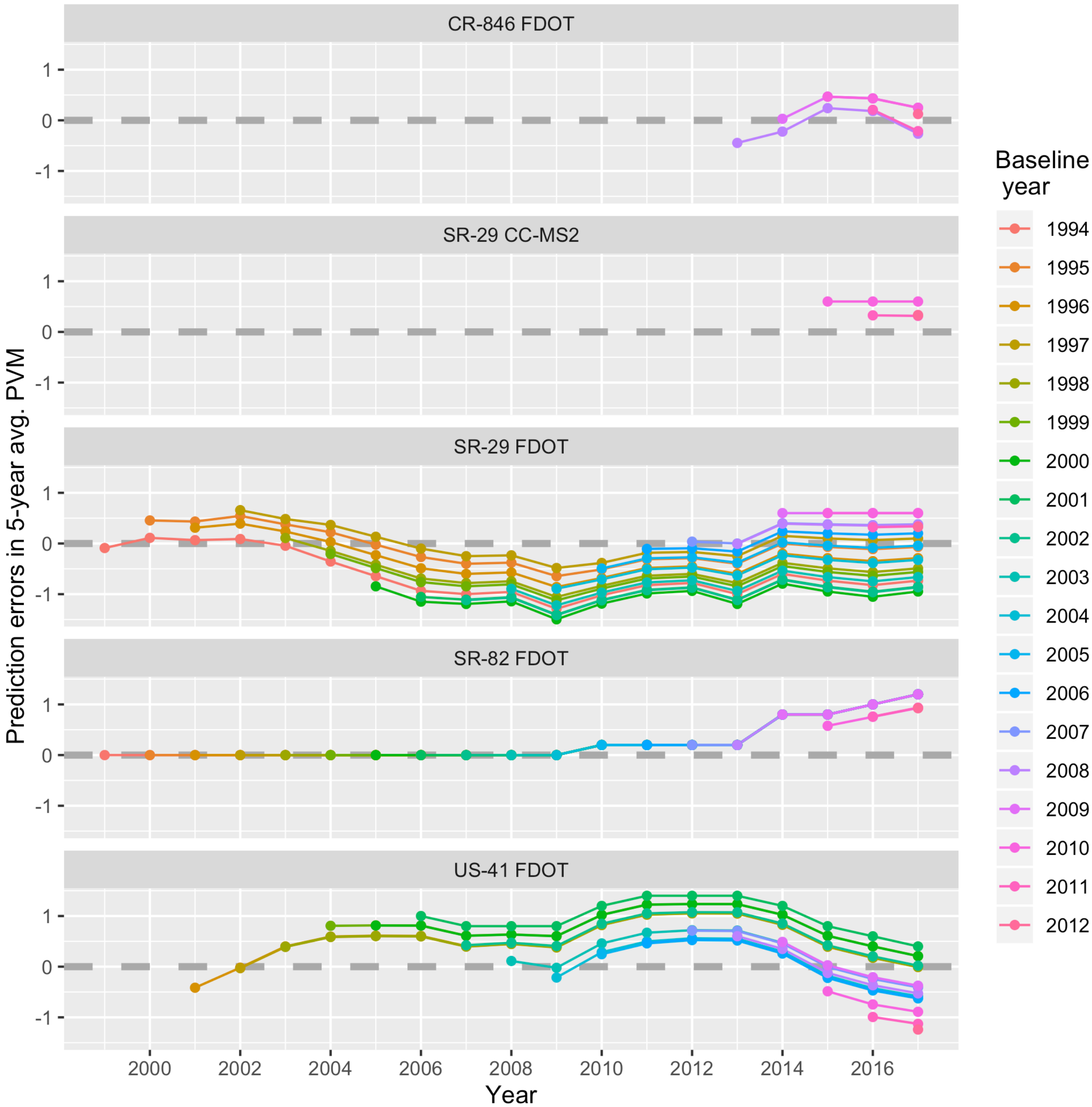

Figure 14 *Prediction errors for the predictions plotted in Figure 13 are shown here. Referring to Figure 13, the prediction errors are the observed 5-year PVM averages (gray points) minus the associated prediction. The prediction errors tend to follow the trajectories for the gray points in Figure 13.*

3.6.3 Incorporating uncertainty into predictions

Uncertainty in AADT values: A known source of uncertainty in predictions that is not accounted for using the FREM approach is uncertainty in the inputs. Traffic volume is measured using estimated AADT – containing several sources of measurement and estimation error, as well as natural variability in the counts over time. The estimation error in AADT depends on the data available to inform it (location of monitoring stations, dates of monitoring, etc.) and/or the method used by the FDOT. It is beyond the scope of this report to go into detail regarding the different methods used to assign an AADT value to a particular road segment for a particular year, but it is important to note that the value is approximate and contains an unknown amount of error relative to actual traffic volumes. Additionally, as described in Section 3.2, AADT does not account for seasonal and diurnal differences in traffic volume that are expected to be important relative to PVM risk.

Sources of information for reasonable values to specify uncertainty: Uncertainty in AADT values is not explicitly provided by FDOT or counties. However, it is possible to use information in the variability of AADT values within a 5-year period, as well information from county data when AADT is actually an average of about 4 counts collected quarterly. As a lower bound on uncertainty, the variability in AADT values during a 5-year time period expected to have relatively stable traffic volumes provides a reasonable starting point. Additionally, for AADT values that are an average of four daily monitoring sessions taken over one year (1 per season), the standard error of the average can be used as another reasonable lower bound. Uncertainty in projected AADT values is assumed to be greater than variability in "observed" AADT values. In summary, there is enough information available to inform reasonable lower bounds on uncertainty in values used for past and future AADT in the FREM equation.

FDOT and Collier County Data from SR29 are used to assess reasonable values for uncertainty. Standard errors for the yearly averages obtained from Collier County quarterly data range from 57 (2017) to 257 (2009) for years 2008 to 2019. The median standard error is 156. The within year standard deviations (not standard error of the average) range from 99 in 2017 to 568 in 2011. The standard deviation of AADT values within 5-year moving windows ranges from 130 (midpoint 2017) to 378 (midpoint 2014) with median of 264 for the FDOT data, and from 241 (midpoint 2013) to 427 (midpoint 2015) with median of 333 for the Collier County data based on four data collection times over the year. The standard deviation for the window from 2014 – 2019 used for predictions for the ECMSHCP is 130 for FDOT values and 382 for Collier County values.

Of note is the discrepancy between FDOT values and Collier County values. While these are only data for one segment, it is worth noting that the discrepancy is reflective of potential uncertainty in the system and in the AADT values used in the FREM formula. For example, for a normal distribution centered on the 2017 FDOT value of 3000, the standard deviation of the distribution would have to be about 450 to include the CC value as the 0.99 quantile of the distribution. This all suggests a realistic range of standard deviations in AADT, at least for values of AADT between about 2000 and 5000, of between 100 and 500. In the subsequent investigations we use values in the lower part of this range – meaning the variability shown in predictions is probably quite optimistic. Given the numeric properties of AADT (non-negative counts), standard deviations are expected to be larger for larger AADT values. For example, based on the Poisson distribution, the variance is equal to the mean.

Variability in observed PVM counts Randomness in the observed baseline PVM can also be propagated through to uncertainty in predictions. Because the observed counts are small, a difference of even 1 PVM in a 5-year period can substantially change the prediction. It is assumed that some PVM are not detected within a 5-year period, so that the reported PVM is a minimum number of PVM for a segment. A probability distribution for a random variable that is a count per unit effort can be useful for assessing potential variability in observed counts even under a constant mean PVM. The Poisson distribution is commonly used to model such counts. In this case it is defined by a mean rate (e.g., mean PVM per 5-year interval for a road segment). The mean rate can be any non-negative number, but the random variable being modeled is a count (non-negative integer) for each 5-year period.

It is useful to look at characteristics of the Poisson distribution for different underlying rates to understand potential implications of basing predictions on small counts. For the ECMSHCP setting, there are two main points to consider: (1) the implication of excluding road segments with zero PVM in the past, (2) FREM predictions for road segments with zero PVM for the baseline interval, and (3) observed counts may be under-counts, but it is assumed they cannot be over-counts.

First, for small mean rates (such as 0.2 corresponding to 1 PVM in five years), the count is expected to be zero in about 80% of years according to the Poisson distribution. Road segments are chosen because they have had an observed PVM in the past, but there may be road segments missing from the collection that have non-zero risk of PVM but have never had a reported PVM. The number of *reported* PVM for a road segment is a combination of two processes: (1) occurrence of PVM and (2) detection of PVM that occur. It is assumed that detection is not perfect and that reported PVM are likely an undercount of actual PVM. Therefore, it is expected that the collection of road segments based on past reported PVM is missing some segments that may have had PVM in the past.

Second, the FREM approach is not designed to account for observed counts of zero PVM. This is a severe limitation given the small observed counts in general. Given the formula, a baseline PVM of 0 will necessarily be a predicted value of 0, regardless of the projected increase in AADT. Given that it is common to observe zero PVM over five years if the mean rate is 0.2, this is an important consideration. It may be argued that those segments with a 5-year PVM of zero can be safely ignored for predictions because, according to FREM, they would not contribute to total PVM, but this assumption or argument should be carefully considered and justified. If the relationship between increases in AADT and increases in PVM is relied on for predictions, then road segments with the potential to be crossed by panthers would be expected to have an increase in PVM rate with an increase in AADT. That is, assumptions of the model should be applied consistently if the model is deemed adequate to be relied on in this context.

For example, under the Poisson model, an underlying mean rate of 0.2 PVM/5-years would result in about 80% of years having a count of 0, 16% percent a count of 1, and 2% a count of 2.0. Combining these into the distribution over 5-years based on the Poisson distribution about 37% of independent 5-year intervals have a count of 0, 37% of 1 PVM, 18% of 2, 6% of 3, and 1.5% of 4, and less than 0.5% of 5. This same distribution applies to a one-year interval if the underlying rate is 1.0 PVM per year.

The Poisson distribution is an example of a common way to account for random variability in observed counts under a constant mean and it is a distribution that tends to produce realistic counts over time (if the mean rate is constant or modeled using other covariates). There are limitations to this approach, but it is a reasonable way to investigate the potential effects of observation error in PVM. If this is incorporated into uncertainty (it is an option in the web applet provided in Appendix B), the counts are not allowed to be less than the observed count to maintain consistency with the fact that the known PVM must be a lower bound for that time period. This source of uncertainty is *not* included in the results summarized in the Figure 15 and conclusions for this section.

Method for propagating uncertainty: Computer simulation is now a readily available tool for investigating how sensitive predictions from algorithms, such as the FREM, may be to identified sources of uncertainty. In this case, the simulation approach proceeds by taking random values (draws) from probability distributions with properties specified using information from relevant AADT data. For each iteration of the simulation (1,000 total), different random values are obtained for the AADT values input into the FREM formula (more detail provided below). The end result is a distribution of PVM predictions (rather than a single number) that characterizes variability in predictions under the assumptions made about the uncertainties (form of the probability distribution, mean, and variance). If the assumptions are reasonable, then the simulation method propagates realistic levels of uncertainty in the FREM inputs through to the FREM predictions, allowing the effects of those sources of uncertainty on the range of potential predictions to be visualized and summarized.

Using computer simulation, the range of potential predictions is investigated by incorporating uncertainty associated with the two AADT values: (1) the estimated/calculated past value (e.g. 2017 AADT), and (2) the FDOT model projected future value (e.g, 2060 AADT). This investigation looks at uncertainty in predictions for an individual road segment. That is, it does not account for combined uncertainty when predictions are aggregated over a collection of road segments. Future investigations can combine over segments by summing at the end of iteration of the simulation. However, judging expected variability in predictions for a single segment is an important starting place.

The simulation assumes both past and future AADT values come from normal distributions centered on the given input value and with some specified standard deviation to represent the magnitude of uncertainty (larger standard deviations representing greater uncertainty). The assumption of a normal distribution is questionable, particularly for projected future AADT that is expected to be right skewed (have some larger values to give the distribution a long tail to the right). The normal distribution is more reasonable if representing values that are averages of counts over the year, but that doesn't account for year-to-year variability that should also be captured in the distribution. For the investigation presented in this review, the normal distribution is used as a best-case scenario situation (i.e., most likely under-estimating uncertainty in predictions by using a symmetric distribution). The distribution(s) can easily be changed for future investigations.

The simulation method proceeds by taking a random draw from the specified distribution to get a value for past AADT, taking a random draw from the distribution for projected AADT, calculating the AADT ratio from the two values, and then multiplying it by the baseline PVM to get a predicted PVM. The AADT values change for each iteration, representing different potential versions of reality, and therefore the predictions also change. Distributions of predictions are displayed at the end of this section to aid in understanding how the assumed uncertainties propagate through the FREM equation into the predictions. This is a common and straightforward approach to assessing the impact of realistic levels of uncertainty on predictions. It is transparent and also allows for easy use of an interactive web applet (see Appendix B) so that stakeholders can further investigate uncertainty in predictions for different scenarios. It can be extended to prediction over all road segments of interest and to include the aggregation step.

Scenarios investigated: Collections of predictions for 4 differing sets of road segment AADT values and baseline PVM are provided here as examples, each run with three levels of uncertainty in the AADT inputs (labeled A, B, and C). The levels of uncertainty specify the standard deviation of the normal distribution that AADT values are assumed to be drawn from. The combination of road segment scenarios and levels of uncertainty is certainly not exhaustive, but it does provide some insight into one source of uncertainty being ignored in the FREM approach and the effect on predictions of realistic levels of uncertainty in AADT values.

The four scenarios are taken from segments included within the ECMSHCP area analysis and meant to provide differing sets of FREM inputs (see Table 1 for summaries of available data, assumed standard deviations, and .025 and 0.975 quantiles of the resulting distributions of predictions). All results assume no uncertainty in the observed PVM count.

<u>Scenario 1</u> Based on data for road segment *CR 846: Jones Mining Rd. to Wild Turkey Dr*. (FID 61815): This segment has AADT values of 7786 (2017 estimated) and 18285 (2060 projected), along with a relatively large PVM (0.8 5-year average). The standard deviations used for estimated AADT are 100, 500, and 1000. The 100 and 500 are consistent with standard errors obtained using CC-MS2 from SR-29, as well as standard deviations observed across AADT values within any 5-year interval. FDOT estimates, or calculated values, are assumed to have more uncertainty (though potentially less variability within any 5-year interval) than the CC-MS2

values. Standard deviations for the projected 2060 AADT are set at two times those for the estimated AADT (200, 1000, and 2000), as the magnitude of the projection is over two times that of the estimated. Because a normal distribution is used to represent potential variability in AADT values, the standard deviations can be interpreted in terms of the range of AADT values generated – about 99% of values generated will fall within 3 standard deviations. Projected 2060 AADT values for the simulation range from about 17685 to 18885 for lowest uncertainty (A), 15285 – 21285 for the medium scenario (B), and 12285 to 24285 for the highest uncertainty scenario (C).

<u>Scenario 2</u> Based on data and projections for road segment *CCR 846: 0.5 mile south of CR 833 (FID 23601):* The standard deviations for this segment are lower than for the other scenarios because the magnitude of AADT values are smaller: 1100 (2017 estimated) and 1241 (2060 projected). The standard deviations for the 2017 AADT are set at 50, 100, and 150; those for the 2060 AADT are set at 100, 200, and 300.

<u>Scenario 3</u> Based on data and projections for road segment *I-75: Collier-Dade County line to SR29 (FIDs 63277, 63284, 63086, 63176):* The standard deviations used for this scenario are larger than for the others given the larger magnitude of the estimated 2017 AADT (24,000). The standard deviations are set to 1000, 2000, and 4000. Likewise, the standard deviations for the projected 2060 AADT are larger than for the other scenarios and set to 2000, 4000, and 6000.

<u>Scenario 4</u> Based on data and projections for road segment *SR 29 at Sunniland Mine (FID 63077):* For this segment, Collier Country MS2 data for (almost) quarterly monitoring of traffic counts to inform the AADT were used to help set standard deviations. The standard errors for the averages over years with available data ranged from about 50 to 257. Standard deviations of FDOT AADT values within different 5-year intervals ranged from about 130 to 378, and those for CC-MS2 AADT values ranged from 241 to 427. For the 5-year time period used as the baseline for predictions, the standard deviation for estimated AADT values is about 131 for the FDOT values and 382 for the CC-MS2 values. Therefore, the A scenario has a standard deviation less than that observed in the FDOT data and the C scenario has a value a little larger than that observed for the CC-MS2 data. The standard deviations for projected 2060 AADT are set to 10 times those of the estimated 2017, which are still judged to be in a realistic range give the magnitude of the projected 2060 AADT.

Table 1 *Description of scenarios and results for assessing propagation of uncertainty in AADT inputs to the FREM algorithm through to PVM 5-year average predictions for 2060 (3/2057 – 2/2062). Three pairs of standard deviations (SDs) are used (A, B, and C in increasing order). The 0.025 and 0.975 quantiles of the 1,000 values (defining the range of the middle 95% of the 1000 values) are displayed in the last two columns.*

Scenario*		**Baseline** (2017; 3/2014 – 2/2019)			**Projected** (2060; 3/2057 – 2/2062)				
		AADT	SD(AADT)	PVM	AADT	SD(AADT)	PVM point	PVM 0.025 quantile	PVM 0.975 quantile
1	A	7786	100	0.8	18285	200	1.89	1.82	1.94
	B		500			1000		1.59	2.22
	C		1000			2000		1.35	2.62
2	A	1100	50	0.2	1241	100	0.23	0.19	0.27
	B		100			200		0.15	0.31
	C		150			300		0.11	0.36
3	A	24000	1000	0.4	37833	2000	0.63	0.56	0.71
	B		2000			4000		0.49	0.82
	C		4000			6000		0.39	1.04
4	A	4104	100	0.4	21717	1000	2.12	1.92	2.35
	B		200			2000		1.70	2.54
	C		400			4000		1.22	3.06

*See descriptions of the Scenarios in the text below.

Summary of Results:

- The predictions for all 1,000 realizations for each scenario are plotted in Figure 15 to accompany Table 1. It is important to realize the predictions are given units of PVM per year (not total over 5 years) and they correspond to ranges in predictions for only a single segment. For the ECMSHCP analysis, total PVM predictions for 2060 are aggregated over 90 road segments.
- Over the road segment and uncertainty scenarios included, it is clear that even modest levels of uncertainty (relative to variability in historic AADT data, as well as standard errors of averages obtained from quarterly measurements to get AADT) can result in a range of predictions large enough to potentially change the outcome of a decision based on FREM predictions.
- The A scenarios likely represent unrealistically low uncertainty and still results in ranges that, when considering a single road segment, can change 5-year total PVM predictions by as much as 2 PVM; the C scenario can change the 5-year total by more than 5 PVM for Scenarios 1 and 4. These are over the reference values, or flags, justified in Section 3.5.1.
- For example, Scenario 4 with unrealistically low uncertainty (scenario A) in AADT results in predictions ranging from about 1.75 to 2.5 (.025 and .975 quantiles of 1.92 and 2.35, respectively). Assuming larger, but still reasonable, levels of uncertainty leads to predictions ranging from 0.75 to 3.75.
- While the results provided here are subject to the scenarios chosen and the levels of uncertainty specified, the results raise concerns regarding the approach of ignoring

uncertainty in AADT values (as well as any other sources) when implementing the FREM algorithm. That is, the potential effects on the range of potential PVM predictions are large enough the problem should not be ignored.

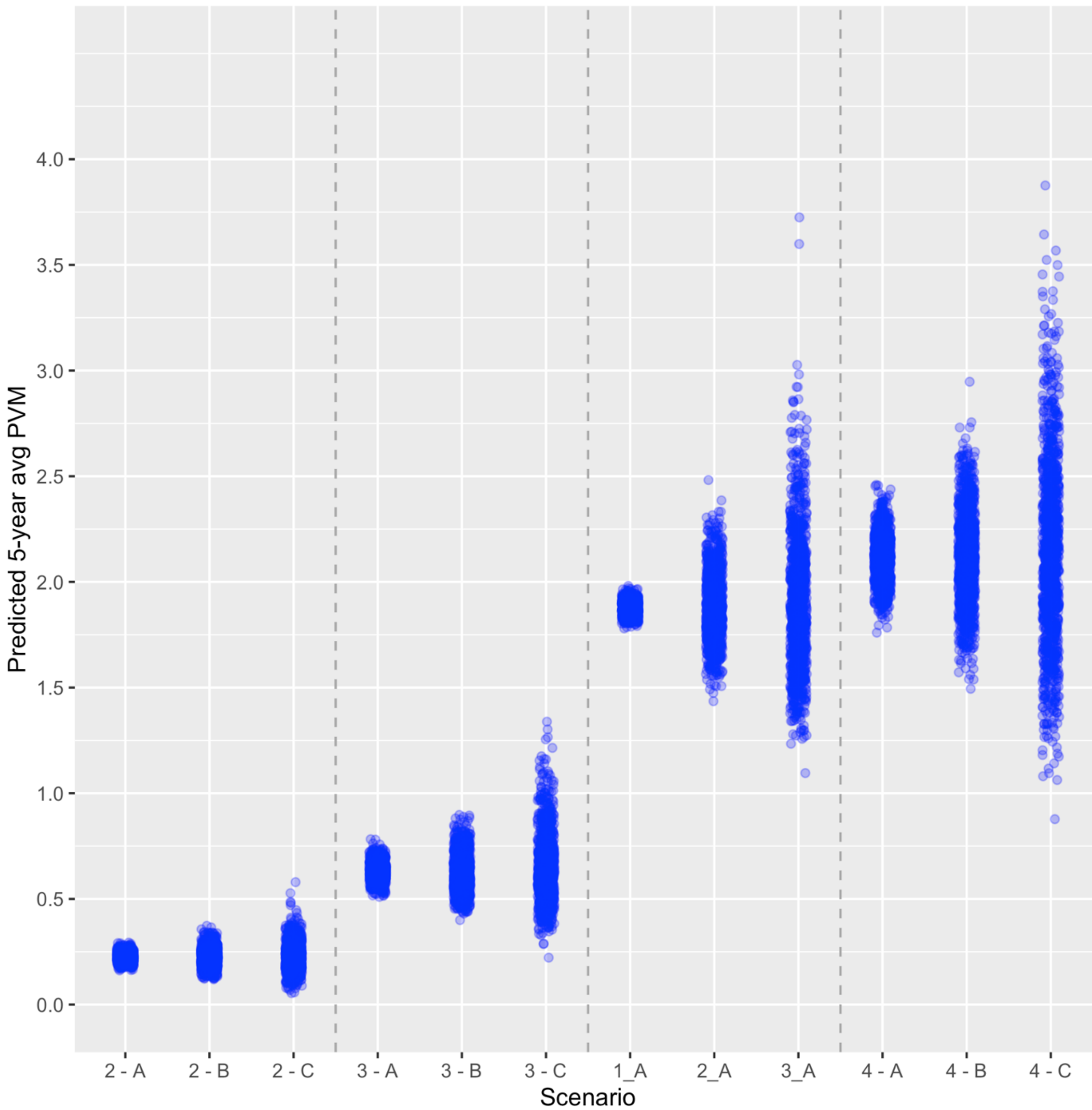

Figure 15 *Predictions of 5-year average PVM after propagating different levels of uncertainty in estimated and projected AADT through to the predictions. See text for descriptions of Scenarios A, B, and C for road segment examples 1, 2, 3, and 4. See Table 1 for the associated AADT values and standard deviations. Even the largest standard deviations are set within the range of reasonable levels of uncertainty given the context.*

Conclusions

- At the very least, this preliminary investigation into the effects of uncertainty in reported and projected AADT values on the range of potential FREM predictions of PVM demonstrates the importance of considering uncertainty in the AADT inputs before relying on the information to guide decision-making.
- The amount of uncertainty included in these scenarios is still expected to understate the actual uncertainty in the PVM predictions due to other sources not captured. Discussion among stakeholders about reasonable values, as well as additional statistical analysis of historic data, and information from FDOT regarding uncertainty in projections from their traffic models, could lead to future work using the foundations provided in this review.
- The results provided are for a single segment and do not reflect aggregation of uncertainty through the summing of predictions over individual segments. Using the same methods, it is possible (with additional effort) to propagate uncertainty through to the aggregated predictions over all segments included in the ECMSHCP area analysis. To implement this, decisions would need to be made regarding standard deviations for each of the baseline and projected AADTs. A simple way to proceed initially is simply use standard deviations at a set percent of the associated AADT value. For the results to be as useful as possible, more work could be dedicated to specifying the distributions and levels of uncertainty based on more analysis of historic data and understanding of the FDOT traffic models.
- For individual segments, a web applet is available (see Appendix B) for stakeholders to use to further assess the effects of uncertainty in AADT inputs, under the same assumed distributions as used for the results presented in this section.

4 Professional opinion regarding FREM approach (Task 3)

Based on the details of the review described under Tasks 1 and 2, this final task presents my professional opinion as to whether the proposed approach (FREM) is adequately justified in terms of its assumptions, as well as its predictive accuracy and precision. Adequacy is judged relative to the context of predicting PVM in year 2060 to potentially guide decisions regarding the effects of potential future developments on panthers through PVM. The FDOT traffic models produce projects AADT values into the future, making the FREM approach attractive in terms of the simplicity and ready availability of its inputs.

My conclusions are based on quality and quantity of information available to support use of the FREM approach, evaluation of the primary assumptions, and uncertainty in FREM-based predictions. While recommendation of an alternative approach for predictions in 2060 is beyond the scope of this review, information in this review should be valuable to future work in that direction.

Based on the information available about FREM and my review based on my statistical expertise, I find inadequate justification for using the FREM approach for predicting PVM in 2060, particularly if the predictions are to guide decision-making. This conclusion is based on the following points, which are described previously in the report:

1. *Documentation of the development and application of the approach is inadequate transparency, utility, and objectivity*. There is no documentation providing definitions, notation, and assumptions, or describing how the approach was developed. The information provided regarding predictive accuracy refers to two examples of successful predictions, but it lacks adequate detail for evaluation and/or reproducibility. The small prediction errors reported for the two examples beg questions about how the scenarios were chosen and what data were used to develop FREM initially. The available documentation does not meet the standards outlined in the *USFWS Information Quality Guidelines and Peer Review*.

2. *Source of uncertainty in predictions are ignored, both quantitatively and qualitatively.* As described previously in this document, there are many sources of uncertainty associated with the FREM approach that are expected to affect predictions. From a statistical perspective, (at least) two such sources that are not justifiably ignored are (1) uncertainty in the AADT values used as inputs, and (2) uncertainty based on extrapolation beyond the observed range of AADT values for a segment. Based on the investigations in this review, the potential range of predictions resulting from the two aforementioned sources are expected to be large relative to the decision contexts the predictions may be used for. That is, after incorporating some uncertainty, the range of potential PVM predictions for a road segment are large enough to potentially change decisions regarding the predicted PVM in 2060). At the very least, the potential variability in the predictions for the same inputs should be acknowledged and

considered in any decision making, rather than following the FREM approach to obtain a single number with no explicit discussion of associated uncertainty. The ignoring of uncertainty in inputs and predictions is a substantial limitation because it leaves serious questions as the practical usefulness of the predictions.

3. *The FREM equation implies a strong association between 5-year PVM and midpoint year AADT value. However, evidence for such an association to support the fundamental assumption of the approach is missing in the exploratory analysis performed for this review.* On the other hand, there is evidence of a strong, positive association between panther annual counts (as a surrogate for changes in population size) and PVM at the regional level. The reliance of FREM on estimates and predictions of AADT (as a measure of traffic volume) implies a strong relationship between the two variables, over space and/or time. The lack of evidence for such a relationship observed in the data investigated for this review is surprising given the FREM formula. This suggests a main motivation for adopting the FREM approach may be the relative ease of obtaining the inputs, particularly future projections of AADT from FDOT traffic models.

In summary, the information and conclusions provided in this review raise serious concerns about transparency and justification of the FREM approach, as well as sensitivity of predictions to the assumptions and sources of uncertainty that are currently ignored. At the very least, additional documentation regarding the development and application of the FREM approach should be required, as well as explicit discussions of the degree of uncertainty potentially associated with the resulting predictions. The point predictions for 2060 PVM as currently calculated are not deemed trustworthy enough to base practical decisions on.

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Appendix A – FREM Notation and Definitions

Description of the FREM approach

Prepared by Megan Higgs, Critical Inference LLC

Introduction

The following reflects my current understanding of the Future Roadkill Estimation Approach (FREM) adopted in 2018 by staff at the U.S. Fish and Wildlife Service (US FWS) South Florida Ecological Services Field Office. The approach uses a simple formula to predict future PVM over a 5-year period for an individual road segment using a past 5-year PVM, the reported AADT value for the midpoint year, and a future year's AADT projected by FDOT traffic models. The goal of this document is to increase transparency of the method by making mathematical definitions, details, and assumptions of the appraoch explicit.

Key information about inputs:

- The predictions are obtained at the level of each road segment and then summed over all road segments to be included in a larger regional prediction.
- AADT = annual average daily traffic is a common measure of traffic volume. As indicated in the name, it is meant to summarize yearly traffic volume while aggregating over within year changes (diurnal, daily, seasonal, etc.). AADT can be estimated or calculated based on data collected at monitoring stations and/or FDOT traffic modeling. Uncertainty in an estimate is expected to depend on methods used to obtain it. AADT values for the future are obtained as predictions from FDOT traffic models.
- Sources of uncertainty in estimated AADT and projected AADT are not quantified or discussed qualitatively.
- A 5-year average PVM is used as a baseline to predict an annual average PVM for a future year, by assuming the ratio of past to future 5-year PVM is equal to the ratio of past to future AADT values.
- As part of FDOT modeling of future AADT, attributions of future AADT for a road segment to a particular development included in the model is also provided. These proportions of future AADT attributed to a particular development are then translated directly into a proportion of future PVM through the FREM formula
- Predictions are made for road segments of interest with at least one PVM since year 1971. Given the FREM formula, any road segment with a baseline 5-year average of 0 PVM will have a prediction of 0 PVM in the future regardless of the projected increase in AADT.

Notation and definitions

Define quantities

$$AADT_{j,t} = \text{estimated AADT on road segment } j \text{ in year } t \text{ in the past}$$

$$\widehat{AADT}_{j,t} = \text{predicted AADT on road segment } j \text{ for year } t \text{ in the future}$$

$$PVM_{j,[t_1,t_2]} = \text{total observed PVM on road segment } j \text{ over time period from year } t_1 \text{ to year } t_2 \text{ (inclusive)}$$

$$\widehat{PVM}_{j,[t_3,t_4]} = \text{total predicted PVM on road segment } j \text{ over time period from year } t_3 \text{ to year } t_4 \text{ (inclusive)}$$

$$\overline{PVM}_{j,[t_1,t_2]} = \text{average annual PVM on road segment } j \text{ over time period from year } t_1 \text{ to year } t_2 \text{ (inclusive)}$$

$$\widehat{\overline{PVM}}_{j,[t_3,t_4]} = \text{predicted average annual PVM on road segment } j \text{ over time period from year } t_3 \text{ to year } t_4 \text{ (inclusive)}$$

1

The formula

Future 5 year annual average PVMs are predicted based on the assumption that the ratio of a projected future year's AADT to a past year's AADT is equal to the ratio of a future 5-year PVM (average or total) to a past 5-year PVM (average or total), where the year associated with the AADT is the midpoint year of the 5-year period. Using the proportional relationship, the future 5-year PVM is solved for given values of the other three quantities.

For example, for the ECMSHCP analysis, a prediction was desired for year 2060. The baseline period used for PVM was the 5-year period from beginning of March 2014 through end of February 2019, and the past AADT was taken from 2017. The predicted 5-year annual average PVM technically applies to beginning of March 2057 through end of February 2062.

The formula for road segment j, assuming t_0 is the midpoint of the baseline 5-year time interval (e.g., 2017 in the previous example) and t_f is the midpoint of the future 5-year time interval.

$$\widehat{PVM}_{j,[t_f-2,t_f+2]} = \overline{PVM}_{j,[t_0-2,t_0+2]} \times \frac{\widehat{AADT}_{j,t_f}}{AADT_{j,t_0}}$$

To obtain a predicted PVM for a collection of J total road segments in region of interest (region), the individual segment predictions are summed:

$$\widehat{PVM}_{region,[t_f-2,t_f+2]} = \sum_{j=1}^{J} \widehat{PVM}_{j,[t_f-2,\ t_f+2]}$$

Accounting for contribution from specific development

Based on FDOT projections of AADT, percent contribution of projected AADT for each road segment attributed to a particular development is also modeled. Continuing with the assumption of a direct proportional relationship between AADT changes and changes in PVM, the fraction of AADT attributed to a potential development is then taken as the fraction of future PVM for each segment attributed to the potential development. The percent attribution varies by road segment and therefore the attribution calculation for 5-year average PVM is performed at the level of the individual road segment before aggregating to a regional prediction.

The percent of projected 2060 Total AADT for segment j in year t attributed by the FDOT traffic model to development k is denoted

$$prop\widehat{AADT}_{k,j,t}$$

The predicted 5 year annual average PVM for segment j attributed to potential development k is calculated as:

$$\widehat{PVM}_{k,j,[t_f-2,t_f+2]} = \overline{PVM}_{j,[t_0-2,t_0+2]} \times \frac{\widehat{AADT}_{j,t_f}}{AADT_{j,t_0}} \times prop\widehat{AADT}_{k,j,t_f}$$

The individual segment predictions are then summed, as described above before accounting for attribution to a development.

For a segment, the predicted 5-year average PVM attributed to development k plus the predicted 5-year average PVM *not* attributed to development k is equal to the future predicted 5-year average PVM provided previously.

Appendix B - Documentation to support data analysis

B.1 Relationships between AADT and PVM

Supplementary files supporting data visualization and analysis:

- B.1.1. Ninety segments used for the FWS ECMSHCP analysis (over space)
  - `HiggsDF_Traffic_analysis_by_segments_143panthers_corrected_20201023.xlsx` (Data file)
  - `PVM_EDA.Rmd` (RMarkdown file)
  - `PVM_EDA.html` (compiled from the RMarkdown file)

- B.1.2 Five individual road segments (over time)
  - `FiveSegments_HistoricData.xlsx` (Data file)
  - `FiveSegments_FREMpreds.xlsx`
  - `Individual_Segments_AADTvsPVM.Rmd` (RMarkdown file)
  - `Individual_Segments_AADTvsPVM.Rmd` (compiled from the RMarkdown file)

B.2 Relationship between annual panther counts and PVM

Supplementary files supporting data visualization and analysis:

- `AnnualCount_PVM_data.xlsx` (Data file)
- `Count_vs_PVM_EDA.Rmd` (RMarkdown file for R Statistical software)
- `Count_vs_PVM_EDA.html` (compiled from the RMarkdown file)

B.3 Moving 5-yr window predictions using historical data for 5 road segments

Supplementary files supporting data visualization and analysis:

- `FiveSegments_HistoricData.xlsx` (Data file)
- `FiveSegments_FREMpreds.xlsx` (Data file)
- `Individual_Segments_Prediction.Rmd` (RMarkdown file for R Statistical software)
- `Individual_Segments_Prediction.html` (compiled from the RMarkdown file)

B.4 Propagating uncertainty into predictions for 2060 for 5 road segments

Supplementary files supporting data visualization and analysis:

- `Propagating_Uncertainty.Rmd` (RMarkdown file for R Statistical software)
- `Propagating_Uncertainty.html` (compiled from the RMarkdown file)
- Interactive web app: https://critical-inference.shinyapps.io/PVM_FWSprediction_uncertainty/
    - Folder for files: `PVM_FREMprediction_uncertainty`
    - R-Code for the shiny web applet is in file `app.R`
    - The web applet was developed to allow real-time exploration how the range of predictions changes as assumed uncertainty in inputs changes. It allows the user to input values for 5yr average PVM, baseline AADT, and projected future AADT; as well as assumptions regarding standard deviations for the AADT quantities. Using simulation from probability distributions, variability representing uncertainty in inputs is propagated into predictions. The collection of potential predictions is graphically displayed.

Appendix C – Other Supplementary Files

The curriculum vitae (CV) of Megan Higgs, Ph.D. is included as supplementary material.