

Green = public comment

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Purple = both public comment and peer review

**ISSUE 13:** Issues regarding Chao2 (our method for estimating population) (Jennifer):

- Confusion about what the Chao2 estimator is
  - The definition of the "Chao2 estimator" in the Glossary is "a bias-corrected estimator of the total number of female grizzly bears with cubs-of-the-year, derived from the frequency of single sightings or double sightings of unique females with cubs-of-the-year as identified based on a rule set by Knight et al. (1995)." However, throughout the Proposed Rule the Chao2 estimator is referenced as producing an estimate of "overall grizzly bear abundance within the DMA"? This discrepancy should be resolved. We have clarified in the text that model-averaged Chao2 provides an estimate of the number of females with cubs-of-the-year, which is then used to derive a total population estimate.
  - Explain the details of model averaging as used with the Chao2 estimator. Model averaging is a method used when alternative methods are evaluated using information-theoretic procedures. This is something that warrants careful attention because of problems that can exist with model averaging (Cade 2015). Or if the intent is to estimate abundance for each year between 2002 and 2014 and to average those estimates clarification needs to be made and the term "model-averaged Chao2 estimate" should be avoided. Our reading of the Cade (2015) paper and others (e.g., Fieberg and Johnson 2015) is that model-averaging of the regression coefficients is not recommended but that model-averaging of predictions (i.e., in this instance, annual estimates of the number of females with cubs-of-the-year based on a linear and a quadratic model) is appropriate. Thus, the term "model-averaged Chao2 estimate" is appropriate and should be continued.
- Lack of transparency regarding the Chao2 estimator
  - Is there published literature describing the Chao2 estimator in its entirety? We have expanded the section describing the Chao2 estimator and provided all relevant literature.
  - Has the Chao2 population estimator been subjected to peer review? Yes, see literature presented in updated text.
  - In general, there needs to be more transparency regarding the Chao2 estimator (i.e., What are the demographic inputs and how were they determined? What are the model assumptions? How were initial population size and the different sex-age distributions estimated? and How were natural mortalities estimated and incorporated? etc.) These details are provided in the literature and would be too technical and cumbersome to provide in PR. Revisions provide all relevant references for this technique.
- Outdated
  - Not the best available science for monitoring population trend The best available science is the estimator that we currently have available and can apply under current monitoring schemes. Of course, there are methods that would likely result

Commented [FTvM1]: Language throughout PR should probably reflect that the total population estimate is **derived** from the model-averaged Chao2 estimate of females with cubs-of-the-year.

in greater precision and lower bias (e.g., DNA sampling) but annual implementation would be prohibitive both in costs and logistics. IGBST estimated that costs for a *single* DNA-based population estimate for the entire GYE would be approximately \$11 million. IGBST will keep investigating cost-effective techniques that may result in relatively unbiased estimates with greater precision.

- **Currently use the Knight rule to distinguish unique females with cubs.** Ordiz *et al.* 2007 proposed a different rule set for counts of FCOY in Europe. Knight rule is how we count unique females with cubs (how avoid counting same female twice). There are multiple techniques and different rule sets can be developed to estimate unique females with cubs-of-the-year. The Ordiz *et al.* (2007) paper does not describe a rule set but examines relationships among distances and number of days of individual females with cubs-of-the-year; data on litter size were not incorporated. Schwartz *et al.* (2008) investigated similar distance and time relationships for GYE female grizzly bears with cubs-of-the-year but no adjustments to the Knight *et al.* (1995) were made to reduce the probability of Type 1 errors (i.e., mistakenly identifying sightings of the same family as different families). IGBST may consider alternatives to the existing rule set in the future; if those alternatives are deemed to improve the best available science, new procedures will be adopted per the process outlined in the PR and CS.
- **Unreliable/biased: Need to acknowledge the risk and bias associated with Chao2.**
  - **Proposed rule fails to account for bias associated with the method or disagreements in the scientific community about the population estimate of ~700** (Doak and Cutler 2014a, 2014b) Revisions address the critique of Doak and Cutler (2014). Based on the rebuttal by van Manen *et al.* (2014) there was no justification to account for “bias associated with the method or disagreements in the scientific community about the population estimate of ~700”; particularly given the demonstrated underestimation bias of the rule set (Schwartz *et al.* 2008) and the Chao2 estimator (Cherry *et al.* 2007). Both sources of known negative bias contribute to conservative population estimates.
  - **No accounting for factors that might influence sightings of FCOY (females with cubs of the year)** One key aspects of the Chao2 estimator is that it reduces bias due to variation in sightability among different females with cubs-of-the-year. Additionally, model averaging smooths annual variations in counts that are due to both sampling and process variation, with the process variation coming from the proportion of females that have cubs at the side in any particular year.
  - **Total population size is strongly influenced by the multipliers used for dependent young, pre-reproductive independent females, and independent males, introducing more bias** The derivation of total population size introduces additional uncertainty into the total population estimate, but we have no data that suggest that bias would increase. Indeed, the vital rates (i.e., survival and fecundity) derived from IGBSTs large sample of radio-marked bears monitored annually, which form the basis for the multipliers, have been published in multiple peer-reviewed papers using well-established techniques (e.g., Schwartz *et al.* 2006, van Manen *et al.* 2016).

- The Chao2 estimate becomes increasingly negatively-biased with increasing density, so “the Chao2 estimates could level off while the population continues to increase, give a false sense of the population reaching carrying capacity (K). Likewise, once the population has exceeded the density threshold of FCOY that precludes further differentiation of distinct individuals, a decline also would not be detectable until dropping below this threshold.” (IBA) The first critique is valid if the Chao2 estimator was the only data used by IGBST for demographic inference. However, IGBST used multiple data sources to assess demographic changes, including 1) another estimator based on a mark-resight technique (Higgs *et al.* 2013), 2) a population reconstruction technique, and 3) population projections based on known-fate monitoring (Schwartz *et al.* 2006). Combined with recent analyses (van Manen *et al.* 2016), these data suggest that density-dependent factors may be operating and are an indicator of the population at or near carrying capacity. Regarding the second critique, it is true that changes in the estimate of females with cubs-of-the-year may be more difficult to detect as it increases. However, this is again a conservative approach. The analogy is a thermometer that does not register temperatures above 102 degrees; as long as the value of interest is below 102, it still registers when it drops to that point.
- The Chao2 is only conservative if the population is indeed increasing. If the vital rates or mortalities are misestimated, the population could decline, undetected. (IBA) The Chao2 and associated rule set for identifying unique females with cubs-of-the-year is conservative and relatively more with a greater number of unique females with cubs-of-the-year. I.e., population level determines the level of bias, not population growth.
- Chao2 could become more unreliable with increased cub mortality because of more difficulty in distinguishing FCOY (i.e., litter sizes are changing). (IBA) If anything, this would increase underestimation bias and thus be conservative. Moreover, while cub mortality has increased, the geographic distribution of observed litter sizes has not.
- Potential errors in usage
  - The survival rate (and the multiplier) was increased for independent males in 2012 but survival rates actually decreased (Mattson) This is incorrect: male survival rates have increased from 1983-2001 to 2002-2012 based on the latest analyses (van Manen *et al.* 2016, Figure 2).
  - Population composition (i.e., changes in sex ratio over time) (how we use sex ratios in population estimation)
    - What has been the trend in sex-age distribution from 2002-2014, the same time period that is used for the Chao2 estimate? These are reported in IGBST (2012).
    - Shift to a more conservative 50:50 sex ratio or assume any probable mortality is an adult female. IGBST is currently using a 50:50 sex ratio based on updated vital rates from 2002-2011 (IGBST 2012). Assigning any probable mortality as an independent female is counter to the notion of staying as close to the data as possible. Randomly assigning sex based on observed sex ratios provides a more accurate reflection.

- To account for annual fluctuations in cub sex ratio, to be conservative alternative assignment of sex and assign female first. See response to previous issue.
- Acknowledge ways to manage this bias in the future
  - Need to specify that population monitoring will continue indefinitely at the same intensity (neither more nor less) and distribution and under the same design given potential biases in the Chao2 method. This issue was already addressed in original language.

## **Proposed Rule language**

### *Demographic Recovery Criterion 1*

The model-averaged Chao2 method ([see glossary](#)) is currently the best available science to [derive annual estimate of](#) total population size in the GYE. [The basis for this estimation is an annual count of female grizzly bears with cubs-of-the-year, based on sightings from aerial surveys and ground observations. Those sightings are clustered into those estimated to be from the same family group \(i.e., female with cubs-of-the-year\) using a “rule set” to avoid duplicate counts, primarily based on spatial, temporal, and litter size criteria \(Knight \*et al.\* 1995\). In clustering the observations, a balance must be obtained between overestimating or underestimating the actual number of unique females with cubs-of-the-year. The rule-set was constructed to be conservative \(i.e., reduce Type I errors or the error or mistakenly identifying sightings of the same family as different families\). Using the frequencies of sightings of unique females with cubs-of-the-year obtained from application of the rule set, an annual estimate of the total number of females with cubs-of-the-year is calculated using the Chao2 estimator, a bias-corrected estimator that is robust to differences in sighting probabilities among individuals \(Chao 1989, Keating \*et al.\* 2002, Cherry \*et al.\* 2007\). In the final step, the annual estimate of total number of females with cubs-of-the-year is combined with those of previous years to assess trend. Changes in numbers of females with cubs-of-the-year are representative of the rate of change for the entire population, but additional process variation comes from the proportion of females that have cubs-of-the-year. Linear and quadratic regression models of are fitted as an initial estimate of trend \(Harris \*et al.\* 2007\). Regression smooths variation to provide an estimate of trend representative of the population if the age distribution is relatively stable \(Harris \*et al.\* 2007\). Support for linear versus quadratic models is assessed using Akaike’s Information Criterion \(AIC<sub>c</sub>; Hurvich and Tsai 1989, Burnham and Anderson 2002\). Respective AIC<sub>c</sub> weights of the linear and quadratic models are then used to obtain a model-averaged Chao2 estimate of the total number of females with cubs-of-the-year, by using the model-](#)

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[averaged endpoint in the time series as the estimate for the current year. Change in trend since 1983 is assessed by examining support for the linear versus the quadratic model using AIC<sub>c</sub> weights. Finally, a total population estimate is derived based on the estimated proportion of the total population that is represented by the estimated number of females with cubs-of-the-year. For this final step, data on vital rates \(i.e., survival of different sex and age classes, fecundity\), as estimated from known-fate monitoring of radio-marked bears, are required.](#)

[Annual estimates of females with cubs-of-the-year based on Chao2 have been reported by IGBST since 2005, accompanied by the derivation of total population estimates. The model-averaged Chao2 estimates of females with cubs-of-the-year and derived total population estimates have been applied and reported by the Interagency Grizzly Bear Study Team since 2007. Doak and Cutler \(2014\) critiqued this approach to population estimation, claiming that increases in grizzly bear population estimates from 1983 to 2001 can be attributed to factors other than actual increases in population size, primarily increased observation effort and sightability of female grizzly bears with cubs-of-the-year. However, in a rebuttal, van Manen \*et al.\* \(2014\) demonstrated that the simulations of Doak and Cutler \(2014\) were not reflective of the true observation process nor did their results provide statistical support for their own conclusions.](#) ▼

As the grizzly bear population has increased, [the](#) model-averaged Chao2 estimates have become increasingly conservative (i.e., prone to underestimation), [primarily due to conservative criteria of the “rule set” \(Schwartz \*et al.\* 2008\) as well as an underestimation bias associated with the Chao2 estimator itself \(Cherry \*et al.\* 2007\).](#) As a conservative approach to population estimation, the model-averaged Chao2 method will continue to be the method used to assess Criterion 1 (see U.S. Fish and Wildlife Service 2016, Appendix C, for the application protocol for annual population estimation using the Chao2 method) until a new population estimator is approved. If new methods become available, these will be considered for application in the GYE as long as they represent the best available science. However,

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until possible new methods are developed, the model-averaged Chao2 method will continue to be used.

*Status:* This recovery criterion has been met since 2003 (see IGBST annual reports available at [https://www.usgs.gov/centers/norock/science/igbst-annual-reports?qt-science\\_center\\_objects=1#qt-science\\_center\\_objects](https://www.usgs.gov/centers/norock/science/igbst-annual-reports?qt-science_center_objects=1#qt-science_center_objects)).

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#### *Factor B*

Accordingly, the agencies implementing the draft 2016 Conservation Strategy have decided that the population in the DMA will be managed around the long-term average population size for 2002–2014 of 674 (95% CI = 600–747) (using the model-averaged Chao2 estimate). The population inside the DMA has stabilized at this population size and density-dependent regulation may be a contributing factor (van Manen *et al.* 2016). The model-averaged Chao2 method will be used by the IGBST to annually estimate population size inside the DMA (in their entirety: Keating *et al.* 2002; Cherry *et al.* 2007, Harris *et al.* 2007), as this currently represents the best available science. To achieve a population in the DMA around the average of 674, the total mortality limits for independent females will be set at 7.6 percent when the population is at 674, less than 7.6 percent when the population is lower, and more than 7.6 percent when the population is higher (as per table 1, above, and tables 2 and 3, below). A total mortality of 7.6 percent for independent females is the mortality level that the best available science shows results in population stability (IGBST 2012, entire). Annual estimates of population size in the DMA will be made each fall by the IGBST using the model-averaged Chao2 method. These annual estimates will normally vary as in any wild animal population. The annual model-averaged Chao2 population estimate for a given year within the DMA will be used to set the total mortality limits from all causes for the DMA for the following year as per table 1, above, and tables 2 and 3, below. Mortalities will be managed on a sliding scale within the DMA as follows (see table 1, above, for more information):

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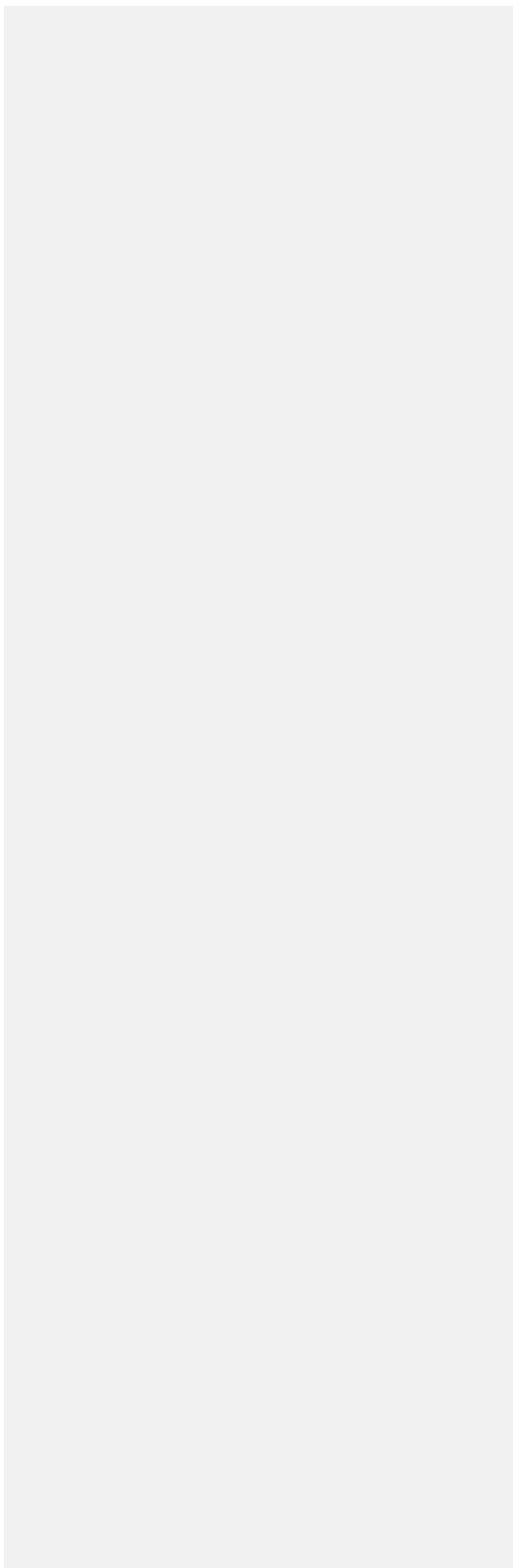
- Below 600: no discretionary mortality would be allowed unless necessary to address human safety issues.
- Between 600 and 673: total mortality limits would be less than 7.6 percent for independent females (>2 years old), 15 percent for independent males (>2 years old), and less than 7.6 percent for dependent young
- At 674: total mortality limits would be 7.6 percent for independent females, 15 percent for independent males, and 7.6 percent for dependent young.
- Between 675 and 747: total mortality limits would not exceed 9 percent for independent females, 20 percent for independent males, and 9 percent for dependent young.
- Greater than 747: total mortality limits would not exceed 10 percent for independent females, 22 percent for independent males, and 10 percent for dependent young.

#### *Glossary*

*Chao2*: The Chao2 estimator is a bias-corrected estimator of the total number of female grizzly bears with cubs-of-the-year, derived from the frequency of single sightings or double sightings of unique females with cubs-of-the-year ([Keating et al. 2002, Cherry et al. 2007](#)) as identified based on a rule set by Knight et al. (1995).

[Model-averaged Chao2: An estimate of the total number of female grizzly bears with cubs-of-the-year based on a statistical weighting of linear and quadratic regression models fitted to data since 1983 to smooth annual variations in the time series, and using endpoint in the time series as the estimate for the current year.](#)





### Draft Conservation Strategy language

*Demographic Criteria for the Greater Yellowstone Ecosystem*, all mortalities and all reports of unique females with cubs-of-the-year (see Appendix C) will be monitored within the DMA (Figure 1). This will result in the management and monitoring of the grizzly bear population in the DMA, as opposed to the system based on the 2007 Supplement as amended to the 1993 Recovery Plan, in which mortalities and sightings of females with cubs-of-the-year were counted within the previously defined Conservation Management Area (CMA). This reduction in the area monitored for population estimates and estimating mortality rates brings in the monitoring efforts within the DMA, which corresponds to the area monitored by the IGBST. Conservation Strategy demographic standards are tied to the DMA, shown in Figure 1. The criteria and objectives in the existing *1993 Recovery Plan* have modified, as described below.

### **Conservation Strategy Population Standards**

This Conservation Strategy and the state management plans set an objective of maintaining a recovered grizzly bear population in the Yellowstone area sufficient to meet management objectives inside and outside the PCA in biologically suitable and socially acceptable habitats. The demographic standards in this Conservation Strategy are designed to meet these goals.

The GYE grizzly bear population exceeds 500 total bears as of 2006 (Appendix M). The intent of the Conservation Strategy is to allow grizzly bears to occupy all biologically suitable and socially acceptable habitats. It is the goal of the agencies of the YGCC implementing this Conservation Strategy to ensure a recovered population in accordance with the established Recovery Criteria. This Conservation Strategy requires continued monitoring of the standards in the 2016 Recovery Plan Supplement to the *1993 Recovery Plan* and some additional standards. These specific population standards will be applied to the population within the DMA.

### Unique Females with Cubs-of-the-Year

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FTVM: this is a very crucial point. Maybe we are misinterpreting the process of amending the *1993 Recovery Plan* with the *2016 Supplement* but we would argue that the reference to the original *1993 Recovery Plan* not very relevant and misleading; we have not been operating under those criteria for a long time. Instead, we are technically still operating under the criteria based on the *2007 Supplement to the 1993 Recovery Plan*. So the **real change** is from the *2007 Supplement* to what is described in this document, NOT from the *1993 Recovery Plan* to this document.

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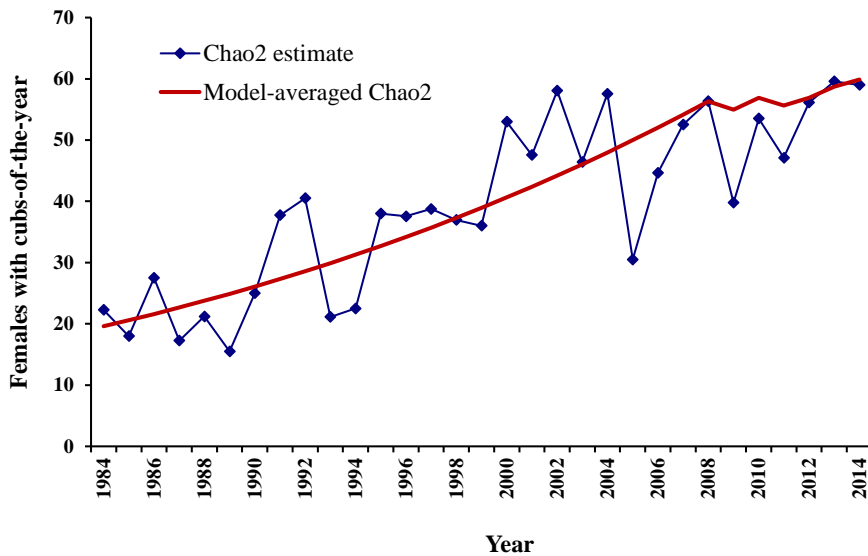
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## Background

Females with cubs-of-the-year occupy all of the existing bear management units within the PCA as well as areas outside the PCA. Not all portions of the DMA currently have observations of females with cubs-of-the-year, however, several have been observed outside the DMA in recent years (Figure 3).

Figure 3. The Chao2 estimate and model-averaged Chao2 of unique females with cubs-of-the-year inside the Demographic Monitoring Area, as per the Recovery Plan, 1984–2014. Estimates of grizzly bear population size in the Greater Yellowstone Ecosystem are based on the Chao2 estimator. Model-averaged Chao2 estimates were implemented starting in 2007. Estimates for 1984–2007 were model-averaged once, and were annually updated after 2007. Model-averaging is not retroactively applied to update entire time series each year. Starting in 2012, only observations from within the Demographic Monitoring Area (DMA) contribute to population estimates.

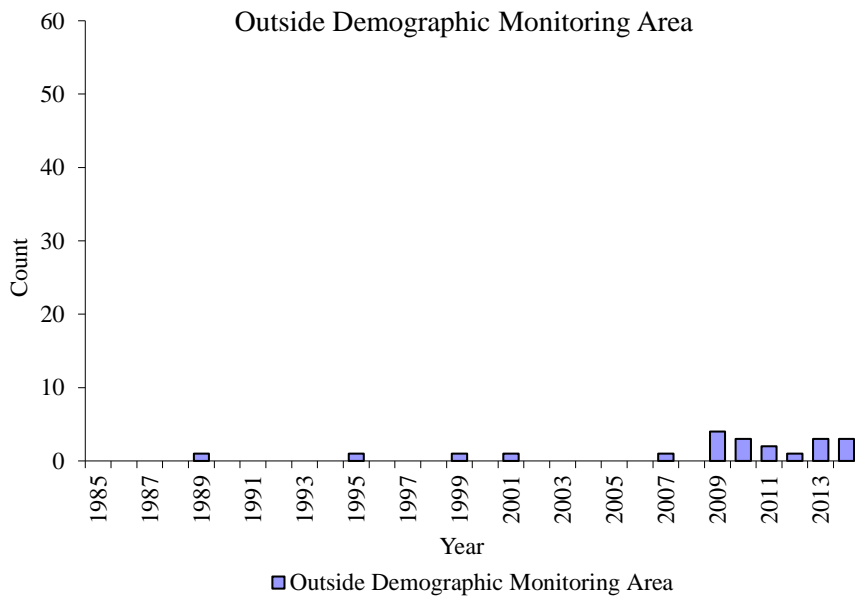


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#### Monitoring Protocol

Monitoring unique females with cubs-of-the-year will provide information to demonstrate adequate reproduction and to derive annual estimates of total population size. Total population size will be derived annually from the model-averaged Chao2 estimate of females with cubs-of-the-year within the DMA (Figure 1), as described in Appendices B, C, L, and M, using the sightings and resightings of unique females with cubs-of-the-year. The IGBST has been calculating population size on an annual basis using the model-averaged Chao2 estimate since 2007. As the grizzly bear population has increased, model-averaged Chao2 estimates have become increasingly conservative (i.e., prone to underestimation). As a conservative approach to population estimation, the model-averaged Chao2 method will continue to be the method used to assess population status and the demographic criteria (see Appendix C for the application protocol for annual population estimation using the model-averaged Chao2

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method). The IGBST will continue to investigate new methods for population estimation as appropriate. If new methods become available, these will be considered for application in the GYE as long as they represent the best available science. However, until possible new methods are developed, the model-averaged Chao2 method will continue to be used. This is a departure from the way the population estimate was done per the [2007 Supplement as amended to the 1993 Recovery Plan](#). In the [2007 Supplement](#), a [total population](#) estimate [using the model-averaged Chao2 method](#) was made based on sightings of [unique](#) females with cubs-of-the-year [within](#) the [Conservation Management Area](#). The revised and improved methodology used in this document allows an estimate of the [total population](#) using the model-averaged Chao2 method [and corresponds directly to the area monitored by the IGBST \(i.e., the DMA\)](#). This allows the calculation of mortality limits based on the total population size for each age and sex class (i.e., independent females, independent males, and dependent young) within the DMA (Figure 1). This method allows mortality management and population monitoring of the grizzly bear population in the DMA, as opposed to the method used in the [original 1993 Recovery Plan](#), which focused mortality management and population monitoring on only a portion of the Yellowstone grizzly bear population inside the PCA (the former Recovery Zone) and within 10 miles of the outer boundary of the PCA.

The numbers of sightings and resightings of [unique](#) females with cubs-of-the-year inside the DMA will be reported by the IGBST. Using these data, the IGBST will produce the model-averaged Chao2 estimate of the total number of independent females in the population inside the DMA, which will then be used to estimate the total population size in the DMA. This total population estimate will be used to apply the mortality limits as per Table 2 within the DMA for independent females ( $\geq 2$  years old) and independent males ( $\geq 2$  years old) from all causes as well as mortality limits for dependent young ( $\leq 2$  years old) from human-caused mortality. For a more detailed description of this methodology, see Appendix C.

Sightings and resightings of females with cubs-of-the-year inside the DMA will be obtained from numerous sources, including [systematic observation flights conducted annually throughout the](#)

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entire DMA, and opportunistic confirmed sightings from other aerial sources and ground observers.

Observation flights are primarily designed to survey the DMA and the number of flights conducted is standardized to ensure equal effort in obtaining data. The IGBST will verify the reliability of all sightings. The IGBST will plot all sightings and summarize data for unique females and numbers of cubs-of-the-year seen for the entire population. Methodology developed by Knight *et al.* (1995) will be used to separate duplicated from unduplicated sightings (see Appendix C for more information).

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