**A worked example of cumulative meta-analysis to identify research waste**

As an example of the approach we can look at the potential of autonomous acoustic recorders to replace human observers in wildlife sampling and monitoring, which now has a long history in the ecological literature (e.g. Ralph et al. 1998). Technological advances over the last two decades have allowed this potential to be explored fully. Well over 150 field studies have been carried out that address this issue either directly or indirectly and seek to address the question of whether acoustic recorders can replace human observers in wildlife surveys. In 2018, Darras et al. explored the pooled effect of these types of studies using a meta-analysis. They concluded that when human observers (using point counts) and sound recorders sample areas of equal size then there is no difference between estimates of bird species richness.

By using a cumulative meta-analysis we can answer the question “Do we need another study quantifying the difference between acoustic recorders and human observers for bird survey point counts?” In addition, we can show the historical point at which studies into this topic could have been stopped and research waste (in a restricted sense) could have been avoided.

We extracted the data and R code from Darras et al. (2018) to recreate their analysis. Building on their random effects meta-analysis we ran a cumulative meta-analysis using the “cumul” function in the “metafor” package (Viechtbauer 2010) in R. The cumulative meta-analysis was ordered by publication year and plotted using the “forest” function. To assess the point at which there is sufficient evidence and no further investigations are required we plotted the z-curve in relation to the cumulative sample size. The thresholds for significance was a z value of 1.96 or -1.96. When the z curve crosses this threshold then the level of evidence is considered sufficient. This approach (known as “trial sequential analysis”) is well developed in medicine (Wetterslev et al. 2008). Plots were produced using ggplot2 in R (Wickham 2016).

The effect size of studies investigating the difference between autonomous acoustic recorders and human observers in terms of bird species richness estimates was consistently close to 0 in each study (Figure 1). Trial sequential analysis shows that an evidence threshold was reached in 2015. This suggests that studies undertaken post 2015 were a waste of research resources.

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