Statistical Sampling for Munitions Response Projects – A Layman's Refresher and Food for Thought

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We will spend the next 45 minutes deconstructing this equation…

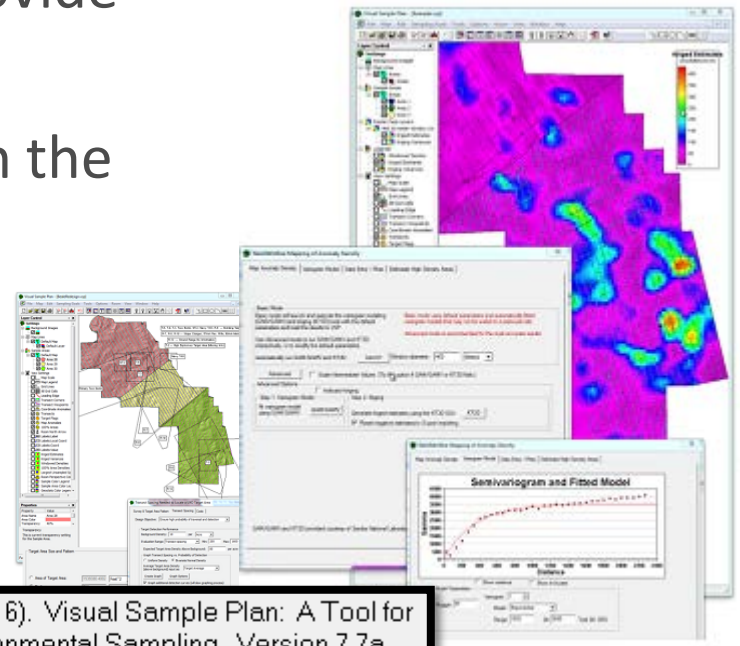
$$f(x) = \frac{n!}{x!(n-x)!} p^x (1-p)^{(n-x)}$$

Objective

- Talk about statistics for 30 minutes without losing you to nap/lunch/cat videos.

A few points to start…

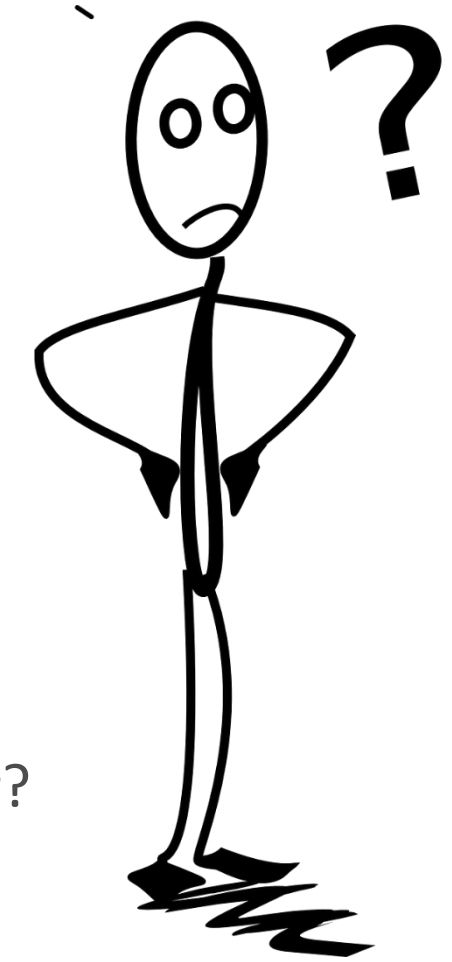
- The U.S. Navy and the U.S. Army Corps of Engineers (UASCE) perform the most MR work
- There is no “manual” to reference for a single “accepted” approach for munitions response investigations; USACE does however provide guidance (EM200-1-15)
- The Interstate Technology & Regulatory Council (ITRC) has taken the lead in terms of technical guidance for regulators, but statistical sampling has not been tackled
- In recent years statistical approaches are more common
- Visual Sample Plan (VSP) (PNNL) is the industry standard for statistical sampling approach planning for MR



VSP Development Team (2016). Visual Sample Plan: A Tool for Design and Analysis of Environmental Sampling. Version 7.7a. Pacific Northwest National Laboratory. Richland, WA. http://vsp.pnnl.gov.

Without Statistics…

- Have you sampled enough?
  - 3% sampling gives you 3% confidence in what is present
  - 5% sampling gives you 5% confidence in what is present
  - 8% sampling gives you 8% confidence in what is present
  - 10% sampling gives you 10% confidence in what is present
  - …
- How confident are you that you found what you are looking for?
  - “Really” confident?
  - “Pretty” confident?



Statistics

- Pros
  - Defensible
  - Transparent
  - Consistent
  - Less sampling than “expected” in some circumstances
- Cons
  - Dependent on parameter inputs
  - More sampling than “expected” in some circumstances
  - Sometimes the answer is not satisfying to the general public (ex: 95% confidence that there are no more than 1 UXO per acre)

X% Sampling

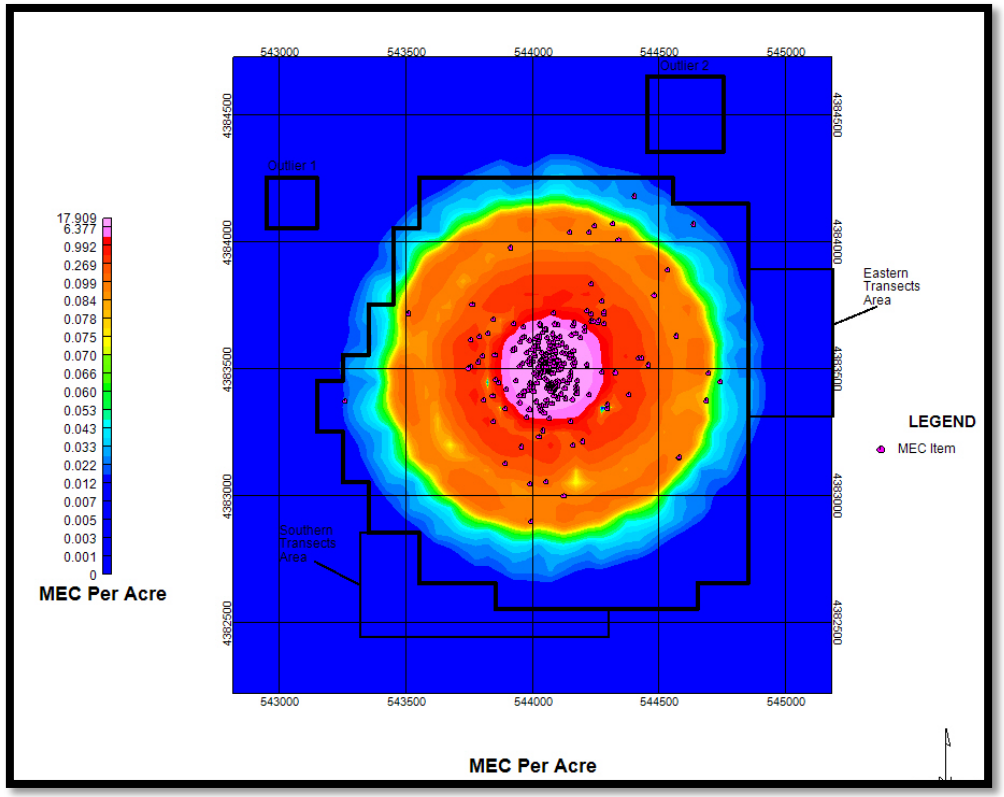
Is there anything wrong with this approach?

Sometimes it will be “overkill”

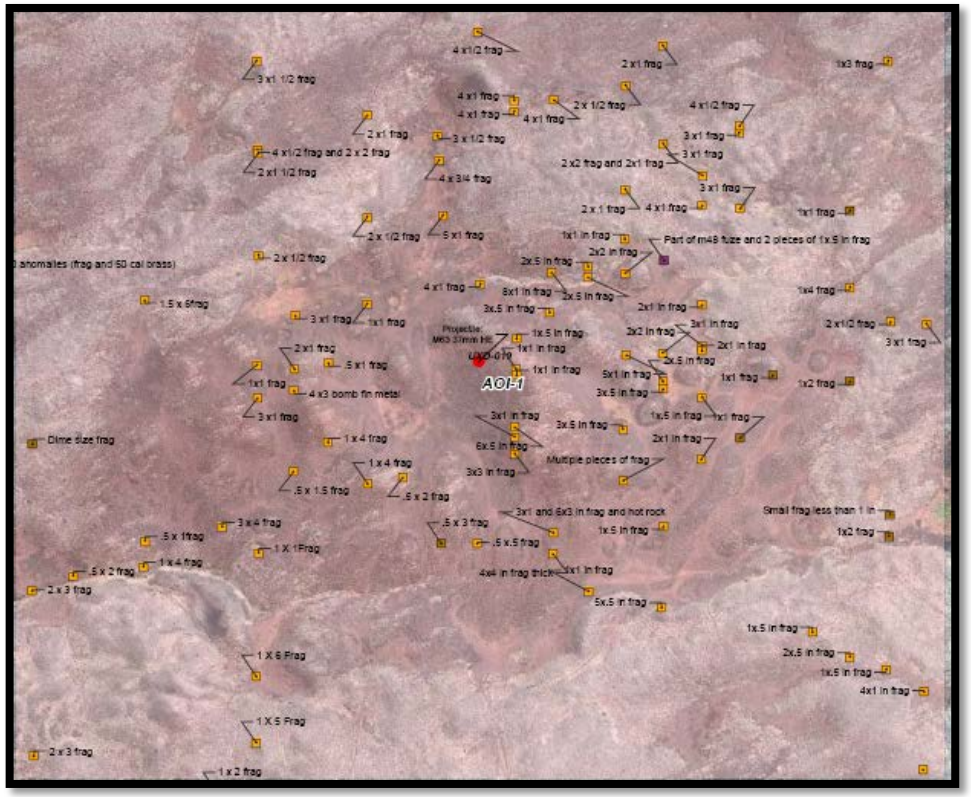
Sometimes it won’t be enough to “answer the question”

Types of sites (using USACE vernacular)

- Concentrated Munitions Use Area (CMUA)
  - EXAMPLE: Target areas



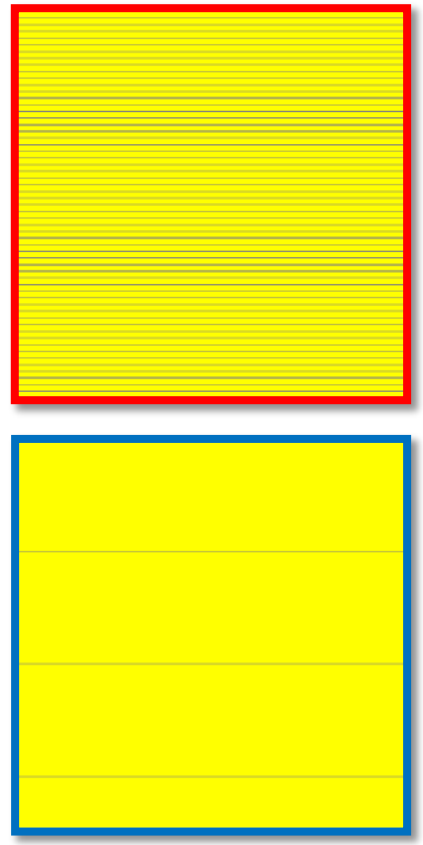
- Non-Concentrated Munitions Use Area (NCMUA)
  - EXAMPLE: Troop maneuver areas



Hypothetical Scenario 1 (Where 10% Oversamples)

- 100 acre site
- 105mm projectile range
- 100,000 metallic items in subsurface across site

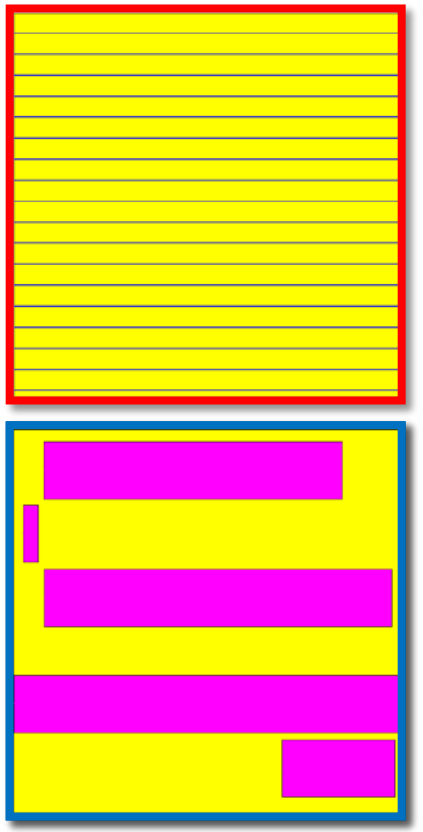
Approach	Transects Length (km)	Intrusive Investigation	Relative Cost to Achieve Objective
10% Sampling • 1 transect every 10m • Investigate all anomalies on transects	40 km	10000	$$$$$$$$$$
Statistical Approach 1 • 95% confidence in locating target area • Investigate all anomalies on transects	2.2 km	540	$$
Statistical Approach 2 (multi-stage sampling) • 95% confidence in locating target area • Investigate statistical subset of anomalies to achieve 95%	2.2 km	225	$



Hypothetical Scenario 2 (Where 10% Undersamples)

- 10 acre site
- Maneuver Area
- 1000 metallic items in subsurface across site

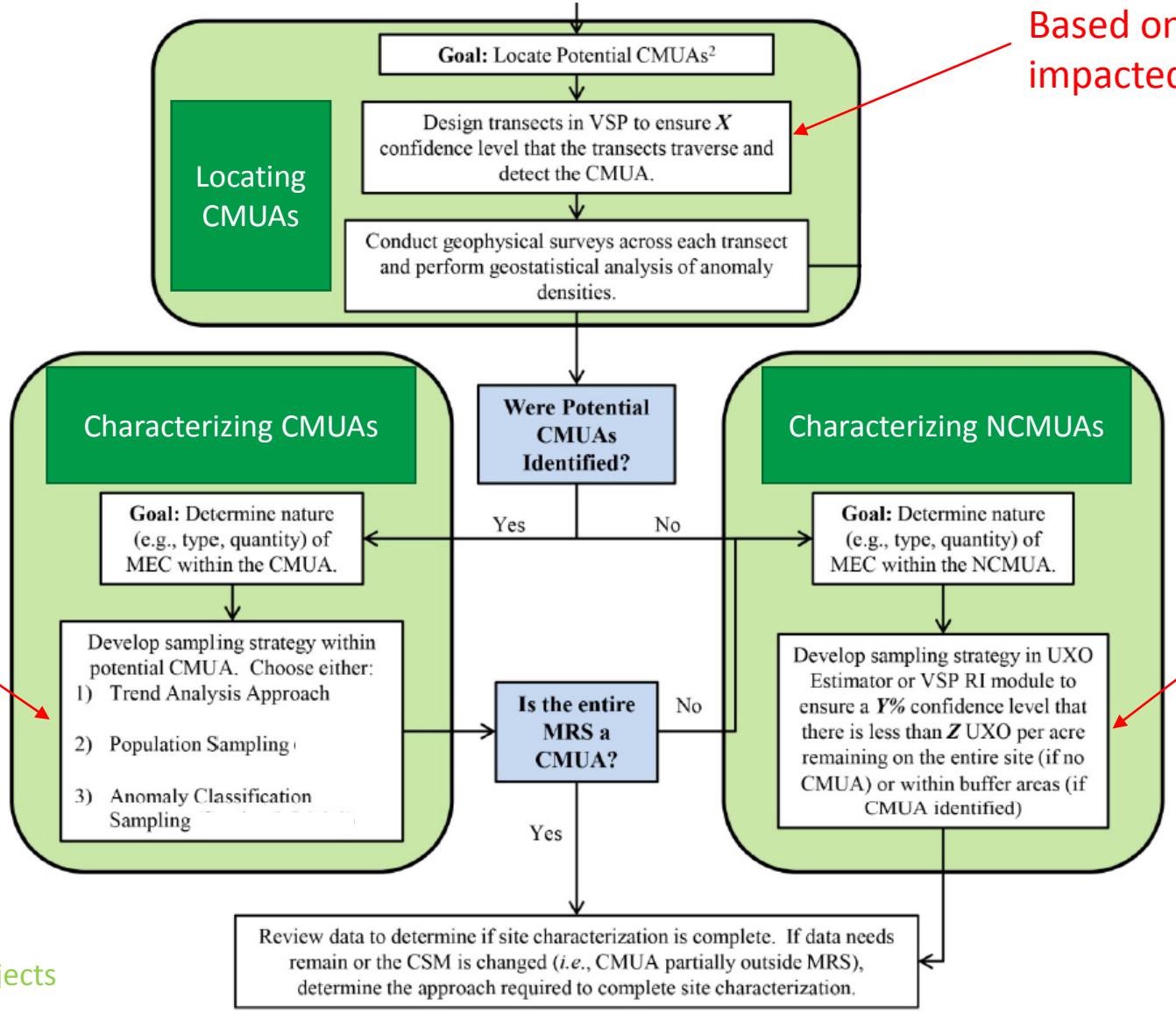
Approach	Transects Length (km)	Intrusive Investigation	Relative Cost to Achieve Objective
10% Sampling			
• 1 transect every 10m			
• Investigate all anomalies on transects	4 km	100	$
Statistical Approach 1			
• 95% confidence in determining <1 MEC item per 2 acres	16.3 km (or 4.5 acres of grids)		
• Investigate all anomalies		405	$$$$



Ultimately, Who Decides?

- Project/Program Delivery Team
- Inputs?
  - Comfort level of team
  - Public Involvement
  - Future land use
  - Need for defensibility/transparency of approach

Example USACE Statistics-Based Approach* to Remedial Investigation



Based on size of expected impacted area

What and how much is out there?

What and how much is out there?

*"Example" approach – not all projects fit this bill

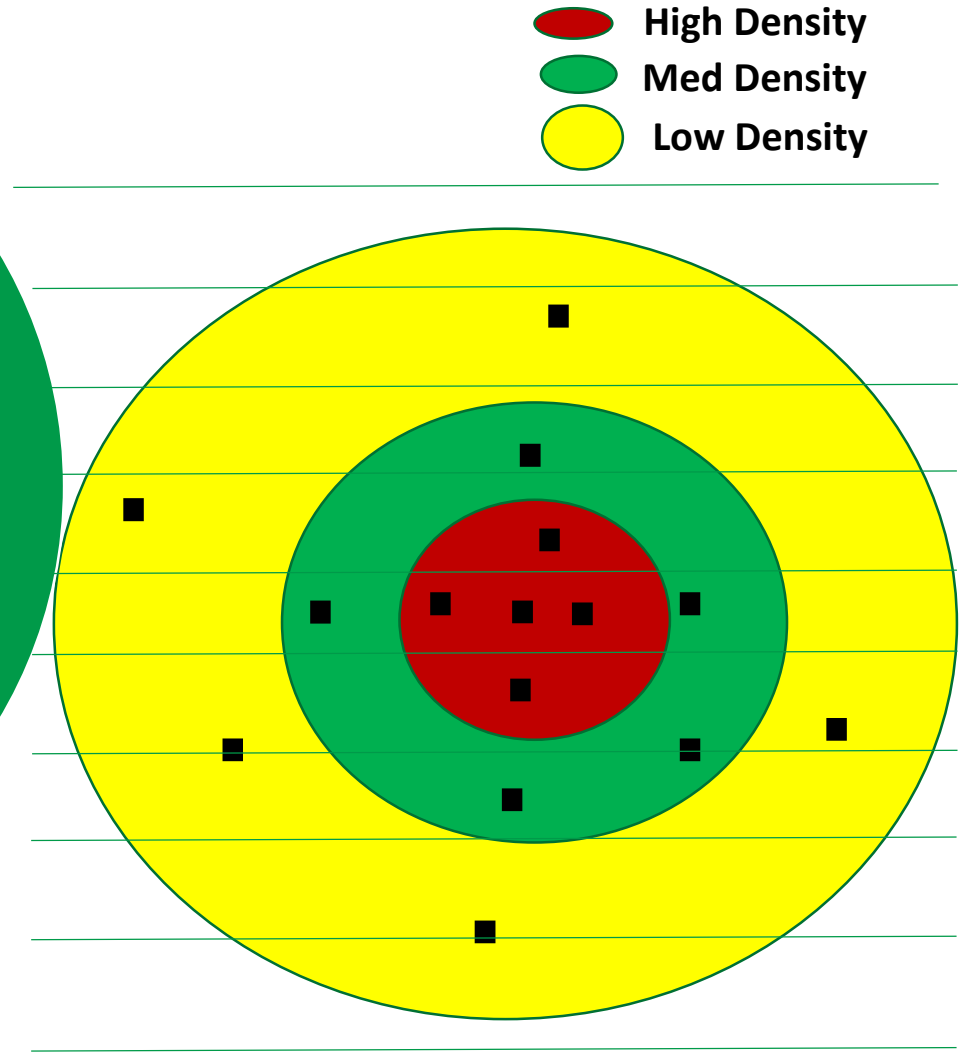
Remedial Investigation Sampling Approaches – Concentrated Munitions Use Area (CMUA)

- Transects for delineation of densities followed by grids
- Transects with investigation of all anomalies detected
- Transects with investigation of statistically derived sampling of anomalies along transects

Remedial Investigation Sampling Approaches – Concentrated Munitions Use Area (CMUA)

Transects for delineation of densities followed by grids

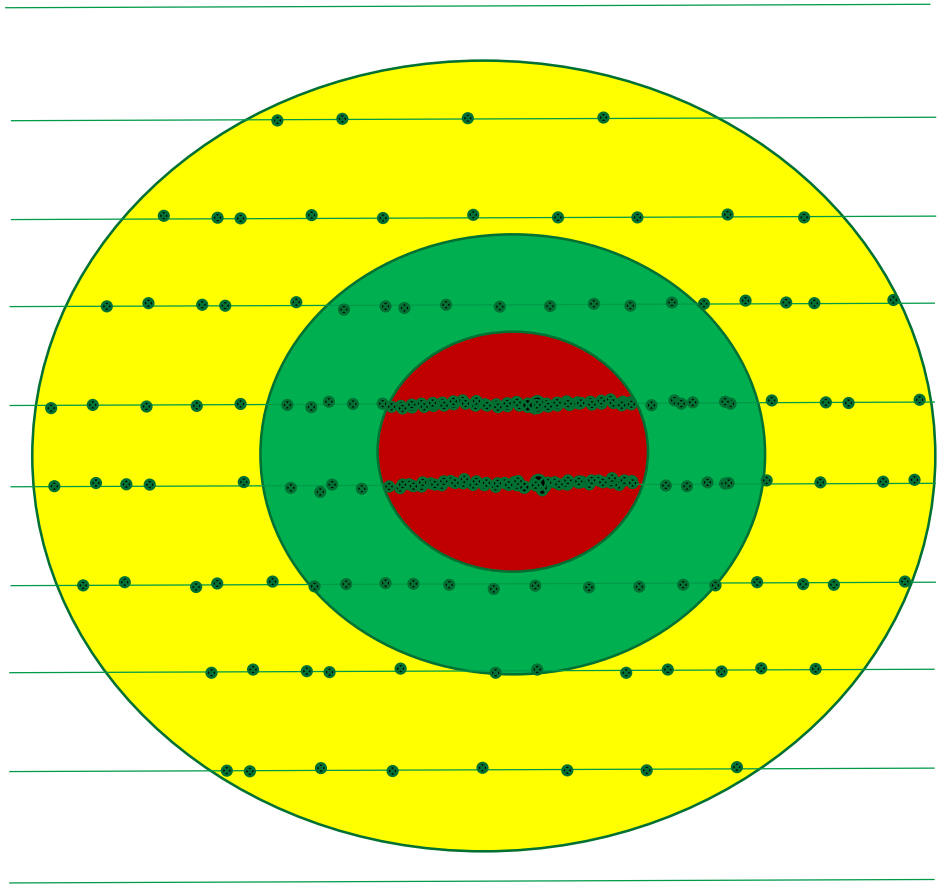
- Geostatistical analysis identifies density "zones"
- Determination of quantity and location of biased grids
  - Statistically significant?
  - Statistics not relevant at this point?
  - Statistical confidence in nature and vertical extent?
- Intrusive
  - Bogging down in HD area
  - When do we know enough?
  - Predictable in advance? (cost management)



Remedial Investigation Sampling Approaches – Concentrated Munitions Use Area (CMUA)

Transects with investigation of all anomalies detected

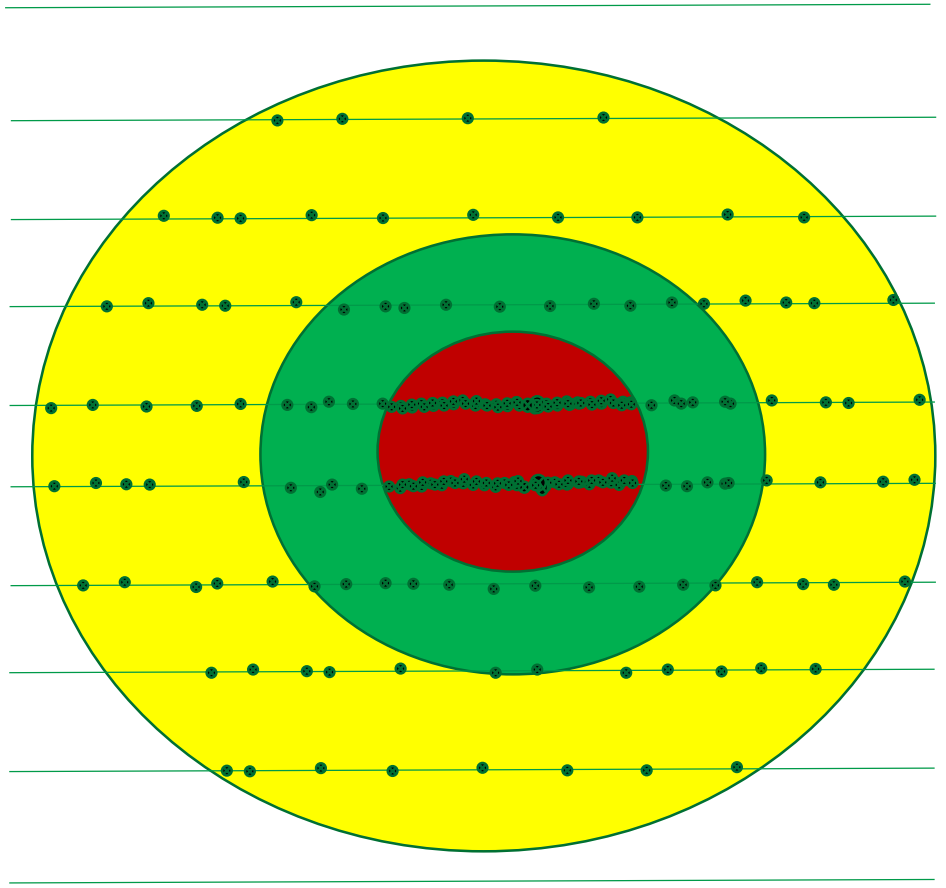
- Detection footprint
- Bogging down in HD area
  - When do we know enough?
  - Statistical limit?
  - Predictable in advance? (cost management)



Remedial Investigation Sampling Approaches – Concentrated Munitions Use Area (CMUA)

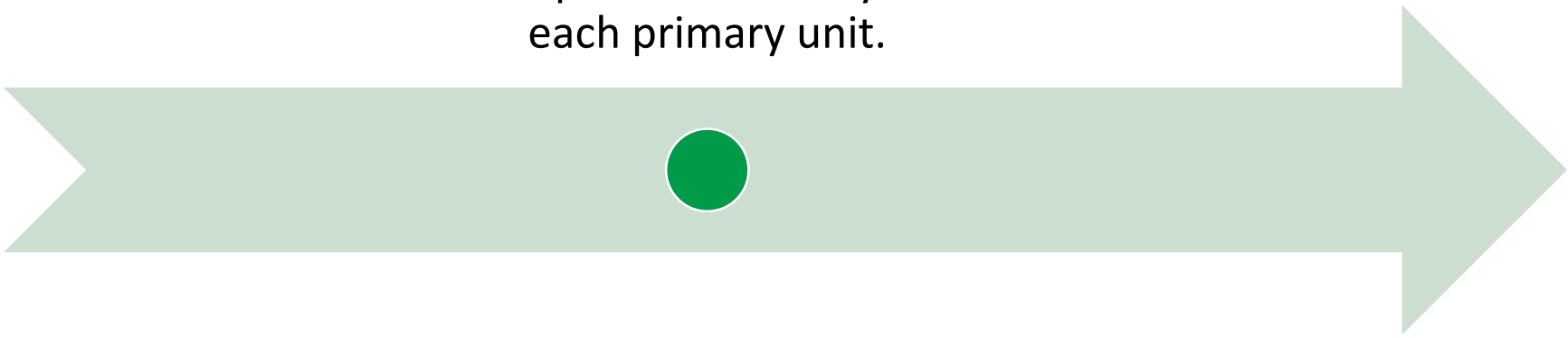
Transects with investigation of statistically derived sampling of anomalies along transects

- Sampling a sample?
- Correlation with site as a whole?

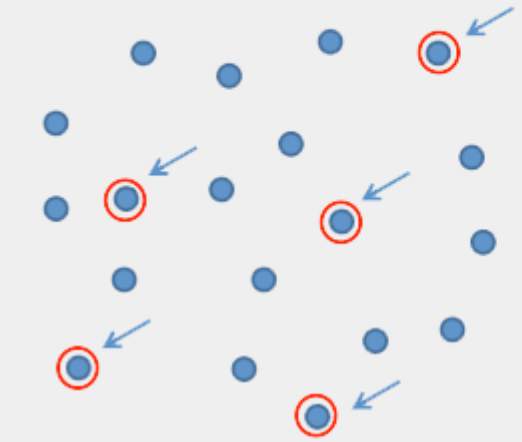


Multi-stage sampling

Multistage sampling refers to sampling plans where the sampling is carried out in stages using smaller and smaller sampling units at each stage. In a two-stage sampling design, a sample of primary units is selected and then a sample of secondary units is selected within each primary unit.



Simple Random Sampling

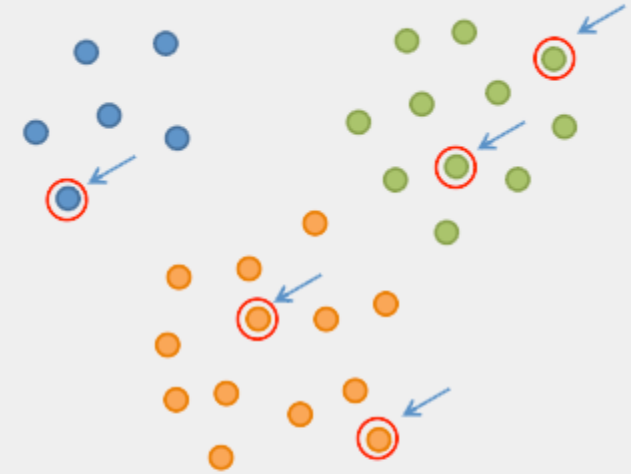


- Homogenous population
- Units distributed over small geographical area

The first is **Simple Random Sampling**, in which a random sample is taken from a relatively homogeneous population. This kind of sampling works when the population of units from which the sample will be taken are homogenous, of limited size or concentrated in a small geographical area, or when they are easily accessible. For example, if one type of clean cookstove is distributed to one target group, such as households which were all previously using a three-stone fire, located within the same geographical area simple random sampling might be most appropriate.

http://carbonfinanceforcookstoves.org/implementation/certification-process/monitoring-and-evaluation/

Stratified Random Sampling



- Sub-populations vary, but are similar within groups
- Sampling occurs within groups

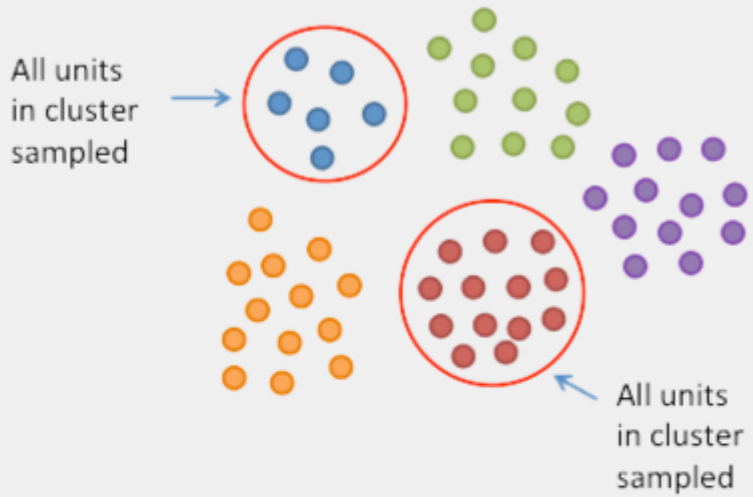
The second method is **Stratified Random Sampling**, which is applied when a population to be sampled consists of several sub-populations which vary, and are more similar within groups than across groups. It involves selecting strata or homogeneous subpopulations and sampling within these. In a cookstove the different types of groups might be, for example, different types of users such as households and institutions (e.g. hospitals, schools).

Systematic Sampling

Sample every n^{th} unit

The third method is **Systematic Sampling**, which is most commonly applied to determine quality assurance within the output of a product. An example is a production line where you can test every tenth product. This could include assessing the n^{th}unit to determine the quality of bricks in a manufacturing process or the efficiency of cookstoves from the factory. When designing a sampling plan under this approach, it is important to ensure that the population to be sampled is ordered randomly.

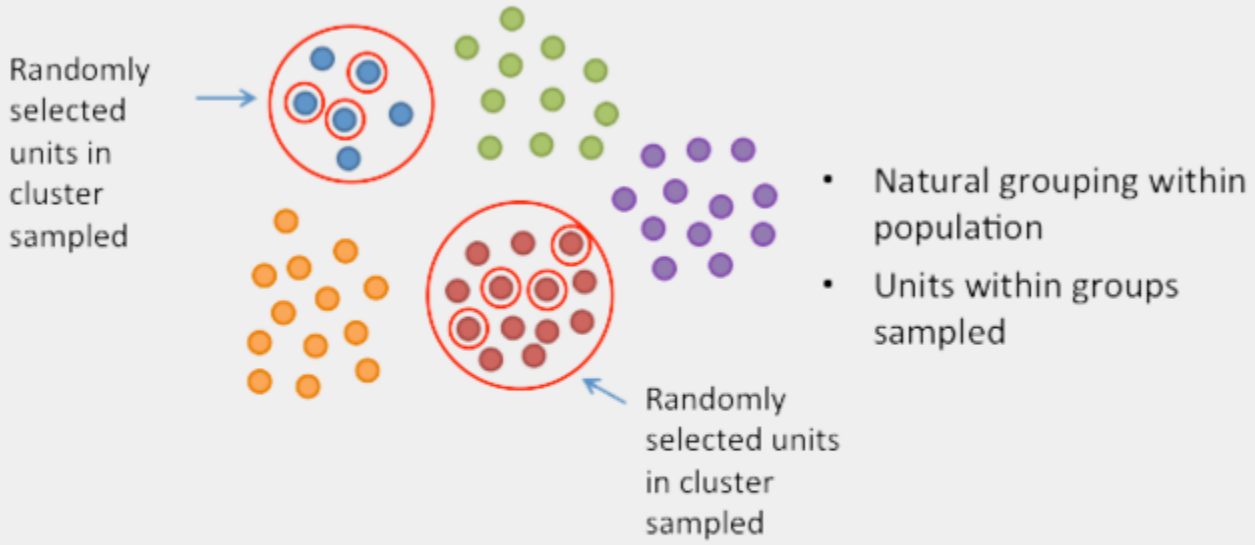
Cluster Sampling



- Natural grouping within population
- Whole groups sampled

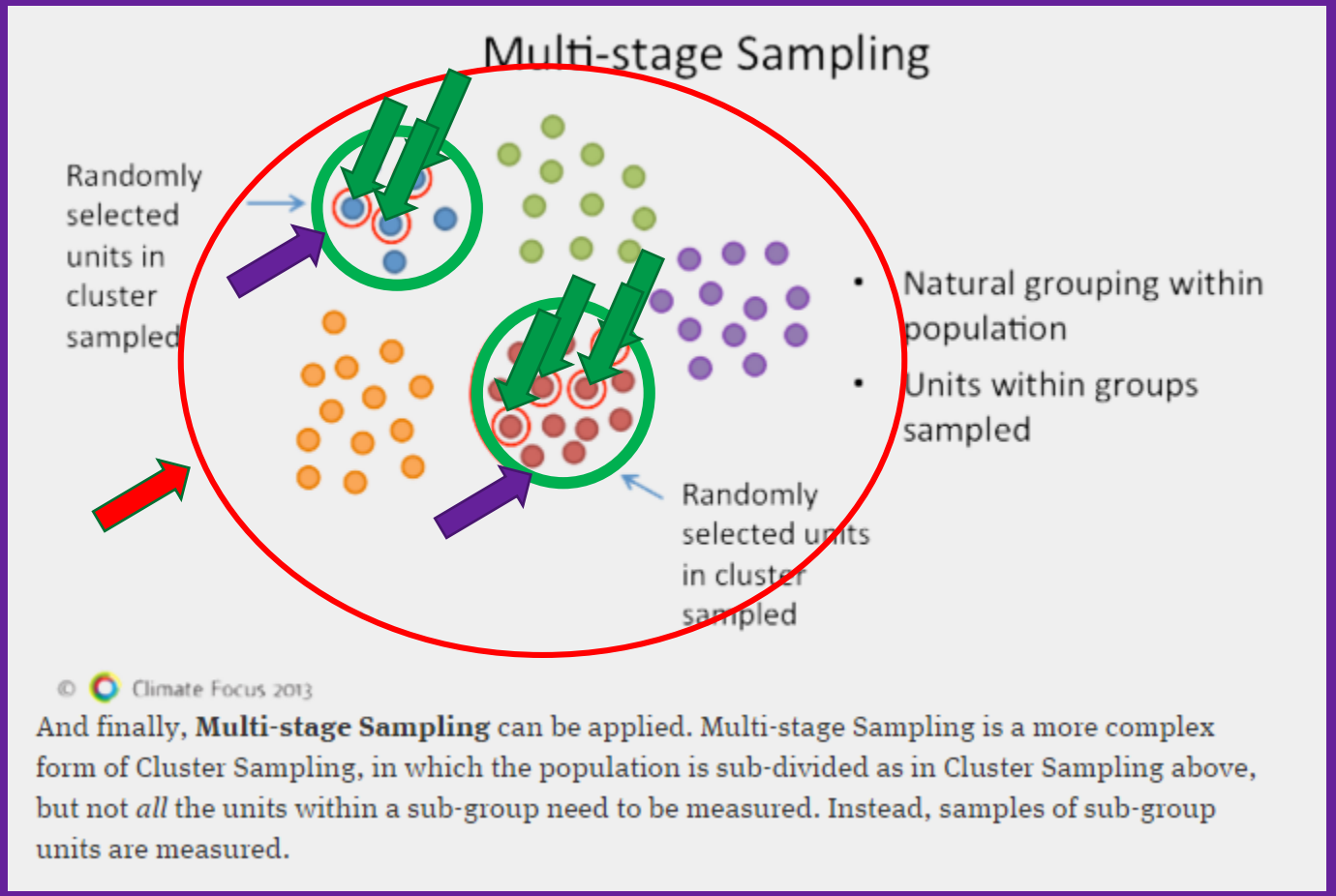
The fourth method is **Cluster Sampling**, which applies when there are natural groupings within the population. In contrast with Stratified Random Sampling, sampling here occurs at group level rather than on the individual units: the population is divided into subgroups, which are then randomly selected. All units within each sub-group are sampled. A clear example of a population in which Cluster Sampling works well is a population that is geographically dispersed.

Multi-stage Sampling



- Natural grouping within population
- Units within groups sampled

And finally, **Multi-stage Sampling** can be applied. Multi-stage Sampling is a more complex form of Cluster Sampling, in which the population is sub-divided as in Cluster Sampling above, but not *all* the units within a sub-group need to be measured. Instead, samples of sub-group units are measured.



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CMUA Equivalent?…

Clusters = every possible transect at the site

Randomly Selected clusters = systematic-random transects (i.e. one transect every 100m)

Circles = Anomalies (simple random sampling or systematic sampled)

Multi-stage sampling

CMUA

Transects
(systematic-random sampling)

- **Example**
  - In Iyoke et al. (2006) Researchers used a multi-stage sampling design to survey teachers in Enugu, Nigeria, in order to examine whether socio-demographic characteristics determine teachers' attitudes towards adolescent sexuality education. First-stage sampling included a simple random sample to select 20 secondary schools in the region. The second stage of sampling selected 13 teachers from each of these schools, who were then administered questionnaires.

Anomalies
(systematic-random or simple random sampling)

Think carefully about how to implement the multi-stage approach. As there is no strict definition to multi-stage sampling, there is no formulaic way as to how to combine the various sampling options (such as clustering, stratified, and simple random). The multi-stage sampling procedure should be constructed in such a way to be cost and time effective while retaining both the randomness and sufficient size of the sample.

Iyoke, C.a et al. (2006) "Teachers' Attitude is Not an Impediment to Adolescent Sexuality Education in Enugu, Nigeria." *African Journal of Reproductive Health/La Revue Africaine de la Santé Reproductive* 10 (1): 81-90

95% confidence in presence/absence of MEC from results…can’t state with certainty

- Are people mis-communicating this?
- If munitions related items (i.e. frag) found across site, but no ‘MEC’, does this mean there is no MEC (given the actual low percentage of actual MEC at most sites)
- If can’t do this, how can we say anything about probability of actual MEC being at site?

Still Awake?

Thank You!

Multi-stage sampling

- Multi-stage sampling represents a more complicated form of cluster sampling in which larger clusters are further subdivided into smaller, more targeted groupings for the purposes of surveying. Despite its name, multi-stage sampling can in fact be easier to implement and can create a more representative sample of the population than a single sampling technique. Particularly in cases where a general sampling frame requires preliminary construction, multi-stage sampling can help reduce costs of large-scale survey research and limit the aspects of a population which needs to be included within the frame for sampling.
- In traditional cluster sampling, a total population of interest is first divided into 'clusters' (for example, a total population into geographic regions, household income levels, etc), and from each cluster individual subjects are selected by random sampling. This approach however, may be considered overly-expensive or time consuming for the investigator. Using multi-stage sampling, investigators can instead divide these first-stage clusters further into second-stage cluster using a second element (for example, first 'clustering' a total population by geographic region, and next dividing each regional cluster into second-stage clusters by neighborhood). Multi-stage sampling begins first with the construction of the clusters. Next, the investigator identifies which elements to sample from within the clusters, and so on until they are ready to survey.

http://betterevaluation.org/evaluation-options/multistage

traditional cluster sampling	multi-stage sampling
Cluster (geographic regions) = CMUA?	1st Stage Cluster (geographic regions) = CMUA?
individual subjects = transects?	2nd Stage Cluster (neighborhood) = transects?
	elements to sample from within the clusters = anomalies?

Multi-stage sampling

- In some cases, several levels of cluster selection may be applied before the final sample elements are reached. For example, household surveys conducted by the Australian Bureau of Statistics begin by dividing metropolitan regions into 'collection districts', and selecting some of these collection districts (first stage). The selected collection districts are then divided into blocks, and blocks are chosen from within each selected collection district (second stage). Next, dwellings are listed within each selected block, and some of these dwellings are selected (third stage). This method means that it is not necessary to create a list of every dwelling in the region, only for selected blocks. In remote areas, an additional stage of clustering is used, in order to reduce travel requirements.[1]
- Although cluster sampling and stratified sampling bear some superficial similarities, they are substantially different. In stratified sampling, a random sample is drawn from all the strata, where in cluster sampling only the selected clusters are studied, either in single- or multi-stage.