LIFE CROLIS

Assessing uncertainty in spatial data analysis

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Uncertainty in spatial data analysis

What is uncertainty?

- **Precision** is the repeatability of an outcome (values of an estimator over different samples);
- In the CROLIS historic LULUCF model:
    - **Estimator** is the unknown area of a certain LC change (within a certain time period);
    - **Outcome** for a given sample is the estimated area of a certain LC change;

- Precision - *closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions* (JCGM, 2012);
- Our analysis does not include *replicate measurements* - instead we use Monte Carlo sampling methods - choosing random subsets of our one sample.

- **Uncertainty** is the opposite of precision - low precision (low repeatability) means high uncertainty of the estimates.

Uncertainty in spatial data analysis

Uncertainty of sample-based estimates

- Characterized by the variance (dispersion) of the estimates - high variance corresponds to low precision and high uncertainty;
- **Variance** - measure of uncertainty/precision - calculated as the mean (over all possible samples) of the squared differences between the estimate for a sample and the population parameter - here the population parameter is the true area of a certain LC change;

- **Exact variance cannot be observed!** But it can be estimated from the <u>one</u> sample obtained.
- Say we have 100 different samples:
  - each sample produces an estimate of the considered population parameter;
  - all samples combined produce a mean estimate of the same population parameter;
- **Sample variance** = calculated as the mean (over all 100 samples) of the squared differences between the estimate for a sample and the mean estimate.

Standard error - the square root of the variance of an estimator;

- The standard error characterizes variability on the <u>same scale</u> as the estimate;
- If we are estimating LC change area in hectares, the standard error is also in hectares, whereas the variance has units of hectares^2.

Uncertainty in spatial data analysis

Confidence intervals

- Estimates are usually reported together with corresponding 95% (99%) confidence intervals;
- **Confidence intervals** = estimates of lower and upper bounds (confidence limits) for a parameter, forming a range in which plausible values of that parameter lie;
  - The percentage (95%, 99%) indicates the level of plausability.
- Unlike (simple) estimates, intervals take into account variability due to sampling - important since an estimate produced from a sample is unlikely to match the population parameter.
- Assuming normal distribution of parameter estimates from different sample realizations (this has to be checked!), the 95% confidence interval is usually computed as

Point estimate ± 1.96 x standard error.

Uncertainty in LC maps

Map accuracy assessment

Uncertainty in land-cover products is fundamentally about map errors (accuracy).

Why does map accuracy matter for uncertainty assessment?

- **Determining whether the map can be trusted at all** - LC maps contain errors, and those errors must be assessed against an independent reference sample; otherwise the map is just a prototype or untested hypothesis.

- W**hat kind of uncertainty is present** - Overall accuracy gives one summary number, class-specific metrics are more informative than a single uncertainty score - different classes can have very different reliability.

- Q**uantifying uncertainty statistically** - using random sub-samples we can report **standard errors and confidence intervals** for accuracy and area estimates.
    - Not only a single estimate, but a reliable measure of how uncertain that estimate is.
    - **Without a rigorous accuracy assessment based on independent reference data, uncertainty remains poorly defined and area estimates derived from the map may be misleading.**

Uncertainty in LC maps

Map accuracy assessment

Confusion matrix and overall accuracy

- **Confusion matrix (error matrix):** a cross-tabulation comparing **map labels** (predicted classes) with **reference labels** (actual classes) for a sample of map units.
    - **Main diagonal:** correctly classified cases.
    - **Off-diagonal entries:** misclassifications, showing where classes are confused.
    - The confusion matrix is the basic tool from which standard map accuracy measures are derived.

- **Overall accuracy:** the proportion or percentage of total area classified correctly.
    - It is obtained by summing the diagonal elements of the confusion matrix when these are expressed as **area proportions**.
    - Overall accuracy is a **single summary measure** for the full set of land-cover classes.
    - It can be computed for an entire map or for subregions, such as countries, biomes, or other domains.

Uncertainty in LC maps

Map accuracy assessment

Class-specific accuracy metrics

- **Class-specific accuracy metrics** describe performance for an individual land-cover class.

- **Omission error:** a case truly belonging to class X is mapped as another class; the class has been wrongly **left out**.
- **Producer's accuracy:** how well the map captures a real class on the ground.
  - Producer's accuracy = **100% – omission error**
  - In binary classification, this is also called **sensitivity** or **recall** for the target class.

- **Commission error:** a case is wrongly **included** in a mapped class.
- **User's accuracy:** how often a mapped class is actually correct on the ground.
  - User's accuracy = **100% – commission error**
  - In binary classification, this is also called **precision**.

- **F1 score:** the harmonic mean of **user's accuracy** and **producer's accuracy** - a balanced score (measure).

Back to CROLIS historic LULUCF model

Weight selection in CROLIS historic LULUCF model:

- Weight selection can be informed by uncertainty/precision;
  - Choosing weight between two extreme weight models which produce least uncertainty.
  - Question: Overall uncertainty, uncertainty per LC change class, ...

- **Model uncertainty** = refers to the repeatability of results between different model runs;
  - Here different model runs mean using different subsets of the training dataset (our sample).

- Produce 95% confidence intervals for LC change areas (for each class).

LIFE CROLIS

Committee on Earth Observation Satellites

Working Group on Calibration and Validation

Land Product Validation Subgroup

Land Cover Focus Area

Land Cover and Change Map Accuracy Assessment and Area Estimation Good Practices Protocol

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