Crop area estimates in the EU.
The use of area frame surveys and remote sensing

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Main approaches to agricultural statistics

Expert subjective estimations

- Local experts fill forms

Farm Census

List frame surveys

- Sample of farms from a census or partial census

Area frame sampling

- Observations on the ground (points, segments….)
- With Remote Sensing as auxiliary information
  - Stratification
  - Post-survey (Regression, Calibration, small area estimates, etc.

List Frame surveys

- Units: households, farms
- Practical: in one interview a lot of information can be obtained.
  - Area
  - Yield
  - Livestock
  - Agricultural practices (fertilisers, pesticides, mechanisation..)
  - Etc…

List Frame surveys

Some possible sources of bias

- The sampling frame does not match the population
  - – Incompleteness of the frame
  - – Some households in the list frame do not exist anymore or are duplicated (this source if bias can be quantified during the survey).
- Bias in the replies provided by farmers.

Area Frame surveys

Mainly to estimate crop area and yield.

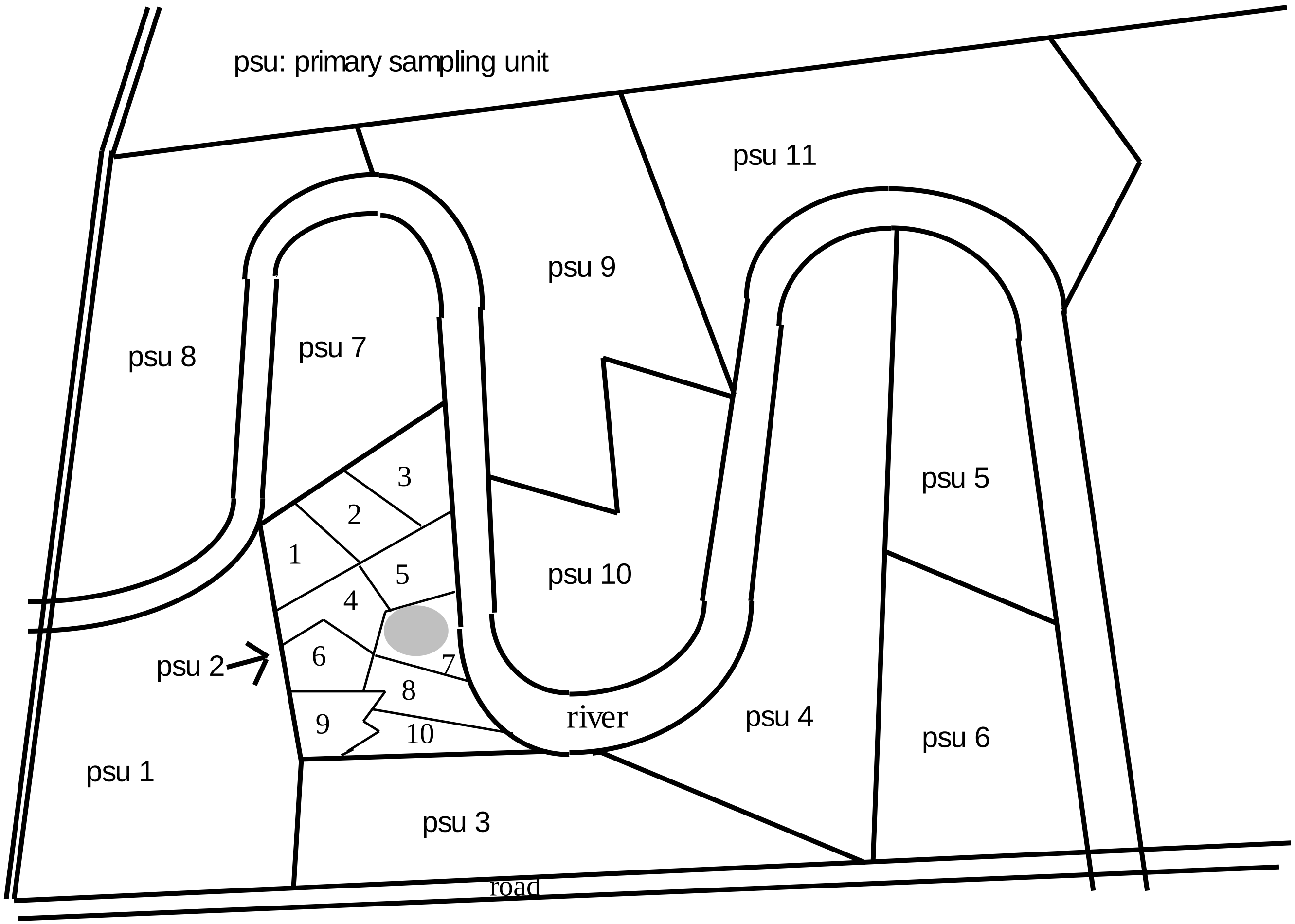
- The sampling frame matches very well the population
- They also have some sources of bias, but they are generally smaller and easier to trace:
  - Wrong location of the enumerators on the ground. It can introduce a bias if it is not independent of the land cover/use.
  - Wrong identification because the crops are rare or because the date of the field visit is inadequate.
  - The identification of the crop is not enough to determine the use (cereals for grain or for fodder)
- The availability of cheap and accurate GPS has improved very much the feasibility of area frames, in particular when the sampling units are points.

Area Frame surveys

- Area segments:
  - Physical boundaries
  - Regular shape (e.g. square)
- Points
  - Clustered
  - unclustered
- Stratification or not?
- Systematic or random sample?

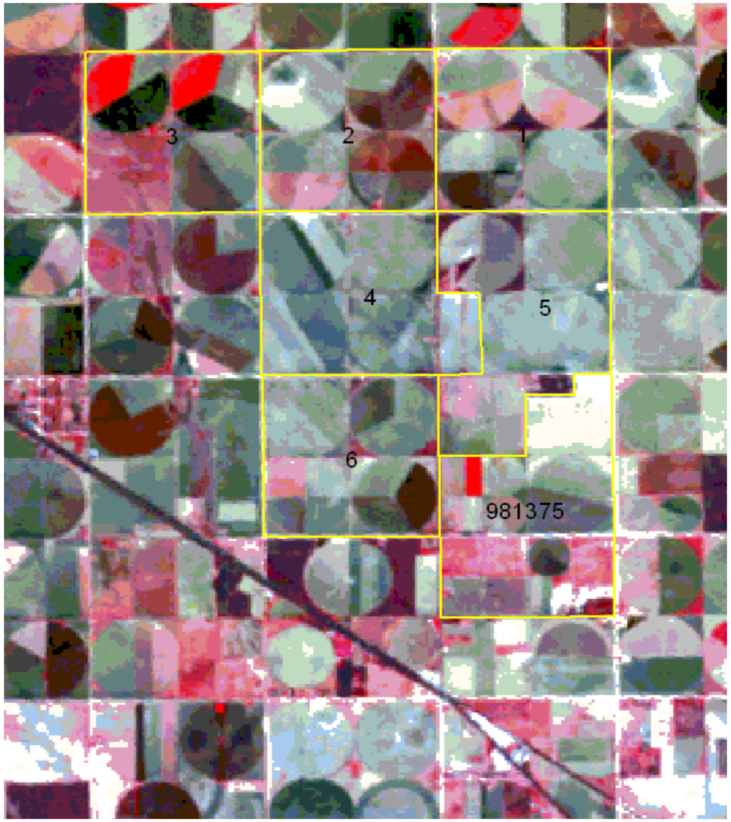
Etc……

Sampling segments with physical boundaries



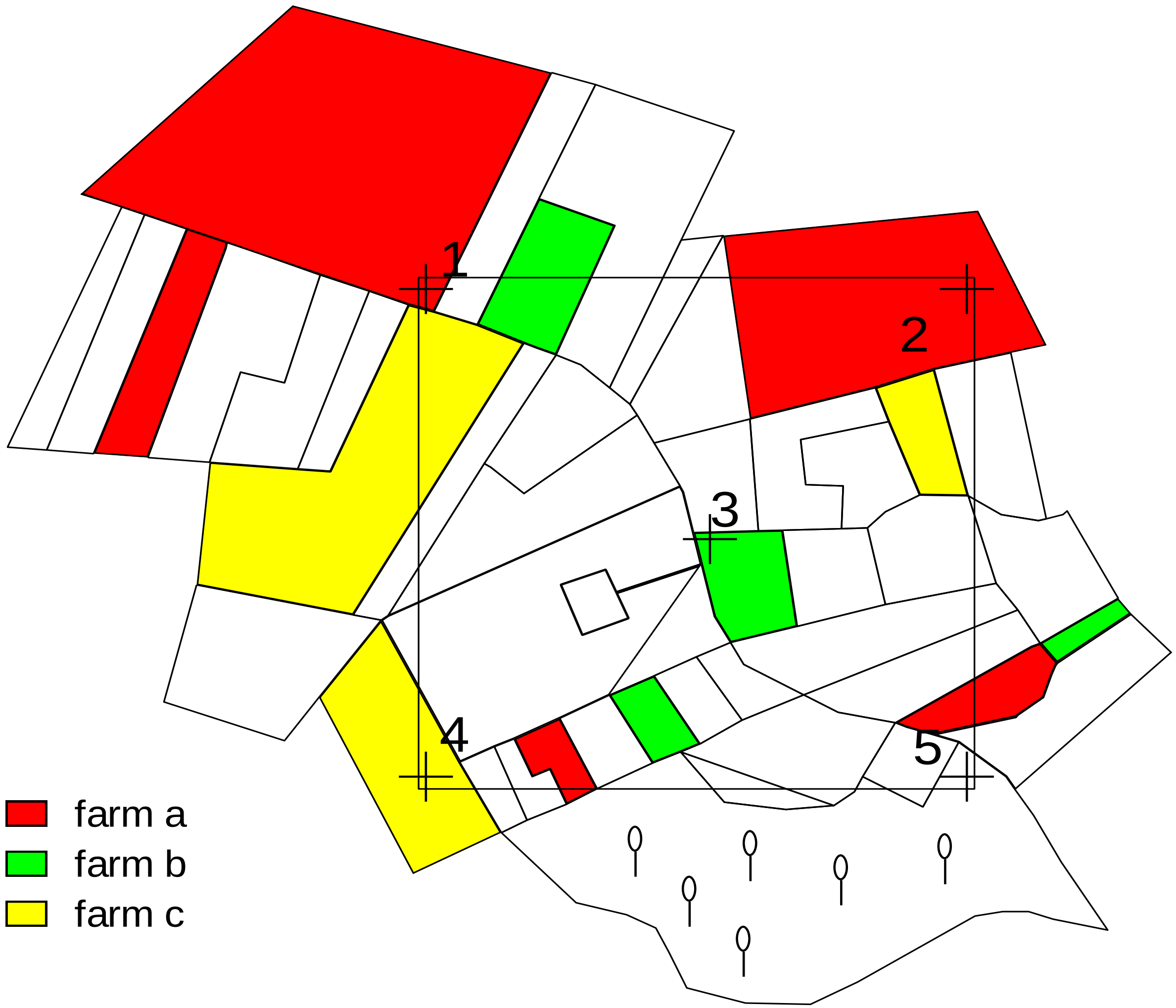
Heavy operation in complex landscapes

Segments with physical boundaries



Agricultural landscape in the US

Square segment and farm sampling by points



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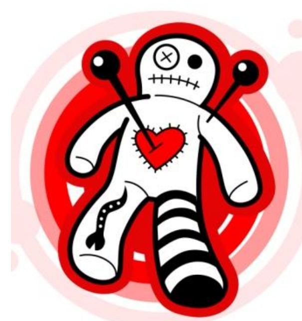
Remote sensing and Crop area estimation:

- An old love story
  (1972- ?????)

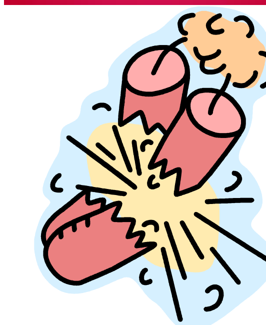
- Or better several possible love stories



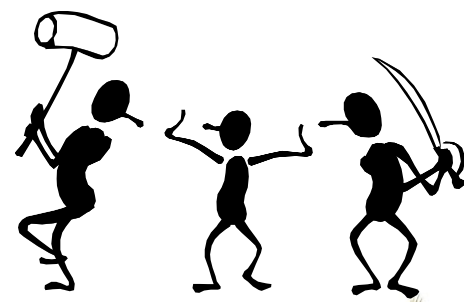
- Sometimes a love-hate story

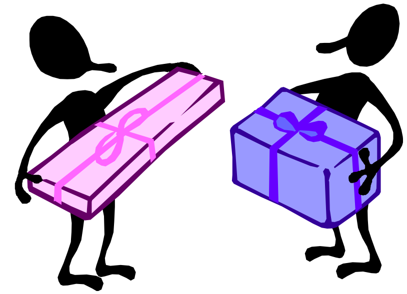
Remote sensing and crop area estimation:

- One possible story:
- **I will stand at your side every day of my life and will provide everything you need. Do not worry. I am here.**
- = I will provide accurate estimates of crop area and yield and you will not need to go to the field to collect data (or very little).

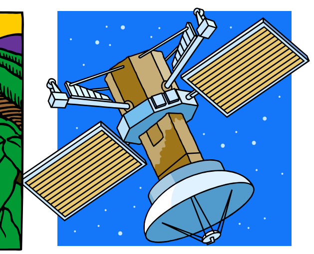


- But such intense love often finishes in a violent divorce.
- At some point the customer realises that objective estimates require an intensive ground survey.





- Another possible story:
- Let’s be friends. Bring your know-how, I will bring mine.
- = *Ground observations give more reliable data on a sample; remote sensing give a general view on a larger area*.
- Less romantic, but more practical
  - – Example: USDA
    - Segment survey + classified images
  - – Long-lasting, happy relationship

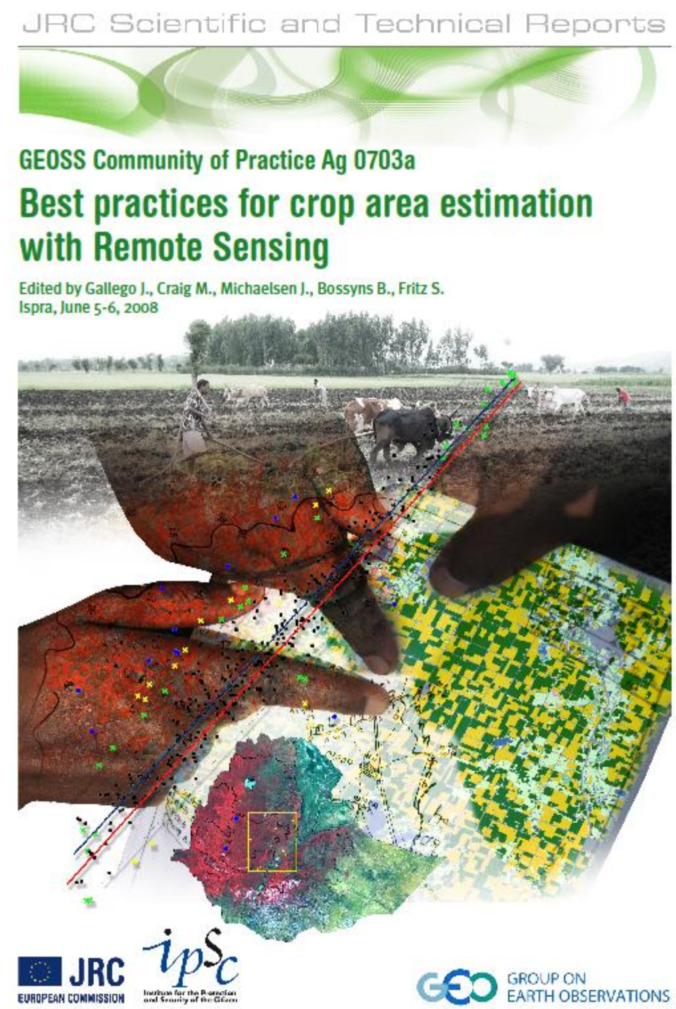


The GEOSS Best practices report

Target: Drafting an easy-to-read recommendations document for users.

Workshop held in Ispra June 2008.

- How often does it need to be updated?
  - When the typical classification accuracy has strong changes.
  - Example: in the EU: accuracy ~ 70-80% for main crops with medium-high resolution images.
    - When it changes to 90-95 %, the recommendations will need to be updated.



GEOSS Best practices report

Some approaches are labeled as “Research status”

no operational applications at short term

- Crop area forecasting (estimation 3-5 months before harvest)
- Applications of SAR (radar)
- Sub-pixel analysis: the size of the pixel is of the same order or larger than the dominant field size.
  - Exception: 2-3 land cover types with strong radiometric contrast (eg: vegetation – non vegetation)

Situation 1: No or few ground data

Example: North Korea

Only the pure remote sensing approach is possible

- Margin for subjectivity: order of magnitude of the commission-omission errors.

				Nomenclature			
				Single crops		**Groups of crops**	
				Timeliness			
				Early	After harvest	Early	After harvest
Landscape	Easy	Required Accuracy	High	*Research*	*Research*	*Research*	*Research*
			Moderate	*(1)*	*(1)*	*(2)*	*(2)*
	Complex		High	*Research*	*Research*	*Research*	*Research*
			Moderate	*Research*	*Research*	*(2)*	*(2)*

(1): feasible when the priority is given to a dominant crop that has little confusion with other types of vegetation

(2): same limitation applies for the targeted groups of crops

Situation 2: A ground survey is possible

The accuracy level depends on

- Size of ground survey
- Relative efficiency of remote sensing
  - The value added by remote sensing is proportional to the size of the ground survey.

				Nomenclature			
				Single crops		**Groups of crops**	
				Timeliness			
				Early	After harvest	Early	After harvest
Landscape	Easy	Required Accuracy	High	(3)	(4)	(3)	(4)
			Moderate	(3)	(4)	(3)	(4)
	Complex		High	(3)	(4)	(3)	(4)
			Moderate	(3)	(4)	(3)	(4)

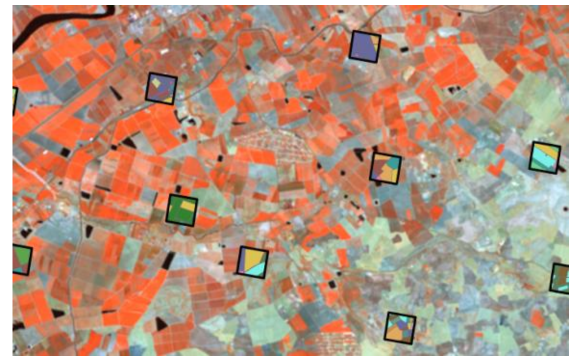
(3): Ground survey has to be carried out quickly and early and there is a short time for data cleaning.

(4): Standard situation: Regression, calibration or similar procedures recommended.

Which data?

Ground data?

Only images?



Ground data
+ images?

- It depends on the circumstances

The "pure remote sensing approach"

- Area is estimated by counting pixels in a classified image
  - Or equivalent methods:
    - Sum of fuzzy classification grades
    - Total polygon area in photo-interpretation
- Sources of area estimation error:
  - Mixed pixels (boundary).

    Error depends on resolution and geometry (% of mixed pixels)

    Minor source of error if most pixels are pure.
  - Misclassification of pure pixels.

Pixel counting as area estimator

Assume you know field data and you have classified images for the whole region (unrealistic).

$$\Lambda = \left[\begin{array}{cccc|c} \lambda_{1,1} & \bullet & \bullet & \lambda_{+1} \\ \bullet & \lambda_{g,c} & \bullet & \lambda_{+c} \\ \bullet & \bullet & \bullet & \bullet \\ \hline \lambda_{1+} & \lambda_{g+} & \bullet & \lambda_{++} \end{array}\right]$$

confusion matrix for the whole population

$\lambda_{g,c}$ is the area in class *g* (ground) that has been classified as *c*

In practice, if you have a full coverage of classified images, you know the totals λ_{+c} of the image classification, but you need $\lambda_{g,+}$

For a class c that appears both in the field nomenclature and the classification, the "pixel counting estimator means estimating $\lambda_{c,+}$ by λ_{+c}

$$\textit{Commission error } \varphi_c = 1 - \frac{\lambda_{cc}}{\lambda_{+c}} \qquad \textit{Omission error } \psi_c = 1 - \frac{\lambda_{cc}}{\lambda_{c+}}$$

$$\textit{relative bias} \quad b_c = \frac{\lambda_{+c} - \lambda_{c+}}{\lambda_{c+}} = \varphi_c \frac{\lambda_{+c}}{\lambda_{c+}} - \psi_c$$

The pixel counting estimator

- The pixel counting estimator does not have any sampling error (if full coverage of images), but has a bias
- Bias ≅ commission error – omission error
  - But both can be tuned in any classification system (as far as I know)
    - Some classification systems have explicit parameters that can be adjusted (prior probabilities in maximum likelihood)
    - With other classification systems, the results can be modified by modifying the training set.
- If we are not happy with the estimator λ_{+c} , we can modify the classification until we get something closer to what we expect.
- Margin (for subjectivity) roughly of the order of magnitude of the commission and omission errors.
- Example: if the classification error is around 20% pixel counting has a margin for subjectivity of that can reach roughly ± 20%
  - If I think my customer wants to hear 1 Mha, I can tune my classification to find 1Mha
  - But if I think my customer prefers to hear 1.2 Mha, I can also tune the classification to find this estimate.

Correcting bias with a confusion matrix

- Bias ≈ Commission error – omission error
- If we have a confusion matrix, we can correct the bias.
- Cannot we?
- Ex: Photo-interpretation made for the EU LUCAS survey
- Raw confusion matrix (simplified nomenclature):

Ground / Strata	Arable	Perm. Crops	Perm. Grass	Forest Wood	Other	*Total*	Comm. Error %	Omis. Error %
Arable land	67313	1751	17597	2035	2760	*91456*	**32.9**	**8.3**
Perm. Crops	651	9516	546	573	287	*11573*	**16.9**	**21.7**
Perm. Grass	4940	658	26969	3693	4244	*40504*	**28.6**	**43.1**
Forest & Wood	308	185	1962	16248	1277	*19980*	**16.4**	**28.5**
Other	195	47	299	186	2925	*3652*	**6.3**	**74.5**
Total	*73407*	*12157*	*47373*	*22735*	*11493*	**167165**		

- Let us look at the class “forest and wood”
- Commission < Omission ⇒ We should increase the estimates by ca. 12%
- Right?

Bias and confusion matrix

- But in LUCAS the sampling rate of the non-agricultural strata is 5 times lower

⇒ the corresponding rows of the confusion matrix should be multiplied by 5

⇒ Weighted confusion matrix

Strata \ Ground	Arable	Perm. Crops	Perm. Grass	Forest Wood	Other	*Total*	Comm. Error %	Omis. Error %
Arable land	67313	1751	17597	2035	2760	*91456*	**32.0**	**10.7**
Perm. Crops	651	9516	546	573	287	*11573*	**15.7**	**27.3**
Perm. Grass	4940	658	26969	3693	4244	*40504*	**24.0**	**52.2**
Forest & Wood	1540	925	9810	81240	6385	*99900*	**21.1**	**8.2**
Other	975	235	1495	930	14625	*18260*	**12.8**	**48.3**
	75419	*13085*	*56417*	*88471*	*28301*	*261693*		

Commission > Omission ⇒ We should reduce the estimates by ca. 13%

Bias and confusion matrix

It is important to weight properly sample observations to compute the confusion matrix

But you cannot do it if your ground data do not follow a statistical sampling method

Calibration estimators with confusion matrices

- ***A*** : Confusion matrix on a sample of test pixels
  - ***Ag*** : ground truth totals
  - ***Ac* :** pixels classified by class
- ***Λ*** : Confusion matrix on the population (estimated by ***A***)
  - ***Λg*** : ground truth totals (unknown to be estimated)
  - ***Λc* :** pixels classified by class
- Error matrices:

$$\Pi_c(g,c) = \frac{\lambda(g,c)}{\lambda(g,+)} \qquad \Pi_g(g,c) = \frac{\lambda(g,c)}{\lambda(+,c)}$$

$$P_c(g,c) = \frac{a(g,c)}{a(g,+)} \qquad P_g(g,c) = \frac{a(g,c)}{a(+,c)}$$

Calibration estimators with confusion matrices

Straightforward identities:

$$\Lambda_g = \Pi_g \ \Lambda_c \qquad \Lambda_c = \Pi_c \ \Lambda_g$$

$$A_g = P_g \ A_c \qquad A_c = P_c \ A_g$$

Estimators:

$$\hat{\lambda}_{dir}(g) = P_g \ \Lambda_c \qquad \lambda_{inv} = P_c^{-1} \ \Lambda_c$$

- Not clear which one is more accurate
- The direct calibration estimator is easier to compute
  - In particular for the variance of the estimators

Regression estimator of a population total

Y: Ground data (% of wheat)

X: Classified satellite image (% od pixels classified as wheat)

We can estimate a regression relatinship

$$Y = a + bX + \varepsilon$$

But this is not what is usually called the "regression estimator" in sampling survey theory.

Regression estimator

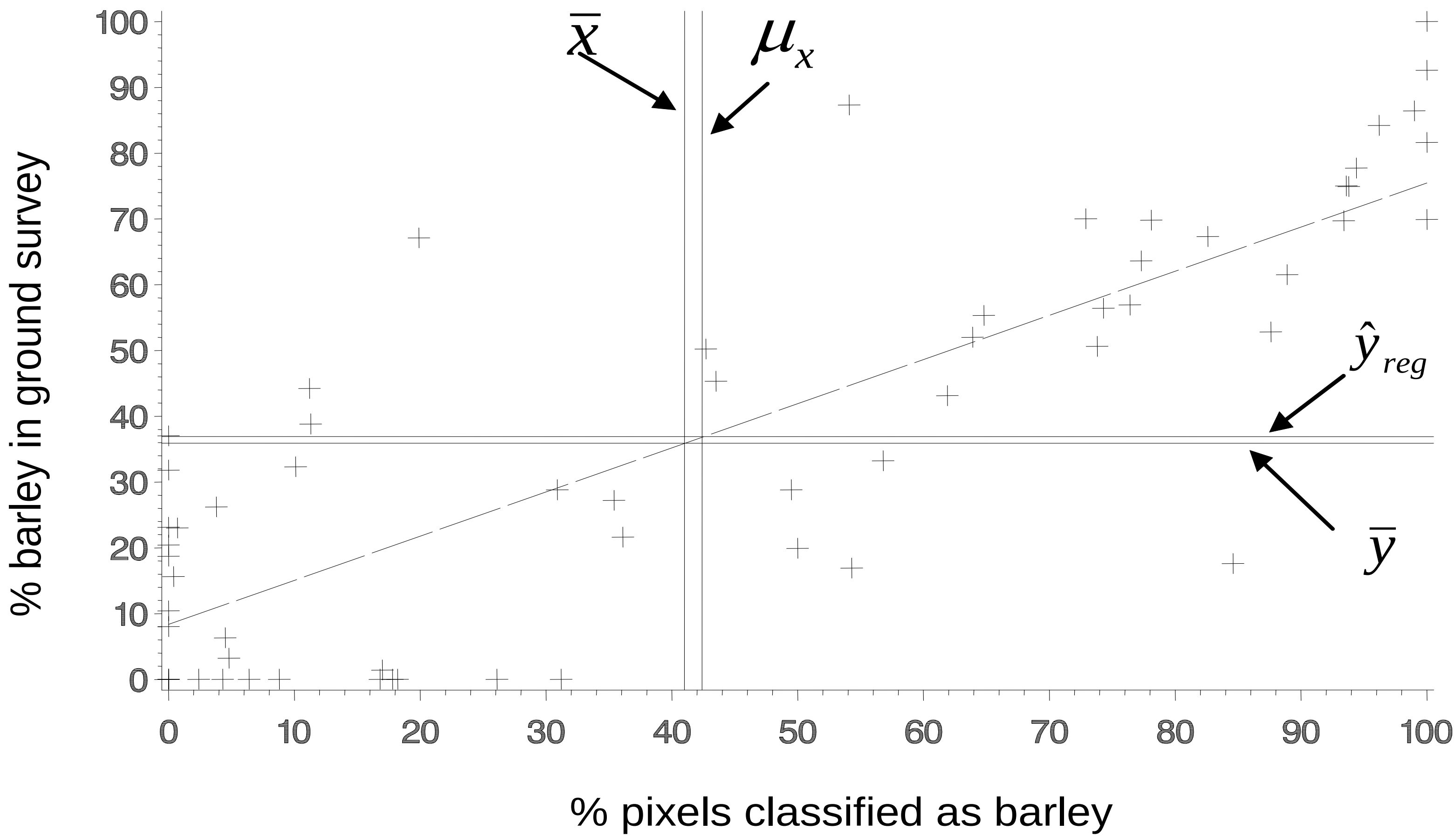
$$\hat{y}_{reg} = \bar{y} + b(\mu_x - \bar{x})$$

Difference estimator if slope b pre-defined: less efficient, but more robust.

Some definitions of the "difference estimator" require b=1

Ratio estimator if $a = 0$

Regression estimator



Regression estimator

Relative efficiency (coarse approximation)

$$rel\ eff \sim \frac{1}{1-r_{xy}^2}$$

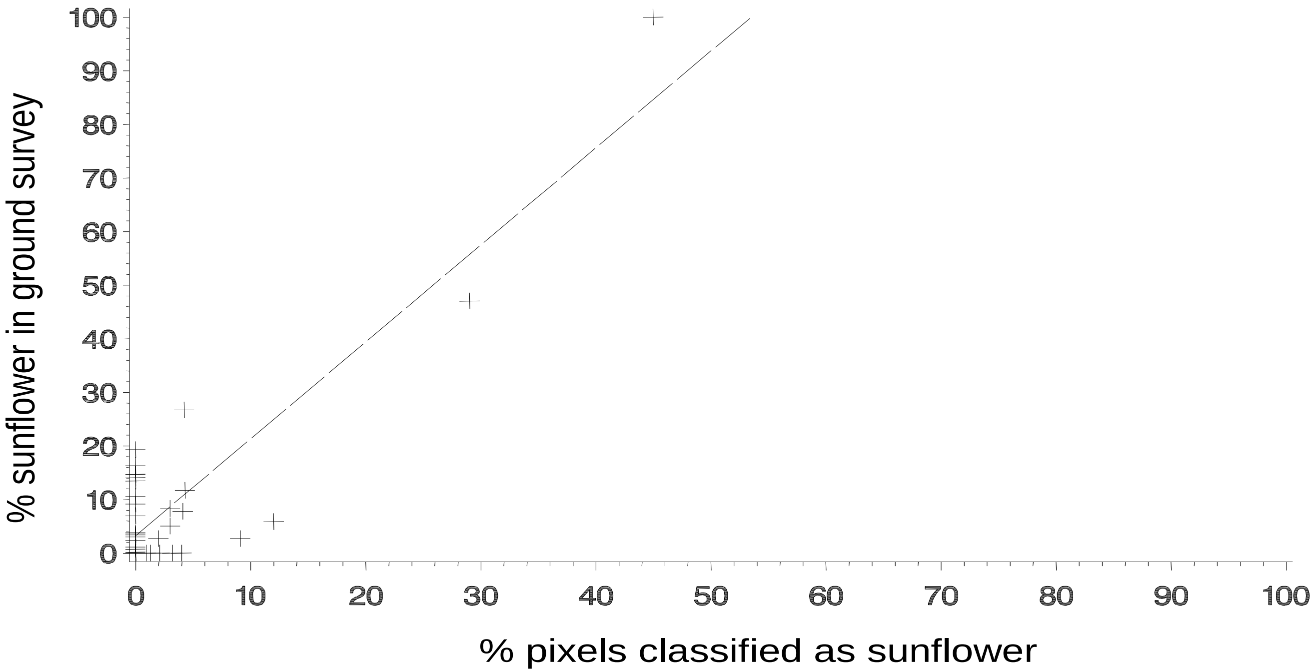
better approximation:

$$V(\hat{y}_{reg}) = \frac{N-n}{N \times n}\left(1+\frac{1}{n-3}+\frac{2G_x^2}{n^2}\right)\sigma_y^2\left(1-\rho^2\right) \qquad G_x = \frac{k_{3x}}{\sigma_x^3}$$

- An efficiency = 2 means that :
- n segments + regression ~ 2n segments (only ground survey)
- Criterion to assess cost-efficiency
- The higher the sample size n, the higher the added value of remote sensing

Regression is not very suitable for point sampling: only 4 points in the regression plot: (0,0), (0,1), (1,0), (1,1)

Regression estimator is not always reliable



n = 39 but unreliable regression (Belsley's β = 4.7)

⇒ use tools to detect influential observations

Regression estimator

- Caution!!!!
- X must be the same variable in the sample and outside the sample
  - Use all pixels (including mixed pixels) to compute X on the sample
  - Do not use the same sample for training pixels and for regression,
    Unless the classification method is very robust (few parameters to estimate)

- If this is not respected, regression estimator can degrade the ground survey estimates

Operational considerations

- In the 80's-early 90's: cost efficiency was insufficient
  - Cost of images
  - Cost/time of image processing.
  - In the late 90's RS area estimation became nearly cost-efficient with Landsat TM,
  - Today it would be cost-efficient but…. no guarantee of image availability
- Timeliness: 1-2 months after ground survey estimates
- Autonomy of official organisations.
- Currently new image types need to be better assessed (e.g: DMCII)
- New satellites in the near future: Sentinel, LDCM (TM)

Combining ground survey and images

- Main approaches: calibration and regression estimators.
- Common features:
  - combine accurate information on a sample (ground survey) with less accurate information in the whole area.
  - Unbiased if the ground survey is unbiased, even id image classification is biased.
- Calibration estimators better adapted if the field data sample is based on unclustered points
- Regression estimators better adapted if the field data sample is based on clustered points or segments

The value added by remote sensing

Measured by the relative efficiency

Example: if the relative efficiency is 2,

- a ground survey of 100 segments + remote sensing ~ ground survey of 200 segments
  - The value added is ~ 100 segments
- a ground survey of 1000 segments + remote sensing ~ ground survey of 2000 segments
  - The value added is ~ 100 segments

Experience shows that the relative efficiency depends very little of the sample size

EU approach to crop area estimation

There is no EU approach to crop area estimation

Each Member state has its own approach

Most frequent: List frame surveys

+ Relatively cheap: in one interview a lot of information
- Requires an updated census
- Assumes that replies of farmers are unbiased
- Traceability: difficult to cross-check.

Some countries use area frame sampling for crop area estimation: France, Italy, Spain, Greece …

Mmmm…. I am not very sure they have run the survey this year in Greece.

Remote sensing: currently only for stratification in Italy, Spain and Greece.

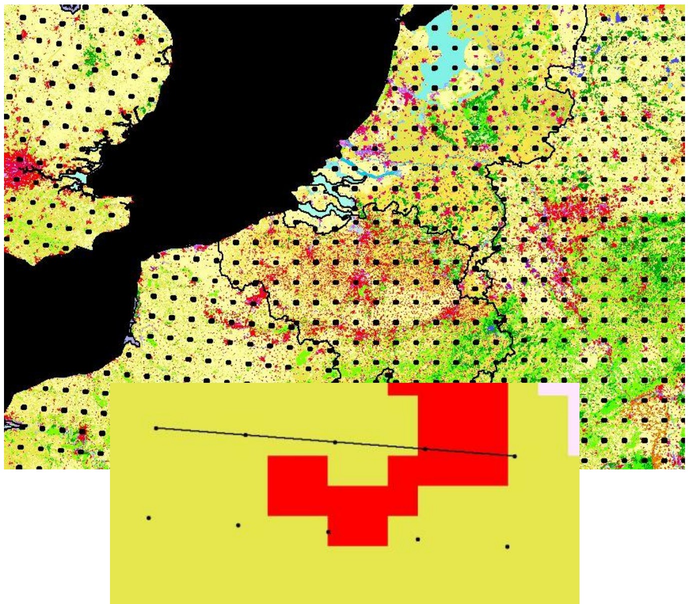
Only marginal contribution.

Why?

The experience of the last 40 years can teach us something

Main tool for land cover area estimation in the EU. (Eurostat)

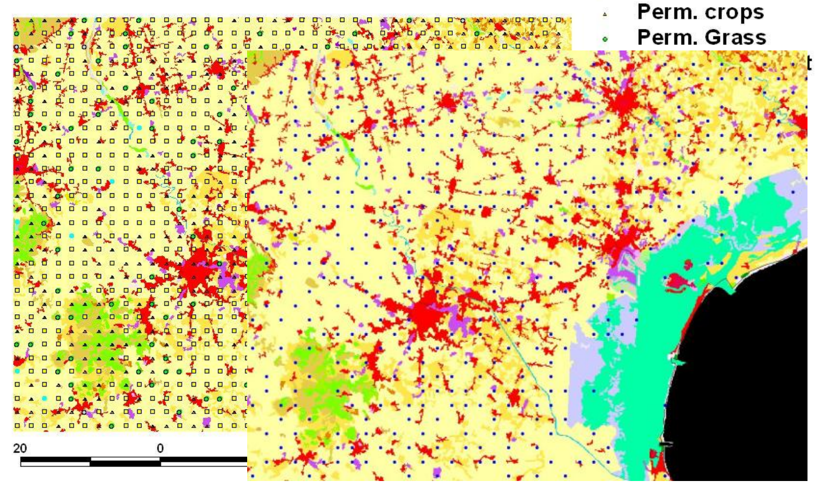
Ground survey of a sample of points



2001-2003

LUCAS 2006/2009/2012

Pre-sample



Relative efficiency

	Systematic -random	Postratif	Unequal prob	Total efficiency
CEREALS	1.11	1.40	1.26	1.95
Common wheat	1.11	1.16	1.42	1.83
Durum wheat	1.43	1.29	1.41	2.60
Barley	1.15	1.17	1.40	1.88
Maize	1.21	1.19	1.43	2.06
Potatoes	1.09	1.06	1.36	1.57
Sugar beet	1.05	1.01	1.59	1.69
Sunflower	1.09	1.07	1.88	2.19

Role of Remote sensing.

- Stratification
- Graphics for ground survey
- Points that cannot be reached

Landscape pictures

from each point:

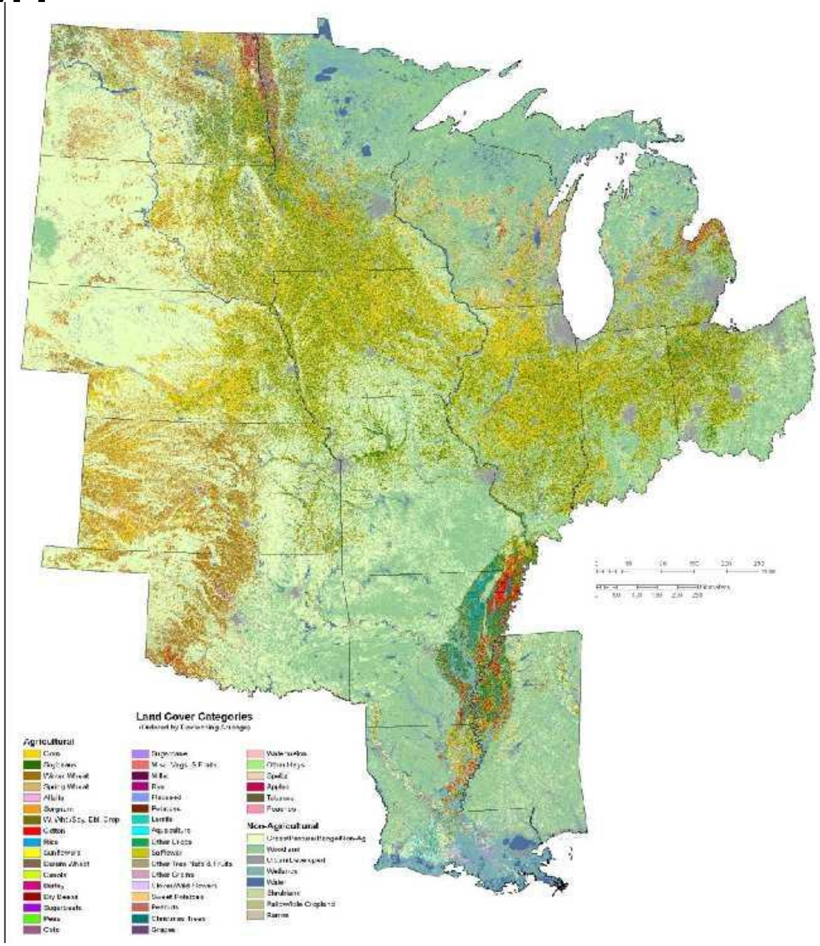
- 4 landscape pictures,
- Point location
- Crop detail

The USDA-NASS approach

Main data: ground observations on a sample of segments

Co-variable: classified satellite images:

- Cropland layer (Intermediate product)
- Mainly AWiIFS (56 m resolution)
- MODIS (time series) give a small contributio
- Administrative declarations of farmers: training data for classification.
- Usually 90-95% classification accuracy
  – Insufficient for a “pure remote sensing approach”



The USDA-FAS approach

Satellite images are used for **auditing** agricultural statistics

Identifying strongly manipulated figures

- “Agricultural Attachés” of the embassies send figures and make field trips.
- Image analysts decide if the figures given by the country seem acceptable.
- Each analyst is quite free to use his personal approach.

MARS Regional crop inventories (1988-1995)

Adapting to the EU the method used by USDA-NASS.

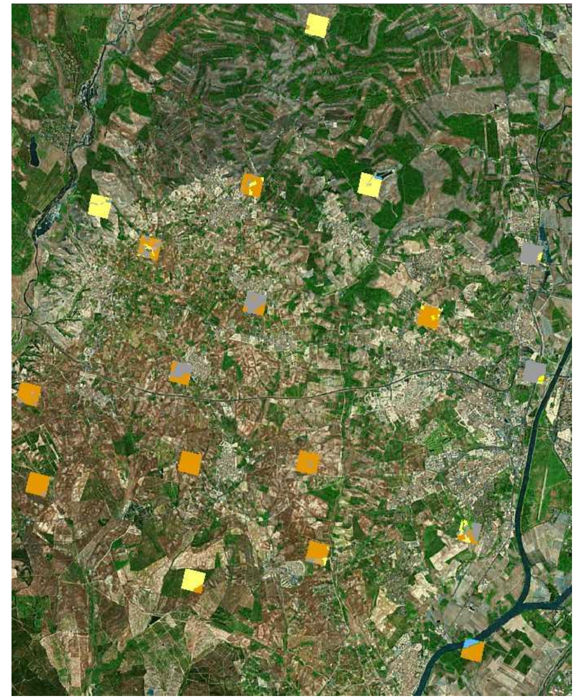
- Square segments were cheaper to implement than segments with physical boundaries and the quality of the estimates was similar.

Images were used for

- Stratification
- Regression estimator with classified images as ancillary variable

Conclusions:

- Relative efficiency was lower than in the US, due to more complex landscape.
- Cost-efficiency with Landsat TM slightly below threshold in the 90's



Ground data

+

images

Estimates

MARS Project: Rapid estimates of crop area change

(Action 4 – Activity B)

Pure remote sensing approach:

Sample of 60 sites of 40x40 km

3-4 images per site every year (mainly SPOT)

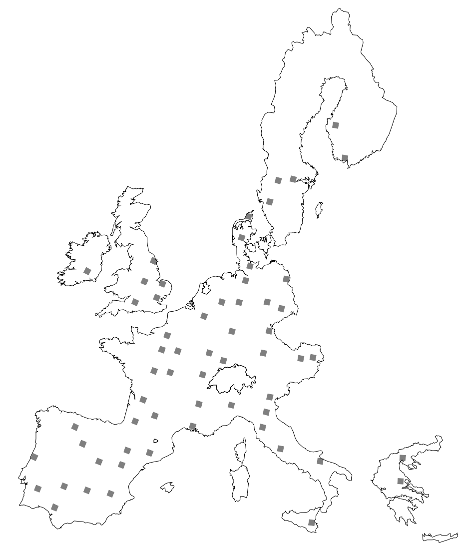
Some ground data of the previous years (for training image classification)

Good results for dominant crops:

Example: 1-1.5 % error for the total area of cereals.

But the margin for subjectivity was around ± 20%

Much weaker results when the changes were difficult to forecast.



MARS Rapid Crop Area Change Estimates (2)

MARS “Rapid Estimates” (Action 4/Activity B): Average RMS errors of the area changes

	April	May	June	July	Aug.	Sept.	Oct.
Common wheat	1	1.2	1.9	1.6	1.5	1.4	1.4
Durum wheat	2.1	3	2.8	2.6	2.7	2.7	2.6
Barley	4	4	3.2	2.5	2.7	2.4	2.4
Rice	7.7	9.9	9.6	6.1	5.7	5	5
Maize	4	2.5	2.4	2.8	4	4.3	4
Total cereals	1.4	1.3	1	0.9	0.8	0.7	0.7
Sugar beet	6.7	4.6	4.4	2.8	4.3	2.9	3
Sunflower	16.6	12	6.5	7.4	6.3	6.7	7.3
Rapeseed	6.3	9.6	9.8	11.5	11	10.4	10.3

For several major crops the estimates were better in April (nearly no images) than in October, after most image analysis

MARS Rapid Crop Area Change Estimates (3)

An expert is somebody who has made all the possible mistakes in a specific field

Niels Bohr

The MARS team became much more expert with the Action 4 / Activity B "Rapid Crop area change estimates with remote sensing"

The big mistake: believing that objective crop area (change) estimates could be obtained from satellite images without an intensive ground survey.

- It took more than 5 years to realise that the "objective" estimates were essentially subjective
  - The remote sensing team was giving the figures that the customer (DG AGRI) wanted to hear
- Second mistake: believing that the agreement of area (change) estimates in the region could be considered as a validation of the method