Efficient statistical sample designs in a GIS for monitoring the landscape changes

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Study area - sampling frame

- **Study area:**
  - 787 km^2 in eastern part of Bologna province which comprises the group of ten municipalities known as the "Nuovo Circondario Imolese"
- **Within a GIS environment:**
  - Analysis of the whole area
  - Detailed analysis of change of buildings on areal photos on a sample of areal units - acquisition (for old photos digitisation), elaboration and so on
- **Sampling frame:**
  - Division borders of the most recent population and housing census (Istat, 2001)
  - Area frame with irregular physical boundaries

Parameter to be estimated

- **Parameter to be estimated: change of building cover density:**
  - difference between the area covered by buildings in 2005 and in 1975 divided by the land area
- **Data acquisition and in depth data analysis time consuming**
  - Thus very efficient sample design
  - Stratification
  - Optimal allocation

Strata combinations of land-use/land-cover class and land suitability classes

Land-use/land-cover classes

1. Fabric of human settlement
2. Arable crops
3. Orchards, vineyards, vegetable gardens, plant nurseries, greenhouses
4. Forest-pasture land, areas with sparse or absent vegetation, wetlands
5. Water bodies and water courses

Land suitability classes

a Level land well suited for agricultural use

b Level land less suited for agricultural use than class "a"

c Hilly regions intermediately suitable for agricultural use

d Hilly regions moderately suitable for agricultural use

e Areas with low suitability for agricultural use

DEFF very disappointing = 0.9991

Sub-stratification

Land-use/land-cover classes

Land suitability classes

Time of urbanisation:

’ already urbanized in 1975

Kind of final destination:

h predominantly residential (1-a.h)

p productive (1-a.p)

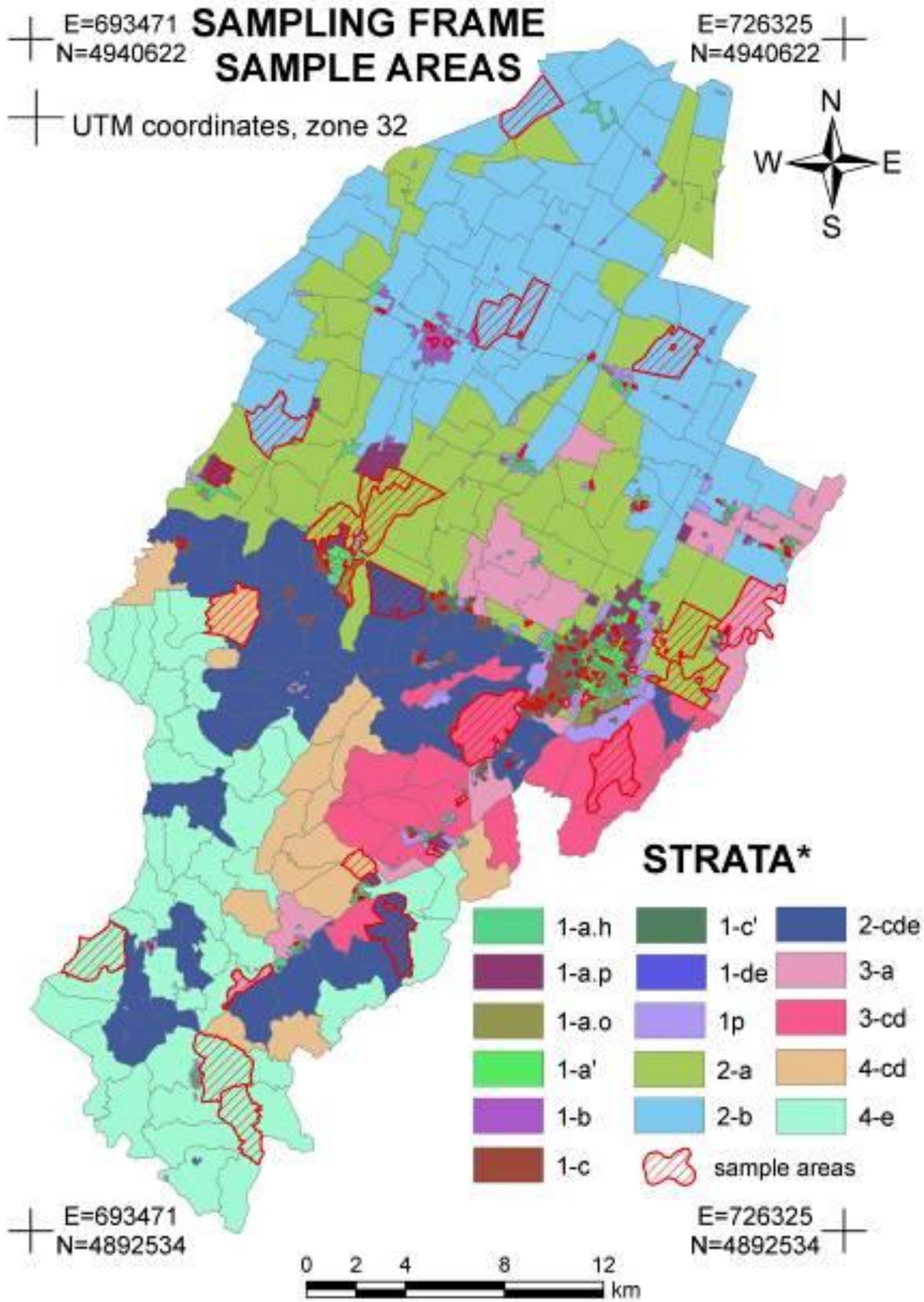
o any other type of urban use (1-a.o)

Sample size 104 **Sampling rate = 7.2%**

CV= 25.5%

DEFF = 0.73 **Relative efficiency = 1.37**

Spatial distribution of pilot sample units in the strata



Sequential sample designs

- **Besides stratification and Neyman's allocation, efficient sample selection procedure**

- **Sequential sample designs very efficient due to:**
  - sample selection dependent on previously selected units
  - stopping rules based on the estimate
  - Biased estimates

Adaptive Sequential Procedure with Permanent Random Numbers (ASPRN)

- Permanent random numbers (Ohlsson‘95) assigned to all units in the population (sections of census 2001)
- A first stratified random sample of sections is selected with probability proportional to stratum size. Call *n* the sample size
- Estimation of standard deviation of change in built area density within each stratum
- Neyman’s allocation is computed with sample size *n+1* and one section is selected in the stratum where the sample size is farthest below the size assigned by Neyman’s allocation
- The change of building cover density and its precision are estimated
- If the precision is acceptable, the process stops; otherwise, Neyman’s allocation is computed with the sample size *n+2*, and so on, until the precision considered acceptable is reached

Advantages of Adaptive Sequential Procedure with Permanent Random Numbers (ASPRN)

- Idea: adopting, in an adaptive procedure, permanent random numbers sample selection method
- Sample size per stratum dependent on previously selected units but sample selection not
- Unbiased estimates under a design based approach
- No need of hypotheses on the distribution of the change of built area density
- Through simulation ASPRN consistent and always more efficient than:
  - stratified sampling with proportional allocation
  - stratified random sampling in two phases (two steps) proposed by Thompson and Seber (1996)

Allocation of pilot sample and of ASPRN sample

STRATA	Nh	nh pilot	nh ASPRN
1-a.res	142	10	11
1-a.prod	72	5	72
1-a.dis_ver	18	2	2
1-a'	415	29	29
1-b	50	4	4
1-c	156	11	18
1-c'	136	9	9
1-de	23	2	2
1p	169	12	23
2-a	60	4	18
2-b	71	5	14
2-cde	36	2	2
3-a	15	2	2
3-cd	18	2	2
4-cd	17	2	2
4-e	43	3	3
	1441	104	213

Comparison of proportional, ASPRN and Neyman's allocation

STRATA	N_h	n_h proport. allocation	n_h pilot sample	S_h	n_h ASPRN	n_h Neyman's allocation
1-a.res	142	21	10	1688	11	**11**
1-a.prod	72	11	5	24527	72	**83**
1-a.dis_ver	18	3	2	3471	2	**3**
1-a'	415	61	29	1448	29	**28**
1-b	50	7	4	1323	4	**3**
1-c	156	23	11	2366	18	**17**
1-c'	136	20	9	1443	9	**9**
1-de	23	3	2	3	2	**0**
1p	169	25	12	2848	23	**23**
2-a	60	9	4	6566	18	**18**
2-b	71	10	5	4103	14	**14**
2-cde	36	5	2	996	2	**2**
3-a	15	2	2	608	2	**0**
3-cd	18	3	2	1286	2	**1**
4-cd	17	3	2	355	2	**0**
4-e	43	6	3	341	3	**1**
Total	**1441**	**213**	**104**	**53372**	**213**	**213**

Operational disadvantages of ASPRN

TSPRN

Operational disadvantages of ASPRN:

- Organisation
- Continuous interaction between statisticians and environmental engineers for choosing, at each step, the next area sample unit to be selected
- Segmentation of data acquisition and pre-processing
- Cost and time

Carfagna (2007) two-steps selection procedure with permanent random numbers (TSPRN)

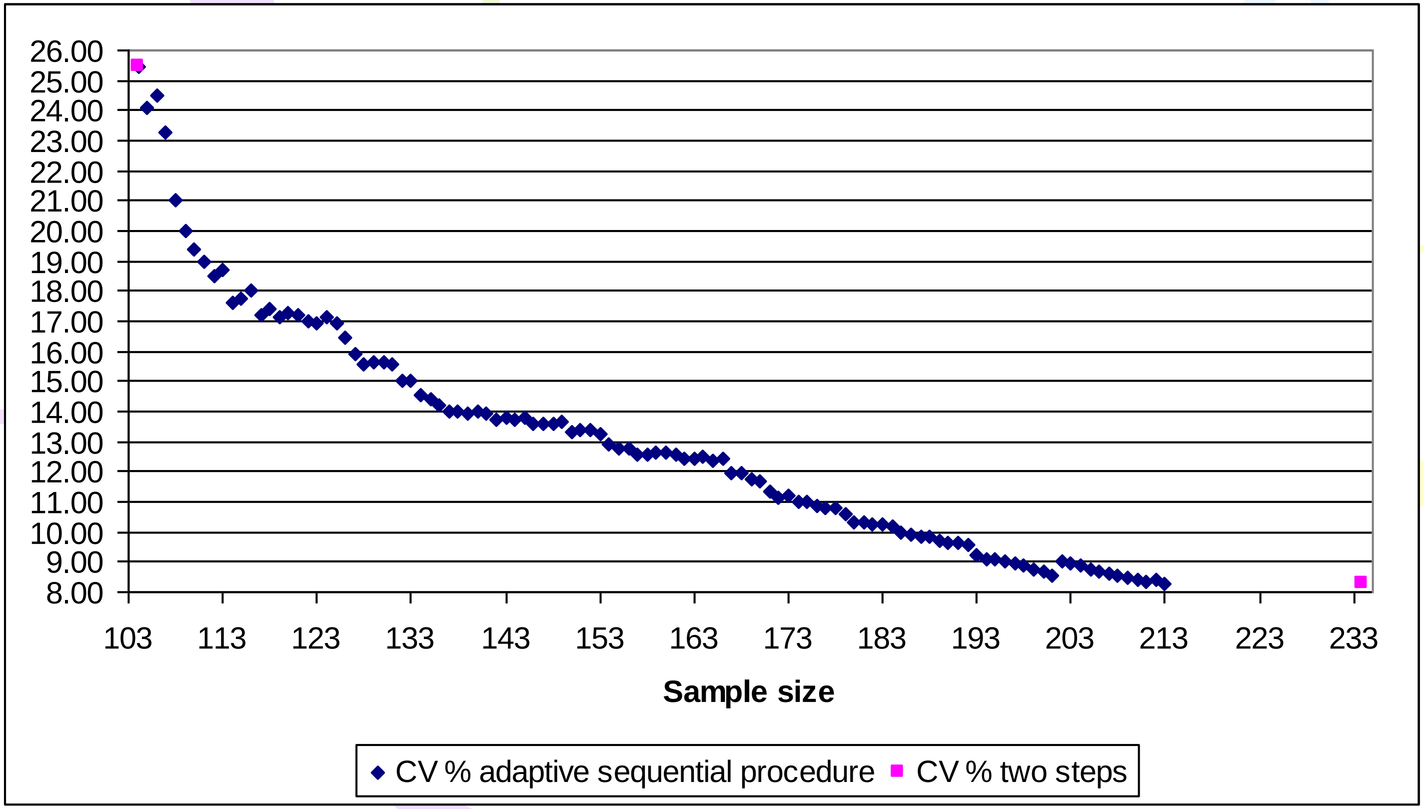
- Overcomes operational drawbacks of ASPRN:
- Less efficient than ASPRN (although more efficient than Thompson and Seber's)

TSPRN for estimating the change of building cover density

- Selection of the pilot or first step sample (104 census sections)
- Estimation of standard deviation of change in built area density within each stratum
- Computation of number of sample units needed for reaching a coefficient of variation of the estimate equal to 10% (234)
- Selection of 130 more units with allocation as near as possible to Neyman's one
- CV obtained: 8.3%, lower than the target CV
- The first phase sample overestimated the standard deviation in some strata

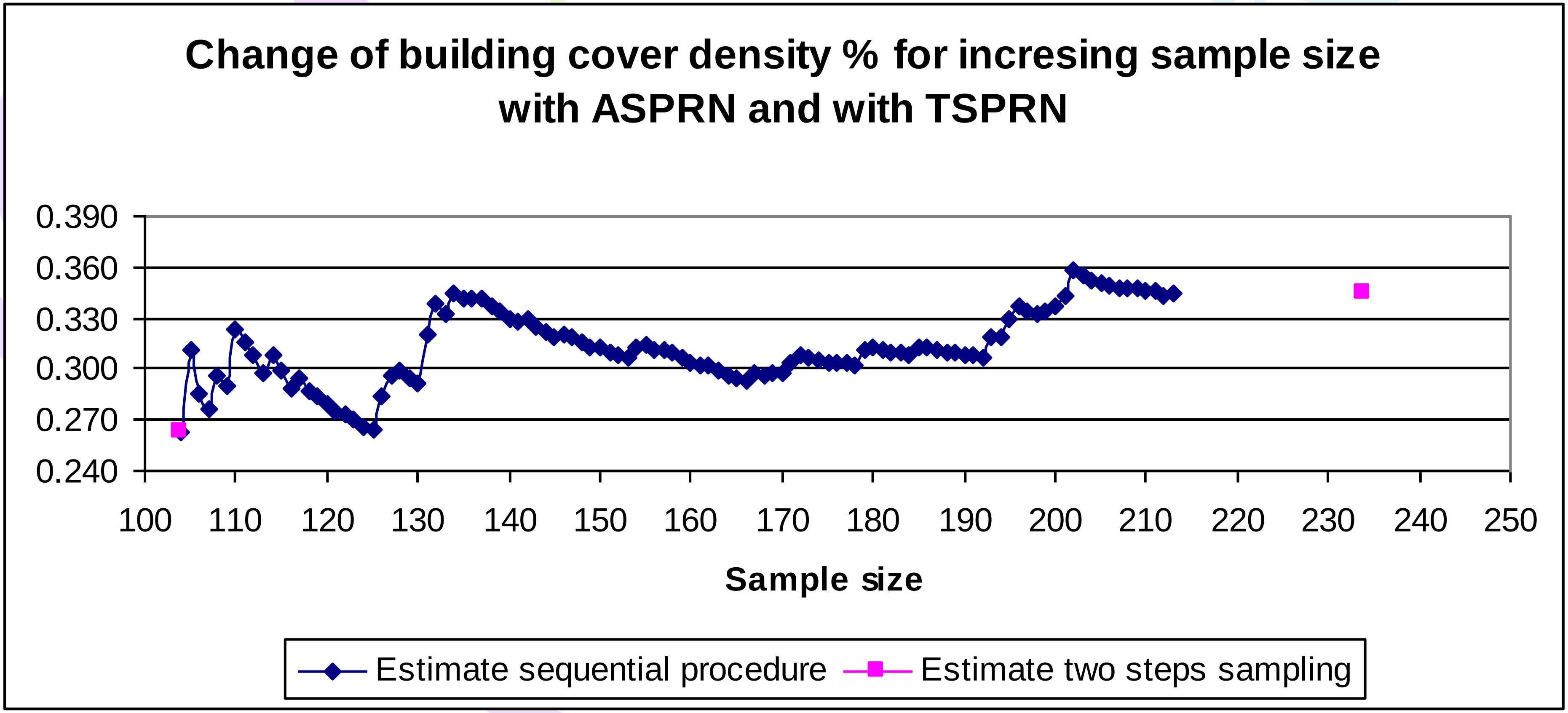
ASPRN much more efficient than TSPRN

- With ASPRN, CV equal to 10% reached with 180 sample units
- CV equal to 8.3% reached with 213 sample units (with TSPRN 234, 21 units more, 10% more)



Comparison of estimates given by ASPRN and TSPRN when the CV for both estimates is about 8%

- Difference of estimates: 81 m^2 (2.9%) - 0.01% of the study area
- Difference between estimates with pilot sample and ASPRN with CV equal to 8.3%: 642 square meters (23.7%), 0.08% of study area



Conclusions

- ASPRN and TSPRN estimates tend to converge
- With real data ASPRN confirms to be much more efficient than TSPRN
- Operational disadvantages of ASPRN are important and in some cases cannot be overcome
- Use ASPRN whenever possible
- Otherwise, use TSPRN
- More efficient than Thompson and Seber’s
- More efficient than proportional allocation if stratification efficient

Thank you

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