ISRIC
World Soil Information

Towards a sampling design for monitoring global soil organic carbon stocks

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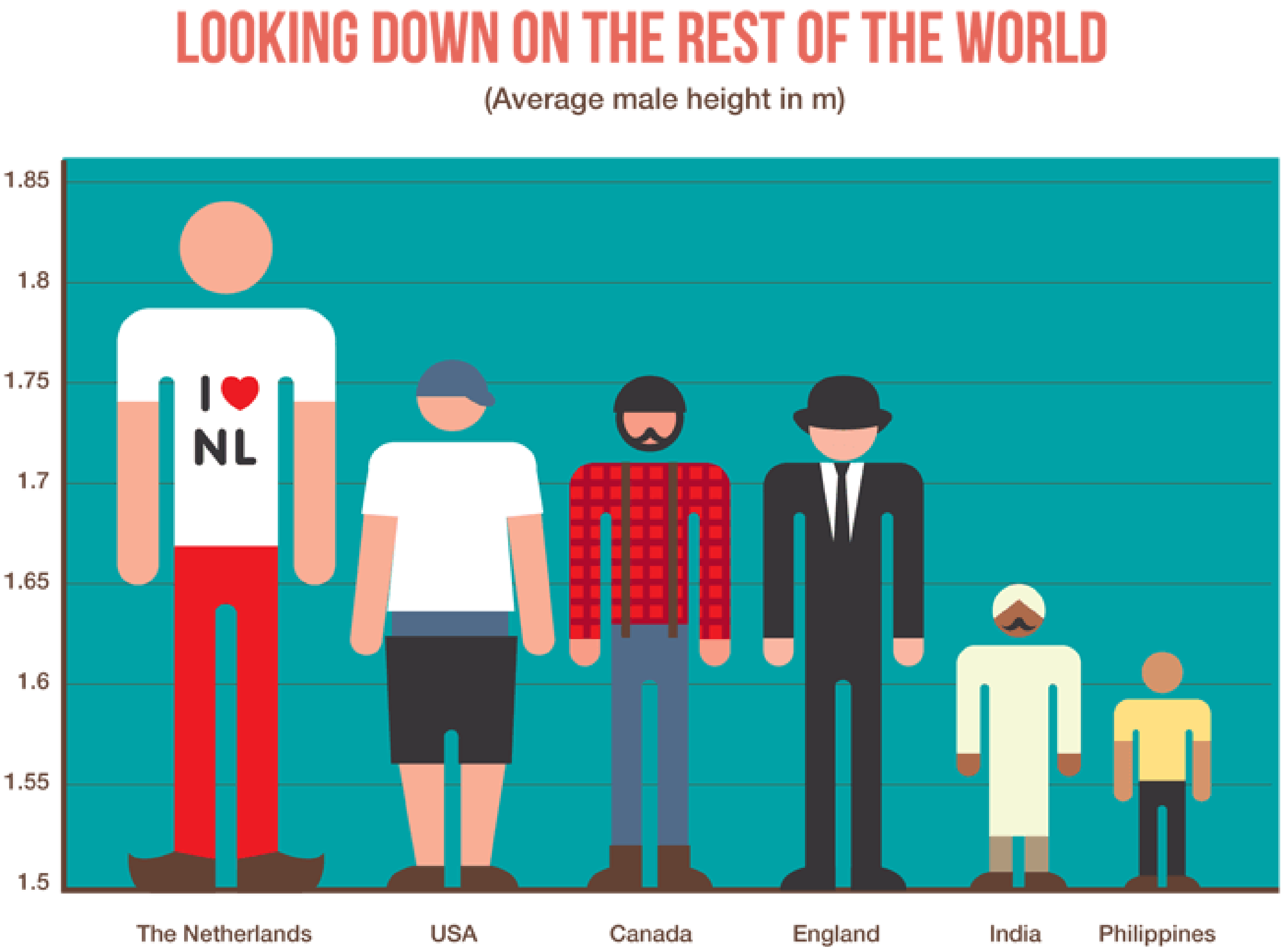
The Dutch are the tallest people in the world



Average height Dutch men: 182.5 cm

Required sample size in case of probability sampling

The Netherlands

- Population size 17,000,000
- Sample size needed to obtain standard error ≤ 0.5 cm: 200

China

- Population size 1,300,000,000
- Sample size needed to obtain standard error ≤ 0.5 cm: 200

In case of large populations, the standard error does not depend on population size

estimate of population mean

true population mean

population standard deviation

$$se = sd(\mu - \hat{\mu}) = \frac{\sigma}{\sqrt{n}}$$

sample size

Same holds for estimation of the global soil organic carbon stock

- Required sample size hardly depends on size of area: whether it is for a region, country or the entire Earth: sample size will be about the same
- We can compute it (in case of simple random sampling) from:

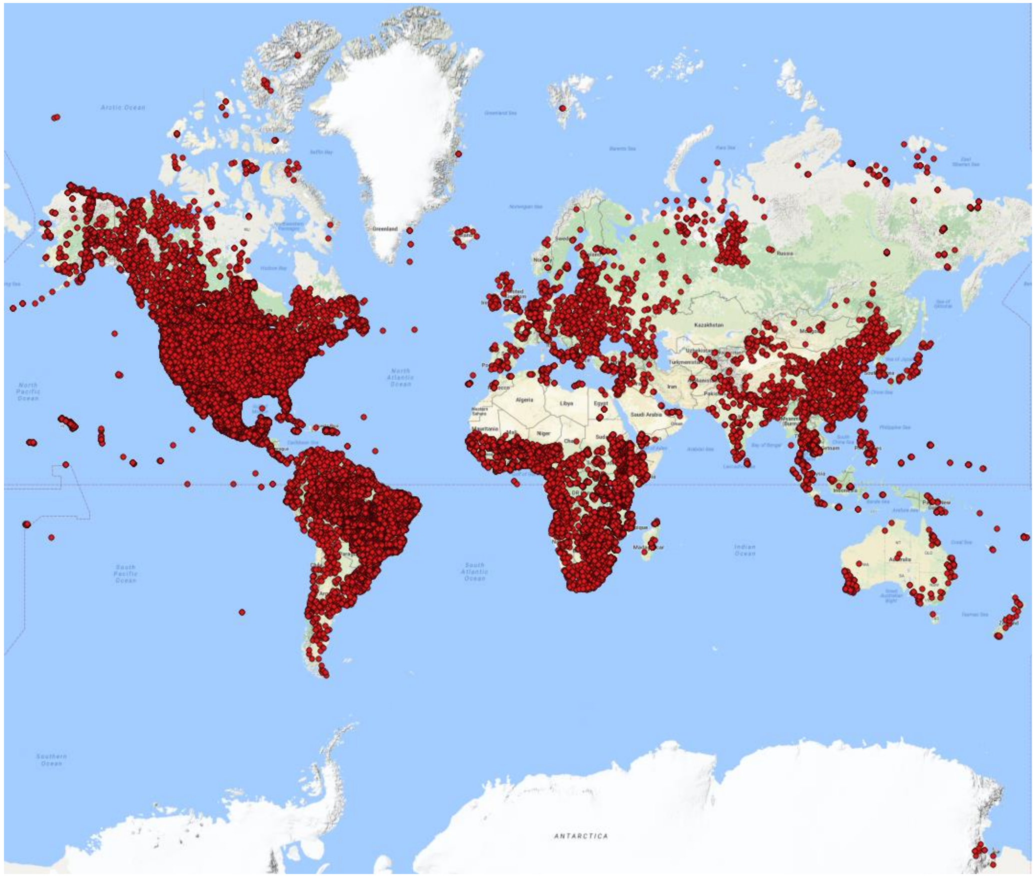
$$n = \left(\frac{\sigma}{se}\right)^2$$

- All that we need is the population standard deviation and the required standard error

Deriving the population standard deviation

- Target variable: soil organic carbon (SOC) stock 0-30 cm (ton/ha)
- ISRIC WoSIS soil database provides SOC stock observations for about 42,000 locations across the world (but note: no uniform spread)
- We used this dataset to compute the standard deviation, this gives:

$$\sigma = 5.5\ ton/ha$$



Deriving the standard error

- 4pour1000 initiative aims to compensate for annual fossil carbon CO_2 emission by sequestering 3.5 Gt C per year (4‰ of the total global stock)
- This means an increase of 17.5 Gt C every five years
- If we let the standard error be 10% of the intended increase over five years, then estimation accuracy will be sufficiently high to evaluate if the 4pour1000 objective is achieved
- We therefore used $se = 1.75\ Gt\ C$, this is about $0.12\ ton/ha$

A modest sample size will do the job

$$n = \left(\frac{\sigma}{se}\right)^2 = \left(\frac{5.5}{0.12}\right)^2 = 2100$$

- This is based on simple random sampling, while the sample size required can be much reduced using more elaborate sampling designs (see later)
- The 2100 refers to estimation of the stock at any one point in time. To estimate SOC stock change over time, it should be multiplied with $\sqrt{2}$, assuming independent sampling at the two points in time (but again, see later for a more efficient alternative)

But is all this really needed? After all, we have already so many SOC stock estimates

SOC stock (Gt C)		Source
0-1 m	0-2m	
1400	-	Post et al.(1982)
1460-1550	2380-2460	Batjes (1996)
1580	-	Kasting (1998)
1500	2460	Robert (2001)
1420	-	Hiederer and Köchy (2012)
1460	1920*	Wei et al. (2013; * to 2.3m)
1410 ± 150	2060 ± 220	Batjes (2016)

Carbon Managem

EODERMA

ELSEV

Globa

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Differences much greater than 1.75 Gt C

What makes design-based estimation so attractive?

- It yields an accurate estimate for modest sample size
- It makes no assumptions, both the estimate and the associated accuracy measure are completely model-free
- Current model-based approaches seem not sufficiently accurate to assess change over time
- Efficiency of design-based estimation can be improved by using more elaborate sampling designs:
  - Stratified random sampling (for example using a soil type map for stratification), calculations that we did for France and New South Wales showed a 50% efficiency gain using the *Ospats* stratification method
  - Model-assisted sampling can benefit from models while still keeping the advantages of design-based sampling
  - For estimation of SOC stock change a static design (revisit locations) increases efficiency dramatically, but note that such approach is sensitive to manipulation

There are disavantages too

- Probability sampling is key, so problems may occur:
  - Parts of the world may be inaccessible because governments refuse access or there are too high risks (e.g. military conflict areas)
  - Parts of the world may be very poorly accessible because they are very remote or have harsh conditions (arctic, deserts, tropical rain forest)
- All observations should be collected and analysed in the same way using a standardised procedure
  - Many countries will want to use their own field protocol and laboratories, it will take considerable effort to get them to agree on a uniform, standardised approach
- Practical implementation will no doubt have imperfections, causing the outcomes to become vulnerable to criticism
- We only get estimates for the population as a whole, i.e. summary measures instead of maps

In summary

- Accurate estimation of the global soil organic carbon stock and changes therein over time using design-based statistics ('probability sampling') requires a remarkably small number of observations
- Estimates and associated accuracy measures are unbiased and completely model-free
- We believe this would make a valuable addition to the many modelling efforts that are already done, at relatively small cost
- Practical implementation will be a huge logistical challenge that requires commitment from many organisations
- The first challenge is to convince researchers (you!) and policy makers of the added value of such project: it can only work if there is broad support

Thank you