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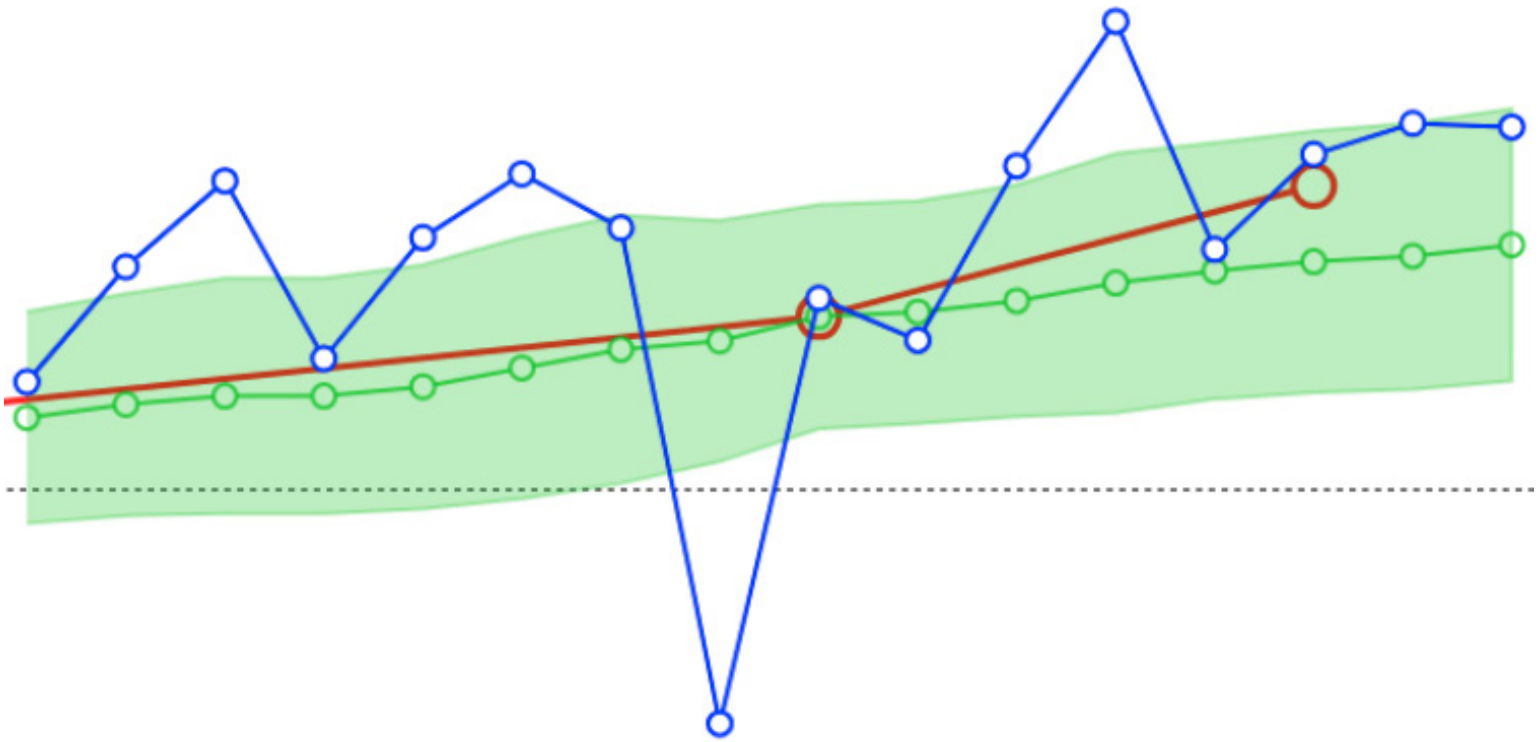
Panel Analysis and Annual Reporting of the Swiss National Forest Inventory



Peter Stoll

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Cover: The graph on the cover is zoomed-in from figure 1 in the appendix. It shows various estimates of forest area from the Swiss National Forest Inventory. The mean estimate of 11'716 km^2 averaged over the entire period from 1982 to 2024 is indicated as dashed line.

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1 Introduction

The Swiss **N**ational **F**orest **I**nventory (**NFI**) was initiated as periodic inventory (Fischer and Traub 2019; Köhl and Scott 1995). A representative sample of terrestrial forest plots was visited and measured over a relatively short period of 3 years (NFI1: 1983–1985). Subsequent periodic inventories were completed in 10 year intervals (NFI2: 1993–1995, NFI3: 2004–2006). The systematic sampling grid was initially a 1.0 × 1.0 km grid. It was reduced to a 1.4 × 1.4 km grid (diagonals) at the beginning of NFI2. NFI results were published (e.g. Brändli et al. 2020) after each inventory or NFI cycle was completed. Printed and digital publications (e.g. CDs) were later complemented with an interactive result query system (www.lfi.ch).

Starting with NFI4, the periodic design of the inventory was changed to a continuous, in which annual panels covering $1/9^{th}$ of Switzerland were visited and measured each year. The annual panels were interpenetrating, i.e. chosen as non-overlapping subset of the entire grid such that they themselves can be considered representative subsamples of Switzerland (Lanz 2015). In principal, each annual panel could be used to report annual NFI updates. But, standard errors would be high because of low sample sizes ($1/9^{th}$ of the total sample size) and different estimates among individual panels are predominantly due to sample variation rather than real changes in forest conditions from year to year. The main reason for the change of the inventory design was a more even partitioning of work load and expenditure. Moreover, it also opened the possibility of annual reporting of inventory results (Lanz 2015).

Since NFI4, intermediate results were published after completing the first 5 panels of each inventory cycle. For example, intermediate results pooling panels 1–5 of NFI5 were published in 2023 covering the years 2018–2022. But if certain panels should consistently yield low or high estimates (**panel effects**), it might be problematic to use packages of panels less than 9. The problem of using more or less arbitrarily chosen packages (e.g. 3, 5 or 7) of panels might be that key characteristics of Switzerlands forests may be under- or overestimated by including or excluding the panels with the lowest or highest estimates in the total sample of 9 panels. Hence, using the continuous panel design, I investigated possibilities to provide annually updated NFI results.

Annual reporting or updates could be implemented in a simple and straight forward way. Since NFI4, $1/9^{th}$ of the total sample of terrestrial forest plots is updated offering the possibility to estimate key characteristics of Switzerlands forests as pooled estimates over 9 panels shifted by one each year. Thus each year, the most recently measured panel would be added while panels older than 9 years would be dropped from the pooled estimate of 9 panels. These packages of 9 years or panels, respectively, would be shifted by one each year yielding **annually updated pooled panel estimates.**

Synopsis of **time line** and **sampling design** of the Swiss NFI

- **periodic design**: terrestrial forest plots **measured in 3 years**, **with temporal gaps** between cycles
  - NFI**1**: 1983 –**1985**, systematic sampling grid 1.0 × 1.0 km
  - NFI**2**: **1993** – 1995, systematic sampling grid 1.4 × 1.4 km **from now on**
  - NFI**3**: 2004 – 2006
- **continuous design**: panels covering $1/9^{th}$ of Switzerland **measured annually**, **without temporal gaps** between cycles
  - NFI**4**: 2009 –**2017**, full cycle of 9 panels completed
  - NFI**5**: **2018** – 2026, panels 1-7 completed by 2024, panel 8 ongoing (2025), completion by 2026
  - NFI**6**: 2027 – 2035, in preparation

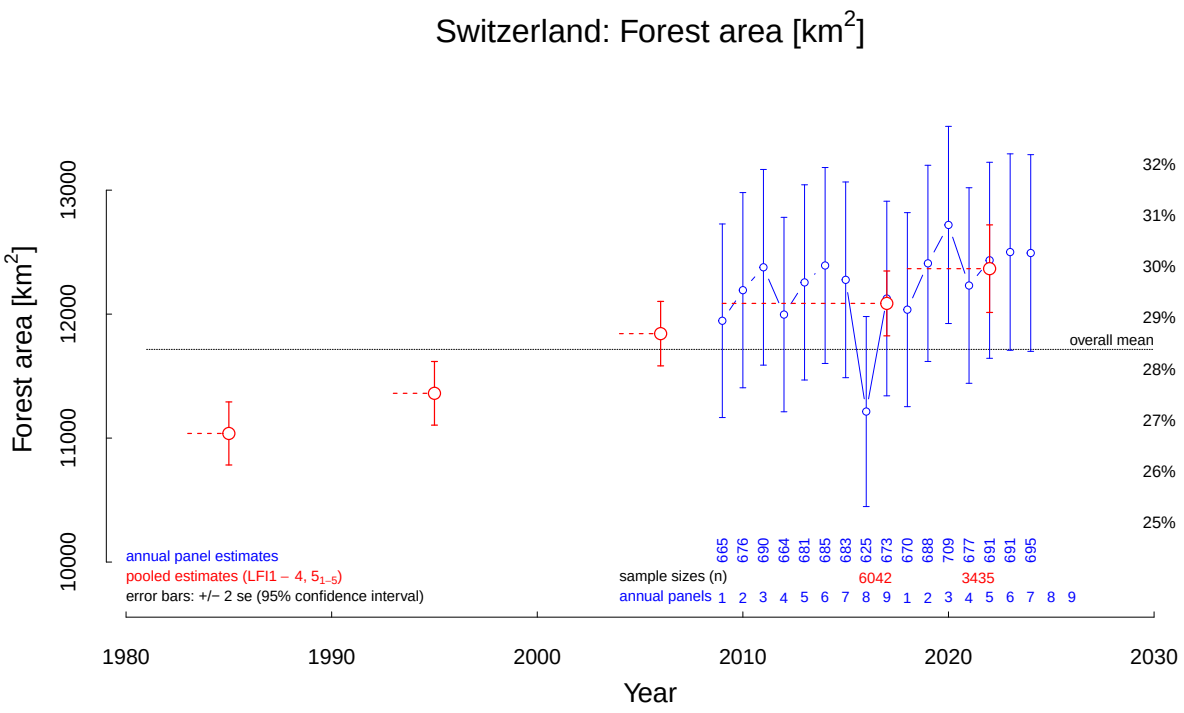

Figure 1: Forest area [km^2] of Switzerland. The **overall mean** forest area (11 715.5 km^2 or 28.4%) over the entire almost 50-year period is indicated as horizontal reference line (dashed). The first 3 inventories (NFI1: 1983–1985, NFI2: 1993–1995 and NFI3: 2004–2006) were periodic and results reported using pooled estimates. With NFI4 (2009–2017), the inventory design changed to continuous with annual panels covering $1/9^{th}$ of Switzerland each year. Intermediate results for NFI5 (2018–2026) are given as pooled estimates of panels 1–5 (2018–2022). Panels 6 and 7 (2023, 2024) are the most recently completed annual panels and panel 8 (2025) is currently measured.

2 Panel analysis

The panels implemented in NFI4 (Fig. 1) were retrospectively assigned to terrestrial forest plots in NFI1–3 and spread along the time axis to graphically emphasize potential panel effects (Fig. 2). It should be kept in mind that panel estimates of NFI1–3 can not be assigned to specific calender years because the panels were not measured at the specific time points they are graphically positioned. Nevertheless, it helps to visualize longterm panel effects. From NFI4, however, exact temporal position of panel estimates is possible.

2.1 Forest area

As might be expected because of slow forest dynamics, panel estimates through time remained relatively constant despite the overall increasing forest area in Switzerland. Panel 3 yielded always the highest and panel 8 always the lowest estimate of forest area. Thus, summarizing and publishing NFI results by pooling subpackages of panels excluding or including panel 8 could be misleading and over- or underestimate forest area. On the other hand, intermediate results from pooled estimates excluding panel 3 will probably underestimate forest area. For example, average forest area estimated from panels 1–5 of NFI4 is 12'154 km^2 and from panels 6–9 12'002 km^2–a decrease of roughly 150 km^2 or 21'000 soccer fields (68 × 105 m) although the long-term trend is clearly increasing (Figs. 2 & 8).

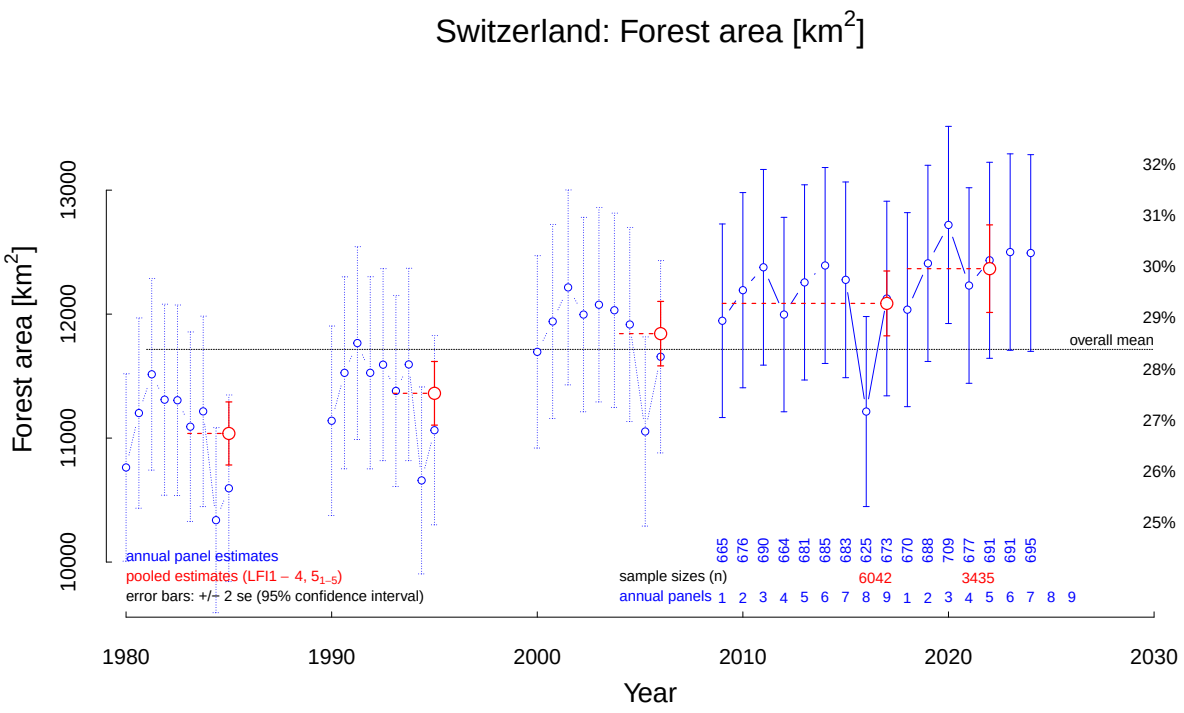

Figure 2: Forest area [km^2] of Switzerland as in Fig. 1. The retrospectively assigned panels of LFI1–3 (dashed) are spread in time to graphically emphasize potential panel effects.

2.1.1 Density distribution of panel estimates

The retrospectively applied panels showed that panel 8 obviously always yielded the lowest estimate of forest area (Fig. 2) raising the question whether this reflects pure sampling variation or might be due to specific structures of the landscape. Therefore, we investigated the distribution of forest area estimates derived from the dense 100 × 100 m grid using the aerial photo interpretations from the Swiss Landuse/Landcover statistics (Arealstatistik). The panels of the NFI grid (1.4 × 1.4 km) were shifted by 100 m steps horizontally and vertically. Because terrestrial plots within a panel are separated by 6 km horizontally and vertically, the shifts yielded 61 × 61 = 3712 estimates of forest area estimates according to Swiss NFI methods and criteria (Fig. 3). This work was done by Christian Ginzlers group (Land Change Science and Remote Sensing, WSL, Birmensdorf).

Minima (panel 8) and maxima (panel 5) of panel estimates for forest area were very close to an estimated 95% interval derived from 3712 estimates based on aerial images on a 100 × 100 m grid across Switzerland (Fig. 3)[1]. Thus, neither the smallest nor the biggest estimate should be considered outside the expected sample variation of forest area. Moreover, the average of the 3712 estimates (29.51%) was very close to the pooled estimate of forest area derived from the 9 panels of NFI4 (29.95%). In other words, the 9 panels of the NFI grid can be considered as truly representative sample of the distribution derived from a much denser grid of sample points across Switzerland.

Nevertheless, estimated forest area of panel 8 always stood out and attracted attention. On the other hand, minima and maxima of the 9 panels are not outside the expected sample variation. Hence, an extended search for a structural reason of the low panel 8 (or high panel 5) estimates does not seem to be necessary. As a side note, the reason why the lowest rather

[1]**Note**: in CG's estimates panel 5 yields the highest estimates whereas in the analysis presented here it's panel 3, cf Fig. 2. The reason is just numbering - a question of labels.

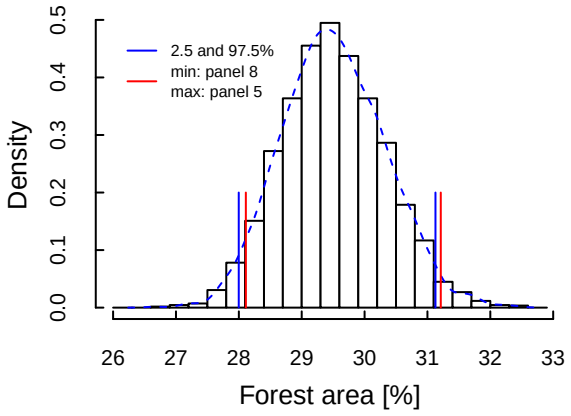

Figure 3: Density distribution of estimates of Switzerlands forest area [% of total area]. The original NFI grid (1.4 × 1.4 km) used to estimate forest area for each of 9 panels was shifted horizontally and vertically by 100 m steps yielding 3712 estimates of forest area according to Swiss NFI methods and criteria. Blue lines indicate 2.5 and 97.5 percentiles (95%) and red lines indicate forest area estimated from panel 8 (lowest) and panel 5 (highest) panel estimates of NFI4. The dashed line gives a normal density approximation of the densities.

than the highest estimate attracted attention is that the difference (732.4 km^2 for NFI4) between the lowest and the second lowest panel estimate of forest area is much larger than the difference (14.5 km^2 for NFI4) between the largest and second largest estimate.

2.1.2 Production regions

Estimated forest area of production region 'Pre-Alps' showed the most conspicuous pattern (Fig. 4) among the 5 production regions of Switzerland (Jura, Plateau, Alps and Southern Alps, not shown). The recurring decrease in forest area from panel 7 to 8 must be seen and interpreted as pure panel effect and not as real change due to some external, internal or management effect. Judged by the confidence intervals of panels 7 and 8, estimated forest area of panel 7 is larger and that of panel 8 smaller than the pooled estimates of NFI4 (2199 km^2). Again, estimates from subpackages excluding panel 7 or 8 will under- or overestimate forest area in the Pre-Alps. For example, estimated mean forest area in NFI4 using panels 2–6 is 2'204 km^2, whereas for panels 3–7 it is 2'272 km^2 or **68** km^2 **more** and for panels 5–9 it is 2'194 km^2 or **78** km^2 **less**. These **differences** correspond to more than 7000 soccer fields (ca. 50 km^2). Standard errors for these packages of 5 panels range from 12 (panels 2–6) to 110 km^2 (panels 5–9) and reflect the relatively low variation among panels 1–6 and the relatively large sample variation among panels 7–9.

In contrast to the 'Pre-Alps' with conspicuous panel effects, forest area of the production region 'Plateau' are not as conspicuous (Fig. 5). Nevertheless, panels 6, 7 and 8 lead to estimates below the overall mean. As a consequence, intermediate NFI results including panels 1–5 of NFI4 and NFI5 lead to the false impression that forest area is slightly increasing. However, using moving averages including 9 annual panels moved by 1 each year (Fig. 6) would communicate a perfectly constant forest area.

2.1.3 Annual *up-date*

In order to annually report new NFI results one could in principal use just the newly available panel or packages of say the most recent 3 panels. However, the most recent panel alone would have a small sample size and hence large standard errors. Moreover, because of panel effects it would give false impressions of increases or decreases. Using subpackages of less than 9 panels suffer from similar problems, because including or excluding panels with small or large estimates would potentially distort any longterm trend or pattern.

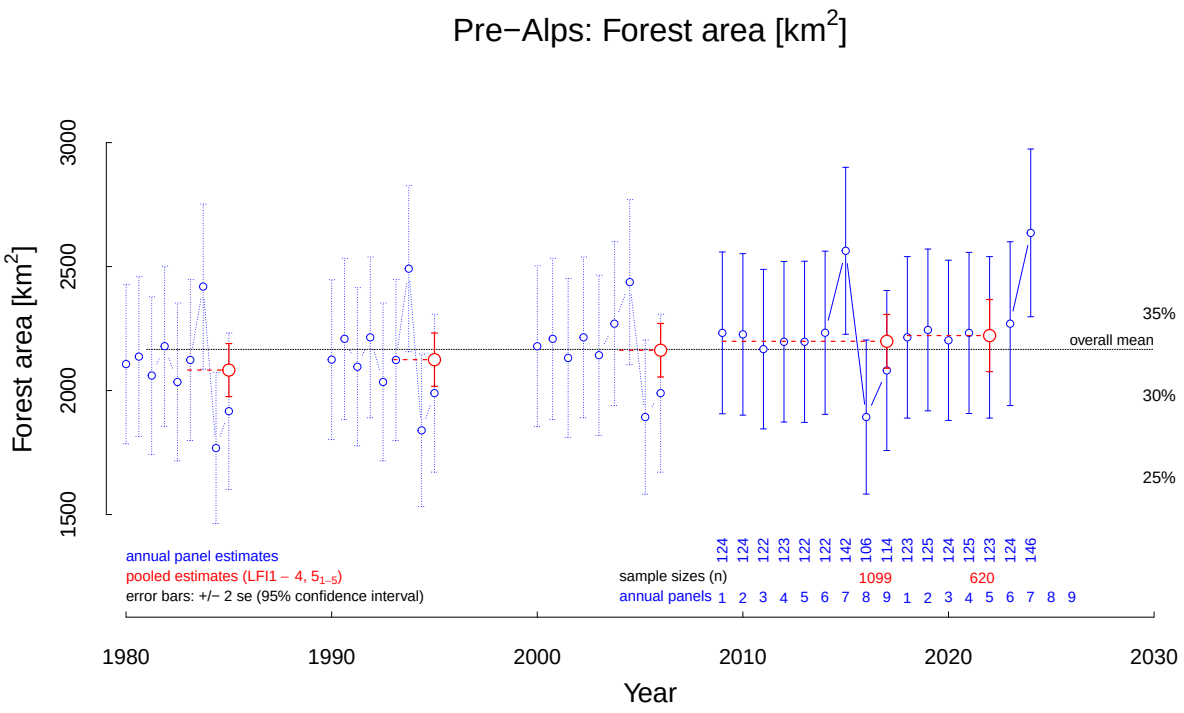

Figure 4: Forest area [km^2] of production region 'Pre-Alps'. The retrospectively assigned panels of LFI1–3 (dashed) are spread in time to graphically emphasize potential panel effects.

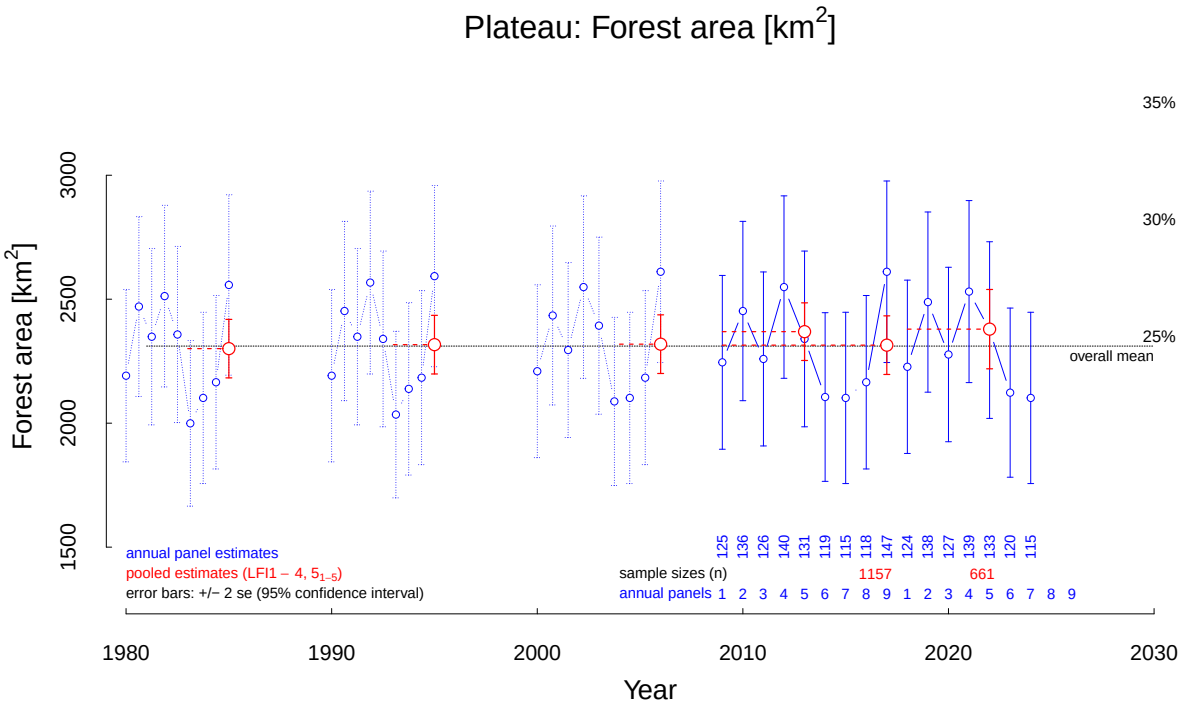

Figure 5: Forest area [km^2] of production region 'Plateau'. The retrospectively assigned panels of LFI1–3 (dashed) are spread in time to graphically emphasize potential panel effects. The two pooled estimates slightly above the overall mean are intermediate results for panels 1–5 of NFI4 and NFI5.

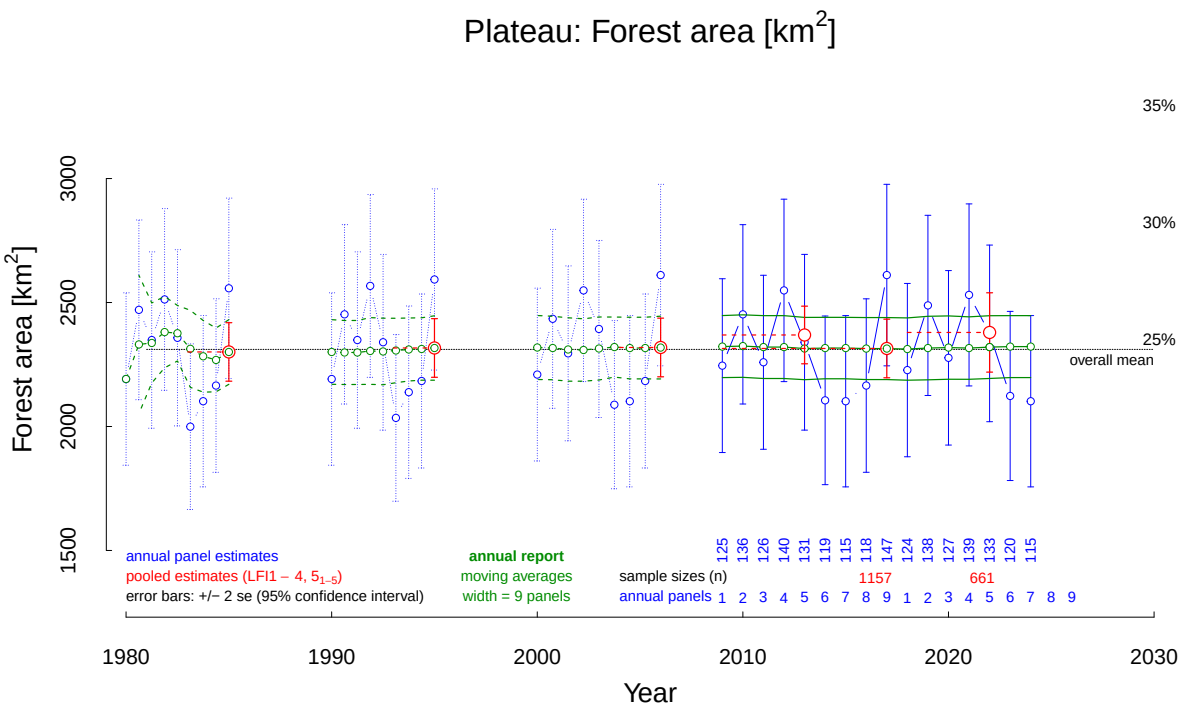

Figure 6: Forest area [km^2] of production region 'Plateau'. The retrospectively assigned panels of LFI1–3 (dashed) are spread in time to graphically emphasize potential panel effects. The two pooled estimates slightly above the overall mean are intermediate results for panels 1–5 of NFI4 and NFI5. Moving averages (green) including 9 panels and shifted by 1 each year with a 95% confidence band (dashed green) are shown to emphasize slight overestimation of forest area by intermediate results using panels 1–5 only.

For example, using the 5 most recent panels to report moving averages would lead to ups and downs in estimates of forest area (Fig. 7). These ups and downs clearly do not reflect longterm trends and should definitely not be interpreted as real changes driven by internal or external forces. They merely reflect panel effects.

On the other hand, right centered moving averages using 9 panels (i.e. the complete set of NFI panels) smooth out panel effects and convey the longterm trend in forest area across Switzerland (Fig. 8). Finally, pooled estimates at the end of each cycle are identical to the moving averages and therefore coincide with previously reported results of Swiss NFI estimates. Nevertheless, such right centered moving averages of 9 panels shifted by one year steps could be used the annually up-date and report Swiss NFI results.

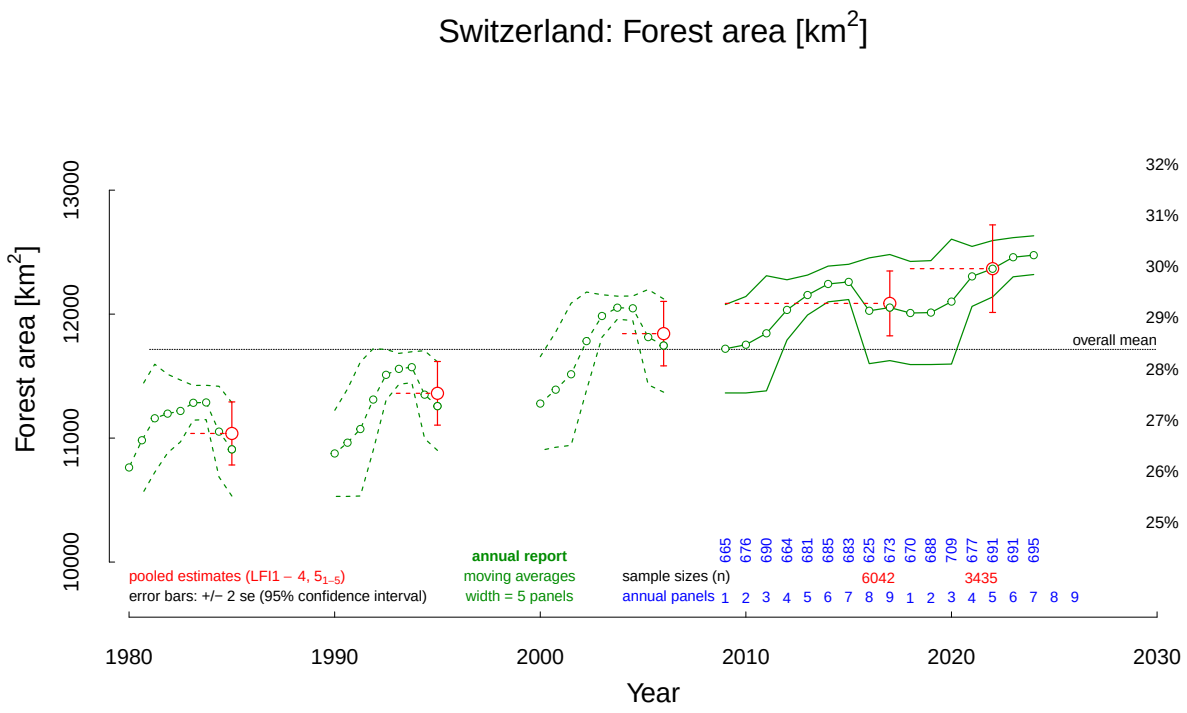

Figure 7: Forest area [km^2] with right centered moving averages (green) of 5 panels shifted by one year steps and 95% confidence intervall (dashed).

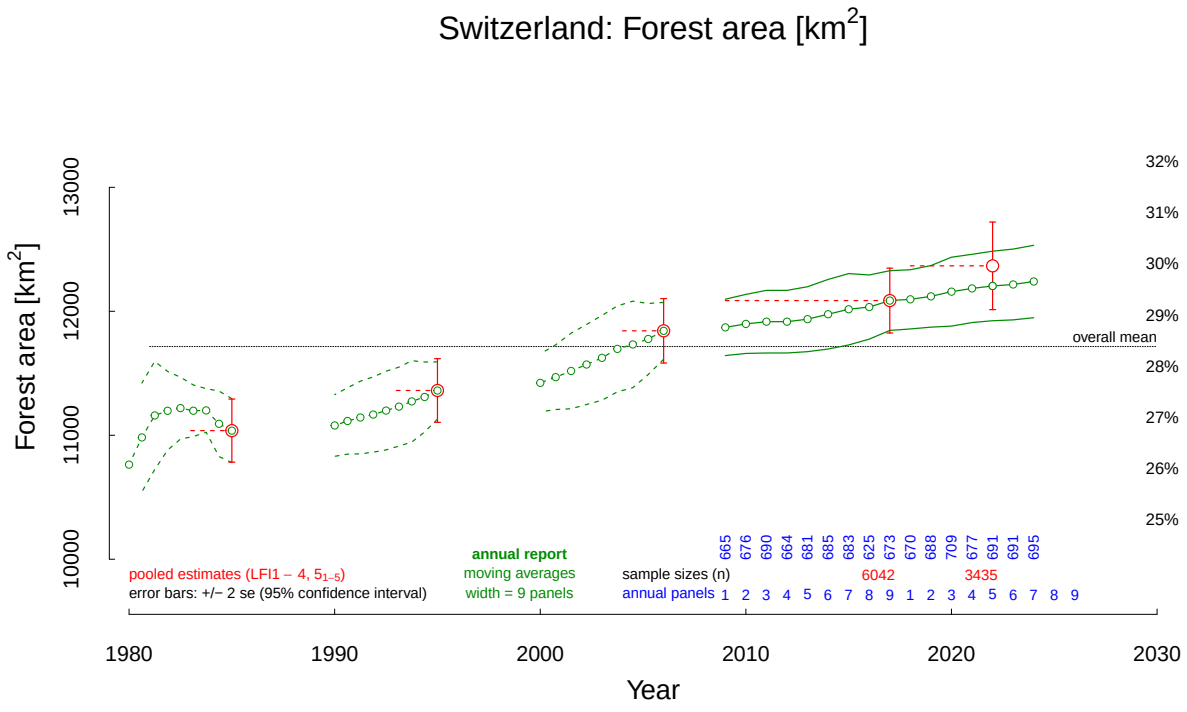

Figure 8: Forest area [km^2] with right centered moving averages of 9 panels shifted by one year steps and 95% confidence intervall (dashed). Moving averages for LFI1 vary because of increasing number of available panels.

2.2 Growing stock

Because growing stock (Tab. 1) is estimated using exactly the same terrestrial forest plots used to estimate forest area, the patterns in the panels area essentially identical to those for forest area. In other words, panel 8 always yields the lowest estimates for growing stock of Switzerland (Tab. 1, **Appendix**). That is, single plot estimates of growing stock are scaled to growing stock per hectare before summing them to growing stock of Switzerland. Since the ratio of forest plots to total number of sample points in the grid representative for the total area of Switzerland is used to estimate forest area, the panel effects for forest area are also seen in other NFI target variables such as for example growing stock. Consequently, the suggestions (see below) for possible annual up-dates in this report for forest area as target variable are also applicable for other target variables such as growing stock.

Note that means, i.e. growing stock per hectare (Hektardichten, m^3 ha^{-1}) are not as affected by panel effects as total growing stock (Tab. 1). This is because means as opposed to totals are not as directly linked to the number of forest plots[2].

Total growing stock in NFI4 (2009–2017) was 424.96 ± 6.24 Mio. m^3 if panels 1–9 were pooled and 424.88 ± 5.10 Mio. m^3 if panels 1–9 were averaged (Tab. 1). As for forest area, panel 8 produced the lowest etimate. Hectar densities or mean growing stock was lowest in panel 1 and for panels 7, 8 and 9 almost identical 352.9, 352.8 and 353.2 m^3 ha^{-1}, respectively.

Compared to pooled estimates, averages of 3 non-overlapping panels showed bigger estimates of growing stock for panels 4–6 and lower estimates for panels 7–9 (Tab. 2). Although differences were within ± 2 standard erros (approx. 95% confidence- or credibility intervall) and therefore not statistically significant, a decrease from 436 to 419 or roughly 17 Mio. m^3 in 3 years from 2014 to 2017 would probably be interpreted as substantial.

If we would use averages of 5 overlapping panels for our annual reporting, our estimates would first show in increase and then a decrease of growing stock in NFI4 from panels 1–5

[2]In addition, it may open an alternative estimation approach. Instead of estimating totals using the currently implemented approach, one could estimate means and subsequently extrapolate totals using estimated forest area (total = forest area * mean). However, such an approach would imply a shift away from classical inventory estimation procedures and algorithms to exclusively sample based estimation procedures and is therefore beyond the scope of the current report.

Table 1: Growing stock [Total, Mio. m^3, Mean or hectar density, m^3 ha^{-1}], NFI4 (2009–2017), NAFIDAS. Se: standard error, N.fpl: number of forest plots, N: number of grid points (1.4 × 1.4 km).

Year	Panel	Total	Se	Mean	Se	N.fpl	N
2009	1	405.69	17.80	339.59	9.96	665	2299
2010	2	423.06	18.38	346.96	10.16	676	2289
2011	3	431.47	18.48	348.58	9.99	690	2299
2012	4	441.46	19.09	367.99	10.34	664	2285
2013	5	424.73	18.26	346.56	9.84	681	2295
2014	6	440.45	19.51	355.43	11.18	685	2289
2015	7	433.18	20.12	352.85	12.04	683	2290
2016	8	395.61	17.50	352.78	10.15	625	2298
2017	9	428.26	18.97	353.18	10.63	673	2294
2009–2017	pooled, 1–9	424.96	6.24	351.60	3.52	6042	20638
2009–2017	average, 1–9	424.88	5.10	351.55	2.61	6042	20638

Table 2: Growing stock [Total, Mio. m^3], NFI4 (2009–2017). Averages of 3 non-overlapping panels. Se: standard error, N.fpl: number of forest plots, N: number of grid points.

Year	Panel	Total	Se	N.fpl	N
2009–2011	average, 1–3	420.07	7.59	2031	6887
2012–2014	4–6	435.55	5.42	2030	6869
2015–2017	7–9	419.02	11.79	1981	6882

Table 3: Growing stock [Total, Mio. m^3], NFI4 (2009–2017). Averages of 5 overlapping panels. Se: standard error, N.fpl: number of forest plots, N: number of grid points.

Year	Panel	Total	Se	N.fpl	N
2009–2013	average, 1–5	425.28	5.87	3376	11467
2010–2014	2–6	432.23	3.83	3396	11457
2011–2015	3–7	434.26	3.08	3403	11458
2012–2016	4–8	427.09	8.42	3338	11457
2013–2017	5–9	424.45	7.68	3347	11466

(2009–2013) to 3–7 (2011–2015) and 5–9 (2013–2017), respectively (Tab. 3). Finally, if we would have used averages of 9 overlapping panels as annual up-dates of our NFI-results as suggested in the current report, our estimates would have shown a more or less continuous increase from 410.6 to 424.9 Mio. m^3 from 2009 to 2017 (Tab. 4). This corresponds with the more or less continuous increase in forest are estimated with moving averages of 9 panels (Fig. 8).

Table 4: Growing stock [Total, Mio. m^3], NFI4 (2009–2017). Averages of 9 overlapping panels across inventories. Se: standard error, N.fpl: number of forest plots, N: number of grid points.

NFI3 Panel	NFI4 Panel	Year	Total	Se	N.fpl	N	annual report
1–9		2004–2006	410.18	6.16	5920	20638	
2–9	1	2009	410.63	7.35	5934	20638	2009
3–9	1–2	2009–2010	411.12	7.43	5948	20638	2010
4–9	1–3	–2011	411.05	7.41	5957	20638	2011
5–9	1–4	–2012	413.16	8.08	5957	20638	2012
6–9	1–5	–2013	413.76	8.16	5967	20638	2013
7–9	1–6	–2014	415.00	8.54	5987	20638	2014
8–9	1–7	–2015	416.73	8.78	6007	20638	2015
9	1–8	–2016	420.15	6.66	6016	20638	2016
	1–9	2009–2017	424.88	5.10	6042	20638	2017

2.3 Change components: mortality

Change components are exclusively estimated using permanent plots that are revisited every 9 to 10 years in the Swiss NFI. The estimates are usually standardised to vegetation periods by dividing raw estimates through the number of vegetation periods between observations. Consequently, estimates of change components such as annual mortality are much less affected by panel effects (Fig. 9), because differences at the level of individual trees naturally remove them similar to detrending by taking first differences in time series.

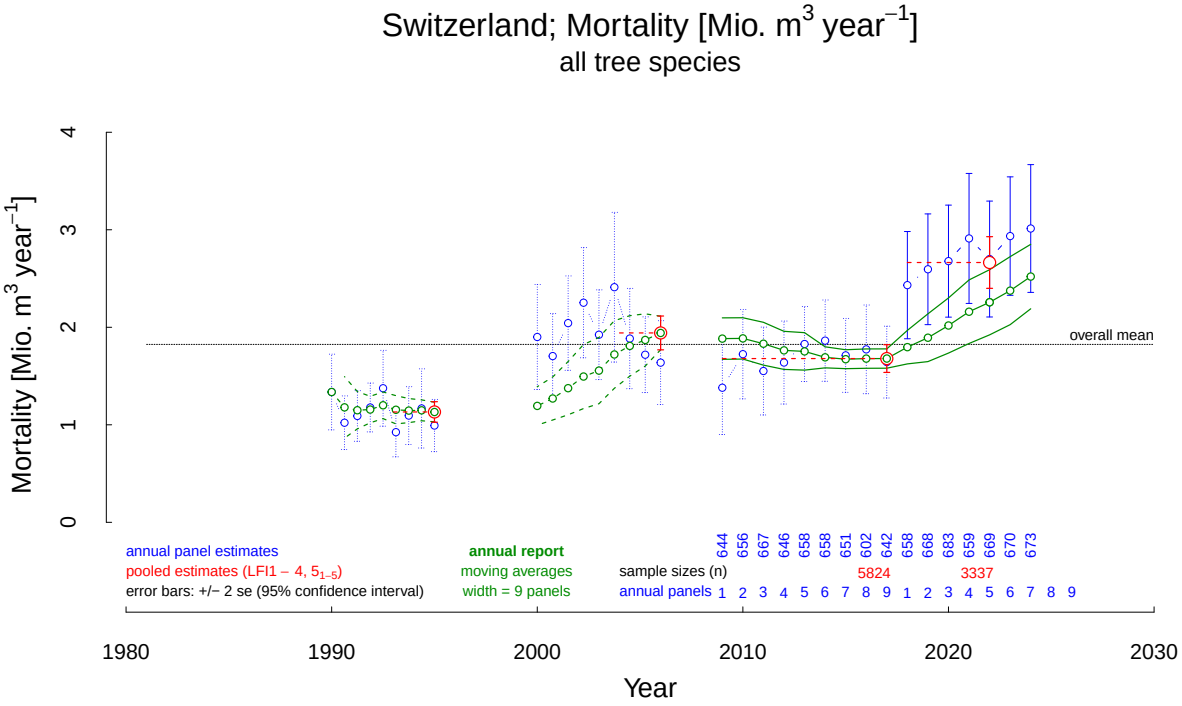

Figure 9: Natural mortality [Mio. m^3 $year^{-1}$] in Switzerlands forest. The retrospectively assigned panels of changes between LFI1/2, LFI2/3, LFI3/4 and LFI4/5 (dashed) are spread in time to graphically emphasize potential panel effects. Moving averages (green) including 9 panels and shifted by 1 each year with a 95% confidence band (dashed green) are shown as annual report which could be updated annually as newly measured terrestrial plots become available.

3 Mixed models

Various statistical models have often been used in estimation procedures known as model-assisted and model-based approaches (e.g. Gschwantner et al. 2022 and references therein). Among others, mixed models have been proposed repeatedly to deal with panel effects (e.g. Pereira and Coelho 2012; Swamy 1970; Magnussen, pers. comm.). Very briefly, they model panel effects by including random effects for intercepts and slopes of panels. Their main goal is to reduce uncertainty (se's) of fixed effect estimates. Fixed effects, i.e. polynomial terms for Year, $Year^2$ and $Year^3$ can be estimated with less uncertainty compared to ordinary linear regression without random panel effects. I used mixed models with increasing complexity and fitted them to the NFI panels in order evaluate their suitability to up-date NFI results with newly available panels each year.

Detailed results are given in the **Appendix**.

The analyses showed that mixed models did not bring any noticeable advantage in terms of accuracy or precision compared to the moving averages proposed in the report to be used in reporting annual up-dates.

Mixed models, however, could be used in forecasting in the sense of indicating future development of Switzerlands forest as a prognosis rather than a prediction.

4 Summary

- Annual panels
  - have relatively low sample sizes and hence large standard errors
  - convey specific patterns, especially for forest area
  - should not be used to report short term changes because comparing single panels mixes sample variation with temporal variation caused by real changes
- Weighting
  - sophisticated weighting schemes (Gompertz, not shown) are difficult to justify
  - giving past estimates lower weights emphasizes panel effects and
  - is similar to decreased lags or window sizes (3, 5 instead of 9)
  - at lag 0, we are back to the annual panel estimates
- Fitted model predictions from **mixed models**
  - mixed models (cf. **Appendix**) could also provide annual up-dates
  - are not more accurate or precise than moving averages
  - would be much more difficult to communicate than moving averages
  - could, however, be used to forecast (as opposed to predict) future development

5 Conclusions

- **Reporting**: **annual up-dates**
  - use current panel mean and previous 8 panel means **without weights**
  - shift country wide sample of 9 annual panels by 1 each year
  - use graphical representation (e.g. Fig. 8) to **convey longterm trends**
- **Maintain historic structure**. A full NFI-cycle is finished after 9 years. The reported annual up-date at the end of a cycle or inventory is identical to previously reported estimates pooling 9 panels.

None of the possibilities to estimate growing stock or any other variable is less or more correct (further or closer to the unknown 'true' value) given the available data and algorithms to calculate the estimates. Each has its advantages and disadvantages. Nevertheless, we should be aware of the messages they might send to our stakeholders and the public. Variations among and differences between estimates of single panels should, in **my opinion**, be interpreted as mainly driven by sample variation although part of it is undoubtedly driven by real changes. However, because the original intention of the Swiss National Forest Inventory was monitoring longterm trends, our results should emphasize these longterm trends and this goal might be achieved most adequately using averages of 9 subsequent panels shifted by one each year to report annual up-dates.

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Appendix: Mixed model results

1. Introduction

Mixed models have been proposed repeatedly to deal with panel effects (e.g. Swamy 1970, Pereira and Coelho 2012, Magnussen, pers. comm.). Very briefly, they model panel effects by including random effects for intercepts and slopes of panels. Their main goal is to **reduce uncertainty (se's) of fixed effect estimates**. Fixed effects, i.e. polynomial terms for Year, Year^2 and Year^3 can be estimated with less uncertainty compared to ordinary linear regression without random panel effects. I used mixed models with increasing complexity and fitted them to the NFI panels in order evaluate their suitability to up-date NFI results with newly available panels each year.

To judge the adequacy of the mixed models and compare them with moving averages, pooled panel estimates are plotted analogous to Fig. 3 in the main text. Table **"NAFIDAS: METHOD/LFI"** summarizes published estimates together with sample sizes.

Table **Model selection** summarizes results using Akaikes information criterion (AIC) to find the best model among a set of competing candidate models. Results are reported as **AIC Tables** and tables of **Parameter estimates** with confidence intervals (CI). To compare results (fitted values) of mixed models with simple moving averages, both were included in the figures. Finally, table **"Comparison with lm"** summarizes parameters, standard errors and CIs of linear models without random effects fitted with ordinary least square (OLS) methods.

Brief descriptions of the main findings and conclusions are included after each figure or table.

Fazit: Mixed models do not substantially increase the accuracy or precision of information compared to simple moving averages.

You get carried away - vom Hundersten ins Tausendste.

Do not use mixed models to report annual up-dates of NFI results.

Use moving averages to report annual up-dates of NFI results.

2. Forest area

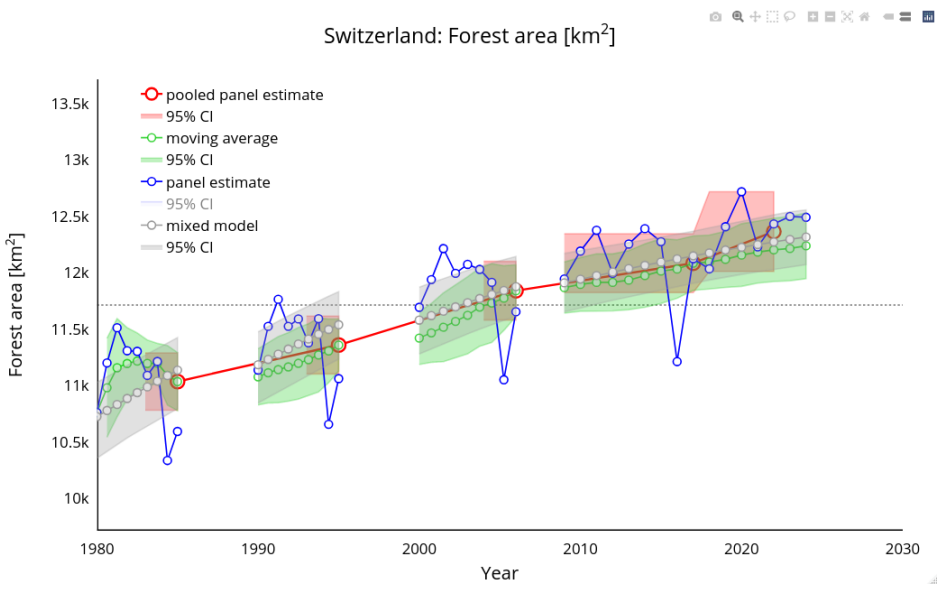

Figure 1: Forest area

Comparing (**hint:** use legend entries to show/hide in interactive version) the estimates and confidence bands of pooled panel estimates (red), moving averages (green), and the best mixed model (grey, l.2, see below) revealed no substantial differences in precision and accuracy of forest area. Overlaying panel estimates (blue) showed that panel 8 always yields the lowest estimate of all 9 panels within complete NFI cycles.

Table 1: **NAFIDAS:** METHOD/NFI

Inventur	Forest area	Standard error	N.Ziel	N.fpl	N.fpl.nezero	N
NFI1, 1-9	11037.43	127.18	64414	5517	5336	20638
NFI2, 1-9	11361.26	128.34	67297	5679	5490	20638
NFI3, 1-9	11842.61	129.98	69960	5920	5691	20638
NFI4, 1-9	12086.46	130.76	71906	6042	5827	20638
NFI5, 1-5	12366.70	176.60	40537	3435	3335	11467

N.Ziel: Number of trees. **N.fpl:** Number of terrestrial forest plots. **N.fpl.nezero:** N.fpl. > 0. **N:** Number of grid (1.4 $\times$ 1.4 km) points.

Table 2: **Model selection:** AICc Table.

Model names	Fixed effects	Random effects	AICc	Delta	AICw
l.0	Year	intercept	569.6	6.3	0.039
l.1	Year	intercept + slope	569.2	5.8	0.050
l.2	Year + Year^2	intercept + slope	563.4	0.0	0.894
l.3	Year + Year^2 + Year^3	intercept + slope	571.3	7.9	0.017

AICc: Akaikes information criterion, corrected. **Delta:** Delta AIC = AICc - min(AiCc), 0 for best model (analogous to highest R^2). **AICw:** Akaike weight or model probability given the set of candidate models ($\sum$ AICw = 1).

The model with random intercepts and slopes and a non-linear, quadratic Year effect (l.2) clearly outperformed (AICw = 0.9) the others (AICw < 0.05). Deltas of the other models (l.0, l.1 and l.3) were all > 2.0 indicating considerably less support than the best (l.2) given the data and the set of candidate models.

Table 3: **Parameter estimates** and 95% confidence interval (CI) from mixed model (l.2) with random panel effects for intercepts and slopes.

	Fixed effects	Standard error	CI 2.5%	CI 97.5%
intercept	10691.43	171.37	10338.74	11041.83
Year	54.40	5.41	43.68	64.94
Year^2	-0.38	0.10	-0.57	-0.18

Confidence intervals of parameter estimates showed that all fixed effects were significantly different from 0. The linear Year effect was positive and the non-linear quadratic Year effect was negative indicating that the rate of increase in forest area decreased over time.

In contrast, Year effects were not significantly different from 0 when estimated from ordinary linear models without random panel effects (below). Thus, fitting mixed models with random panel effects clearly reduced the standard errors which is just another way of **demonstrating significant panel effects** in the Swiss NFI data.

Table 4: **Comparison with lm**: without random panel effects for intercepts and slopes.

	Estimate	Standard error	CI 2.5%	CI 97.5%
intercept	10915.32	199.52	10512.08	11318.57
Year	32.45	19.92	-7.81	72.71
Year^2	0.08	0.42	-0.77	0.93

3. Growing stock

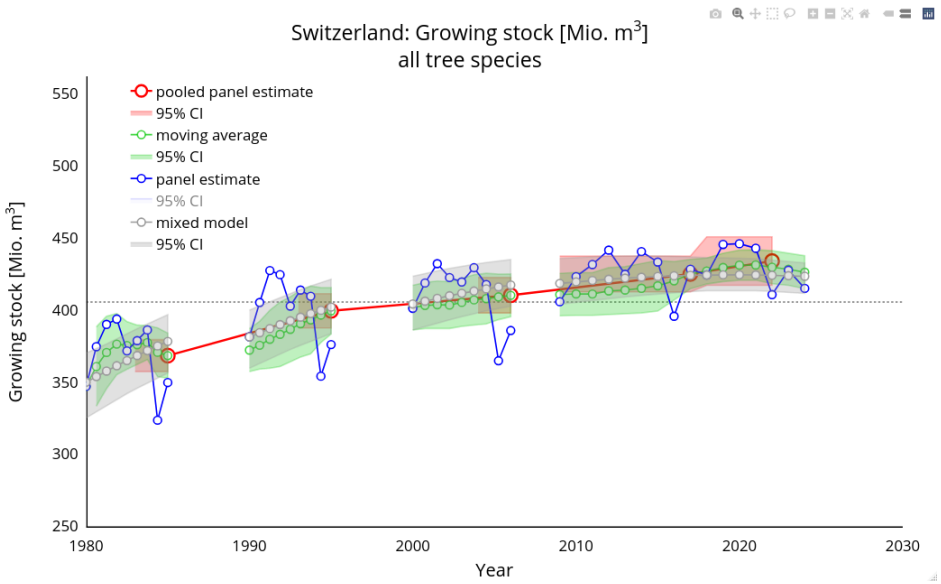

Figure 2: Growing stock

Comparing (**hint:** use legend entries to show/hide in interactive version) the estimates and confidence bands of pooled panel estimates (red), moving averages (green), and the best mixed model (grey, l.2, see below) revealed no substantial differences in precision and accuracy of forest area. Overlaying panel estimates (blue) showed that panel 8 always yields the lowest estimate of all 9 panels within complete NFI cycles.

Table 5: **NAFIDAS:** METHOD/NFI

Inventur	Growing stock	Standard error	N.Ziel	N.fpl	N.fpl.nezero	N
NFI1, 1-9	368.31	5.54	64414	5517	5336	20638
NFI2, 1-9	399.36	5.95	67297	5679	5490	20638
NFI3, 1-9	410.18	6.16	69960	5920	5691	20638
NFI4, 1-9	424.96	6.24	71906	6042	5827	20638
NFI5, 1-5	433.86	8.40	40537	3435	3335	11467

N.Ziel: Number of trees. **N.fpl:** Number of terrestrial forest plots. **N.fpl.nezero:** N.fpl. > 0. **N:** Number of grid (1.4 $\times$ 1.4 km) points.

Table 6: **Model selection**: AICc Table.

Model names	Fixed effects	Random effects	AICc	Delta	AICw
l.0	Year	intercept	365.7	12.1	0.002
l.1	Year	intercept + slope	364.9	11.4	0.003
l.2	Year + Year^2	intercept + slope	353.5	0.0	0.994
l.3	Year + Year^2 + Year^3	intercept + slope	368.8	15.3	0.000

AICc: Akaikes information criterion, corrected. **Delta:** Delta AIC = AICc - min(AiCc), 0 for best model (analogous to highest R^2). **AICw:** Akaike weight or model probability given the set of candidate models ($\sum$ AICw = 1).

The model with random intercepts and slopes and a non-linear, quadratic Year effect (l.2) clearly outperformed (AICw > 0.99) the others (AICw < 0.001). Deltas of the other models (l.0, l.1 and l.3) were all > 10.0 indicating essentially no support given the data and the set of candidate models.

Table 7: **Parameter estimates** and 95% confidence interval (CI) from mixed model (l.2) with random panel effects for intercepts and slopes.

	Fixed effects	Standard error	CI 2.5%	CI 97.5%
intercept	347.31	11.70	323.22	371.04
Year	3.98	0.46	3.08	4.88
Year^2	-0.05	0.01	-0.07	-0.03

Confidence intervals of parameter estimates showed that all fixed effects were significantly different from 0. The linear Year effect was positive and the non-linear quadratic Year effect was negative indicating that the rate of increase in growing stock decreased over time.

In contrast, Year effects were only marginally significantly different from 0 and non-linear Year effects were not significantly different from 0 if estimated from ordinary linear models without random panel effects (below). Thus, fitting mixed models with random panel effects clearly reduced the standard errors which is just another way of **demonstrating significant panel effects** in the Swiss NFI data.

Table 8: **Comparison with lm**: without random panel effects for intercepts and slopes.

	Estimate	Standard error	CI 2.5%	CI 97.5%
intercept	358.31	11.75	334.56	382.06
Year	2.95	1.17	0.58	5.32
Year^2	-0.03	0.02	-0.08	0.02