Eickenscheidt N, Augustin N, Wellbrock N (2019).
Spatio-temporal modelling of forest monitoring data: modelling German tree defoliation data collected between 1989 and 2015 for trend estimation and survey grid examination using GAMMs
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Supplementary Material

Appendix 1 - R code example for spatio-temporal modelling.

```
library(mgcv)
library(Hmisc)     #for wtd.quantile()
library(MASS)      #for mvrnorm()

# 1) fit spatio-temporal model

#def is defoliation [%]/100; 0 and 1 need to be set a little bit higher and lower,
respectively
#x,y are the coordinates
#n_tree is the number of spruce trees per sampling location

#set up factor for sampling location
data$xy <- factor(paste(data$x, data$y,sep=""))

mod <- gamm(def~te(y,x,year,bs=c("tp","cr"),d=c(2,1),k=c(25,20))
+s(age,bs="cr",k=10),data=data,
correlation=corARMA(form=~year|xy,p=1,q=1),family=gaussian(link="logit"),
weights=data$n_tree, method="REML")


# 2) plot of age effect
int<-mod$gam$coefficient[1]
max_age<-max(data$age)
plot(mod$gam,residuals=FALSE,shade=TRUE,shift=int,trans=function(x)exp(x)/
(1+exp(x))*100,
xlim=c(0,max_age),ylim=c(-2,2),las=1,ylab="",xlab="")


# 3) map

mod$gam$data<-data
med_age<-
wtd.quantile(data$age[data$year==2015],weights=data$n_tree[data$year==2015],probs=0.5)

par(mfrow=c(5,3),oma=c(3,2,0.5,2),mar=c(0.5,1,2,1))
for(i in 1989:2003){
      vis.gam(mod$gam,view=c("x","y"),zlim=range(0,0.75),cond=list(year=i,age=med_age),
       n.grid =
      60,plot.type="contour",type="response",too.far=0.02,nCol=12,color="terrain",
       main=i,xaxt="n",yaxt="n",ylim=c(5200000,6100000),xlim=c(4000000,4800000))}


# 4) plot of time trend (age- and grid-adjusted)

n.sim<- 1000
gobject<- mod$gam
backt <- gobject$family$linkinv
dat <- gobject$data
indi <- order(dat$year)
dat <- dat[indi, ]
pred_age<-med_age

uniq.loc <- unique(dat$xy)
years <- unique(dat$year)
```

```
# is x coordinate
nx <- rep(as.numeric(substring(uniq.loc, 1, 7)), length(years))

# is y coordinate
ny <- rep(as.numeric(substring(uniq.loc, 9, 15)), length(years))
nyear <- rep(years, rep(length(uniq.loc), length(years)))
nage <- rep(pred_age, length(nyear))

ndat <- list(nx, ny, nyear, nage)
names(ndat) <- c("x", "y", "year", "age")
ndat <- data.frame(ndat)

# re-evaluate smoother basis for new data and use this as design matrix
M <- predict(gobject, newdata = ndat, type = "lpmatrix")

# simulate from predictive distribution
simcoef <- mvrnorm(n = n.sim, coef(gobject), gobject$Vp)
simfit <- as.matrix(M) %*% t(simcoef)

#backtransform to response scale
simfit2 <- backt(simfit) * 100
simfit3 <- aggregate(simfit2, by = list(ndat$year), mean)
simfit <- simfit3[, -1]

#2.5, 50% und 97.5% quantiles
simquant <- apply(simfit, 1, quantile, p = c(0.025, 0.5, 0.975))

plot(years, simquant[2, ], type = "p", pch = 19,cex=0.5,col = 1, ylim = c(0, 40), xlab
= "", ylab = "Defoliation[%]", axes = F)

axis(2,las=1); axis(1, at = years, labels = as.character(sort(unique(data$year))))
lines(years, simquant[2, ], lty = 4, col = 1)
lines(years, simquant[1, ], lty = 1, col = 1)
lines(years, simquant[3, ], lty = 1, col = 1)
```

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Fig. S1 - Results of spatio-temporal modelling of defoliation for spruce from 1989 to 2015 using a nationwide consistent stand age of 73 years. Modelled defoliation is indicated in colour (see legend) and the isolines further reflect the modelled defoliation (e.g. 0.2 is 20%). The sample plots for the respective year are shown as points. Black points indicate plot defoliation < 25% and red points indicate plot defoliation ≥ 25% (observed defoliation at given actual stand age).

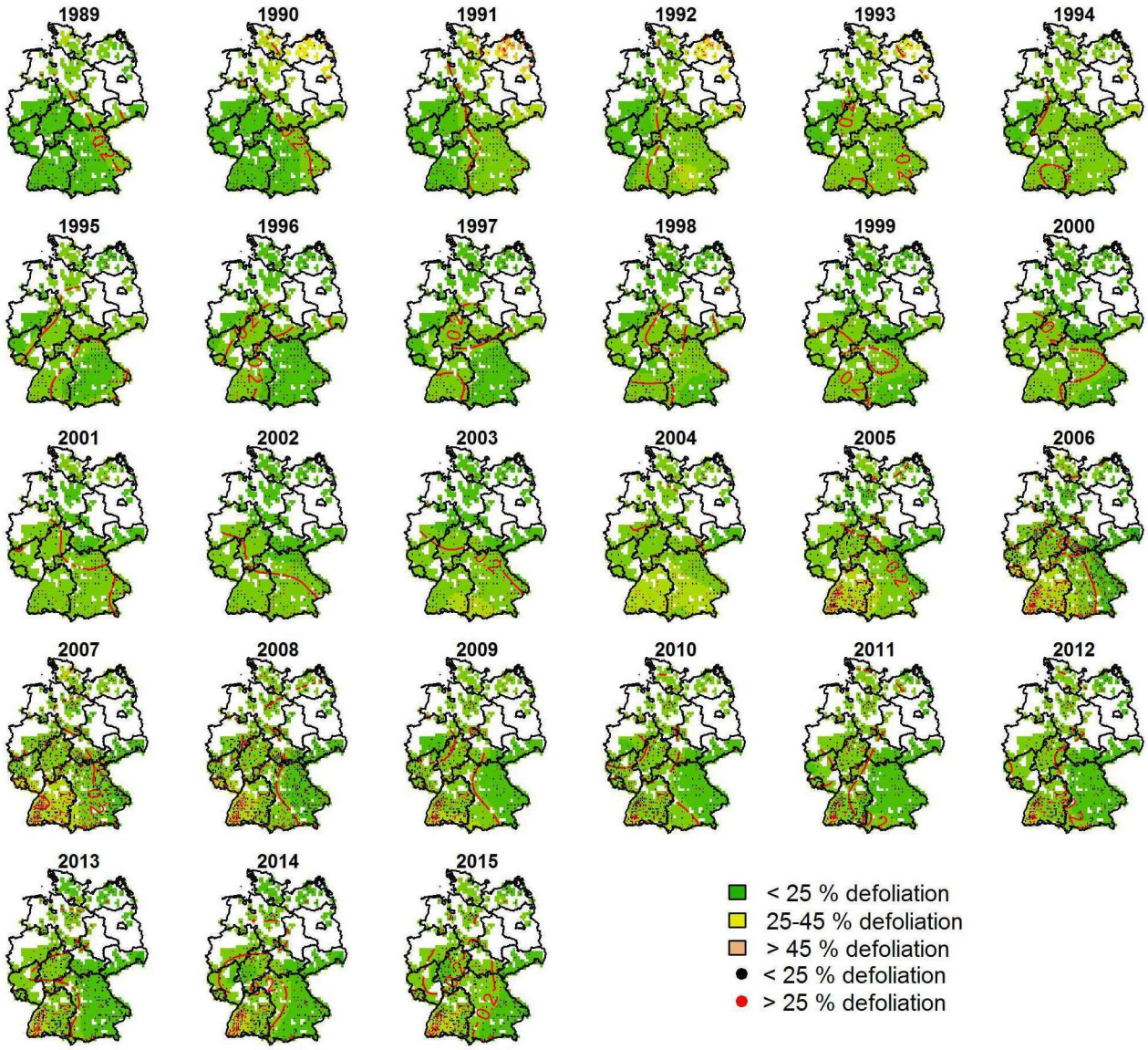

Fig. S2 - Results of spatio-temporal modelling of defoliation for pine from 1989 to 2015 using a nationwide consistent stand age of 86 years. Modelled defoliation is indicated in colour (see legend) and the isolines further reflect the modelled defoliation (e.g. 0.2 is 20%). The sample plots for the respective year are shown as points. Black points indicate plot defoliation < 25% and red points indicate plot defoliation ≥ 25% (observed defoliation at given actual stand age).

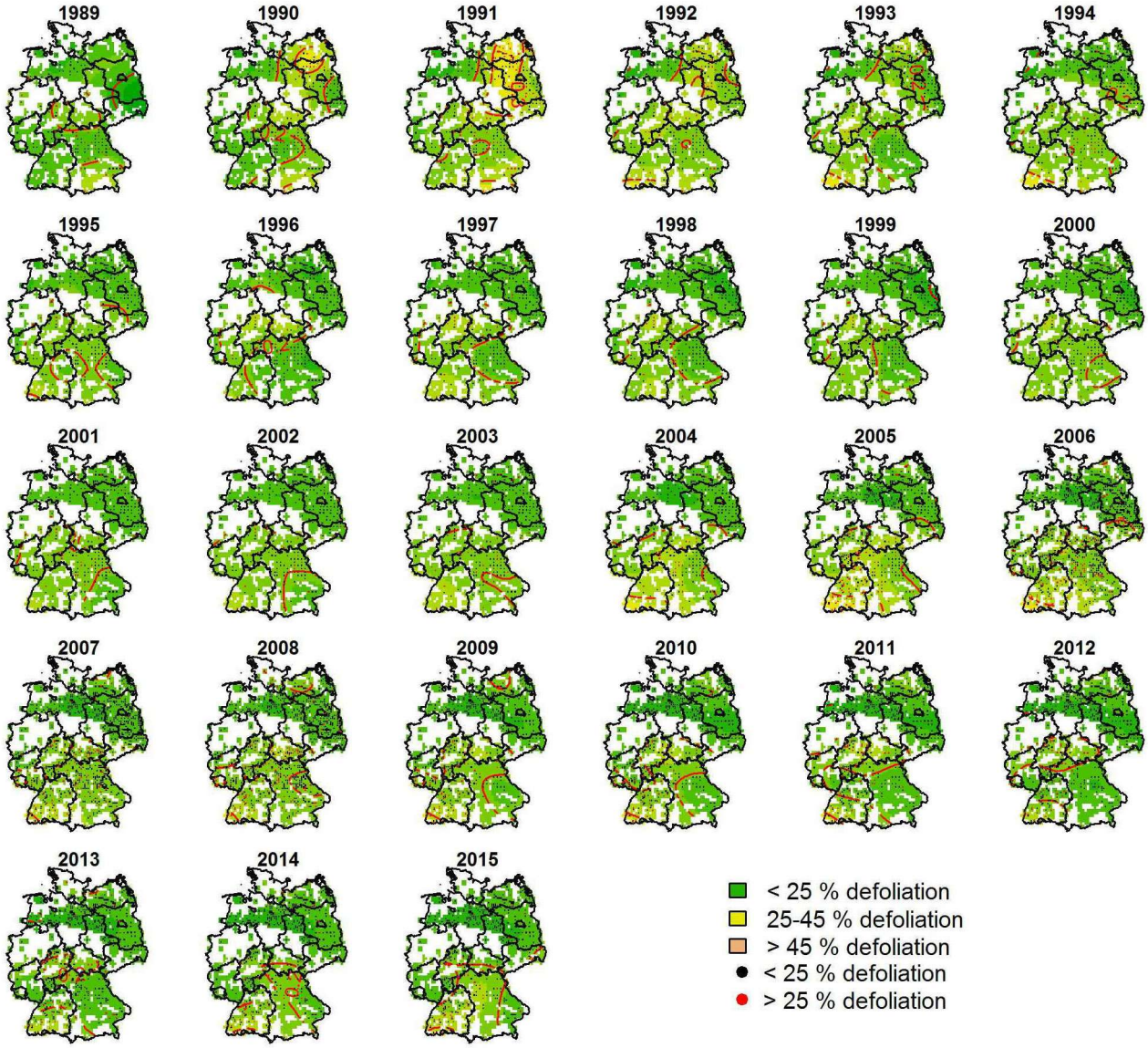

Fig. S3 - Results of spatio-temporal modelling of defoliation for oaks from 1989 to 2015 using a nationwide consistent stand age of 110 years. Modelled defoliation is indicated in colour (see legend) and the isolines further reflect the modelled defoliation (e.g. 0.2 is 20%). The sample plots for the respective year are shown as points. Black points indicate plot defoliation < 25% and red points indicate plot defoliation ≥ 25% (observed defoliation at given actual stand age).

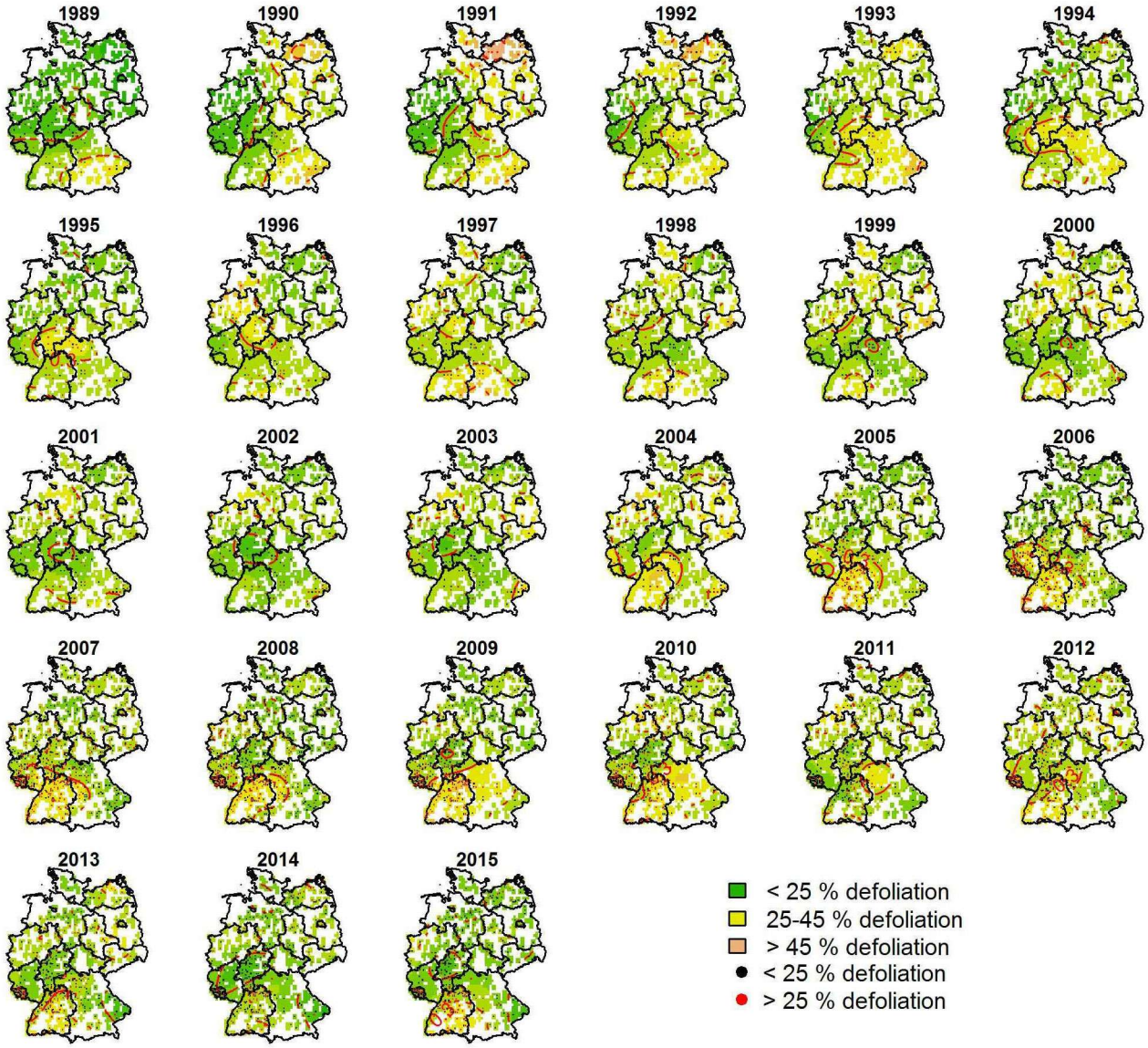

Fig. S4 - Highest estimated root mean prediction error ($RMPE_{it}$) of defoliation in pine for the grid densification (at least 8 × 8 km grid) and 16 × 16 km grid (approach II) for the years 2006 to 2015. Black points indicate all possible sample plots (corresponds to the grid densification). The grey circles show the sample plots considered for the estimation of the RMPE (grid densification and 16 × 16 km grid, respectively). Blue crosses indicate $RMPE_{it}$ > 5% and red triangles $RMPE_{it}$ > 10%. The federal states Rhineland-Palatinate, Saarland and Schleswig-Holstein have grid densities that deviate from 8 × 8 km (denser grids).

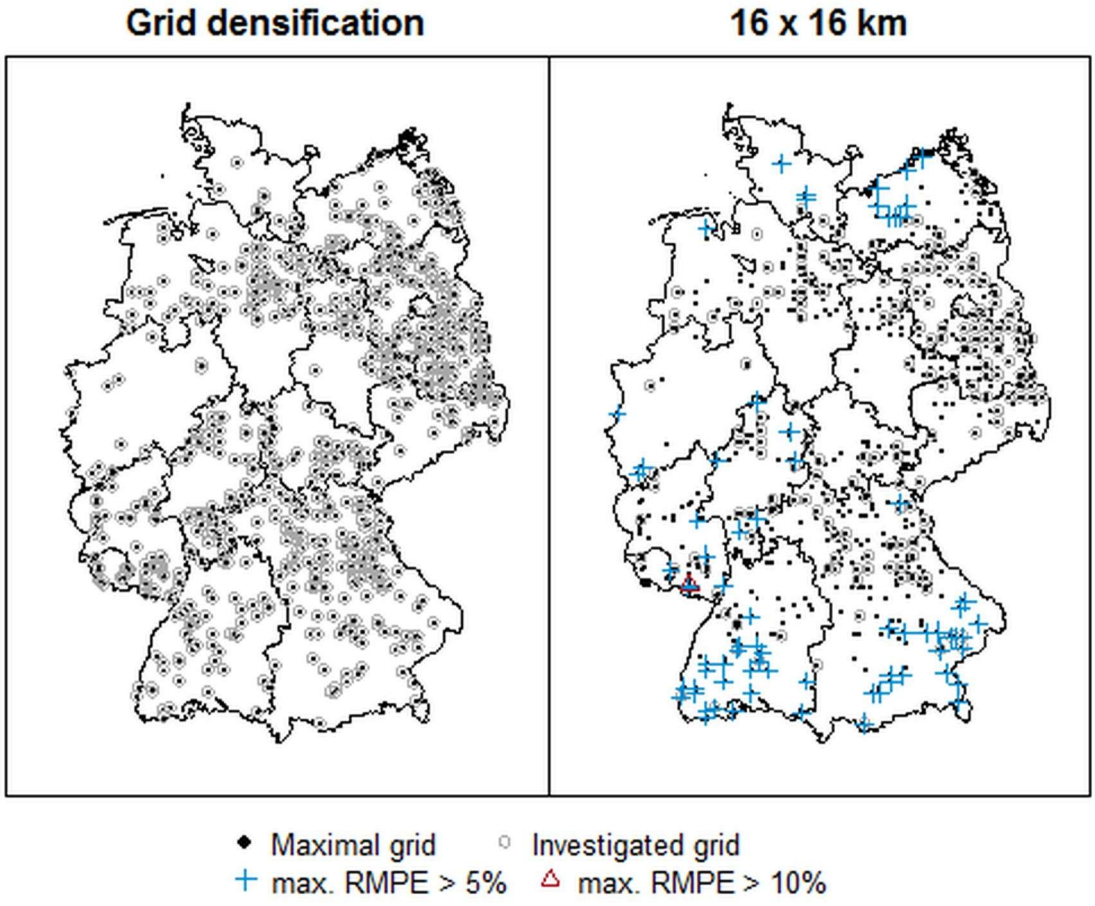

Fig. S5 - Highest estimated root mean prediction error ($RMPE_{it}$) of defoliation in beech for the grid densification (at least 8 × 8 km grid) and 16 × 16 km grid (approach II) for the years 2006 to 2015. Black points indicate all possible sample plots (corresponds to the grid densification). The grey circles show the sample plots considered for the estimation of the RMPE (grid densification and 16 × 16 km grid, respectively). Blue crosses indicate $RMPE_{it}$ > 5% and red triangles $RMPE_{it}$ > 10%. The federal states Rhineland-Palatinate, Saarland and Schleswig-Holstein have grid densities that deviate from 8 × 8 km (denser grids).