Ecography

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## Supplementary material

Appendix 1) **Features used for the echo classification and WBF estimation**

***Table A1**: Description of features used for the echo classification and WBF assessment.*

| **Feature category** | **Description** | **Used for** |
|---|---|---|
| Fundamental Frequency Estimators (FFE) | These features are 'weak' estimators of the fundamental frequency of a signal. If WBF pattern is absent, the feature still has a numeric value. If WBF pattern is present, generally only a subset of the values are valid approximations. | Echo classifier and WBF estimator |
| FFE-prominence | These features estimate the prominence of the spectral peaks used for the FFE and can be understood as a rough metric of quality for these features | Echo classifier and WBF estimator |
| Radar Cross Section (RCS) | This is an estimator of Radar Cross Section i.e. a target's intrinsic reflectivity which is a crude approximation of a target's size. It often underestimates the actual size. | Echo classifier only |
| Relative Magnitude of Fluctuations | These features estimate the relative magnitude of fluctuations in target's reflectivity. | Echo classifier only |

Appendix 1) **Estimated object size**

***Table A2**: Reference RCS from the 0.90 RCS quantile distribution.*

| **WBF [Hz]** | $\sqrt[2]{RCS}$ **[cm]** | | |
|---|---|---|---|
| | Unidentified-bird-type | Passerine-type | Wader-type |
| **2** | 11.92 | 5.73 | 10.43 |
| **3** | 11.92 | 5.73 | 10.43 |
| **4** | 11.92 | 5.73 | 10.43 |
| **5** | 11.92 | 5.73 | 10.43 |
| **6** | 11.28 | 5.73 | 10.50 |
| **7** | 11.28 | 5.73 | 10.50 |
| **8** | 8.46 | 5.73 | 9.74 |
| **9** | 8.46 | 5.73 | 9.74 |
| **10** | 6.33 | 5.53 | 5.36 |
| **11** | 6.33 | 5.53 | 5.36 |
| **12** | 6.17 | 4.17 | 7.84 |
| **13** | 6.17 | 4.17 | 7.84 |
| **14** | 4.74 | 3.83 | 5.69 |
| **15** | 4.74 | 3.83 | 5.69 |
| **16** | 4.57 | 3.73 | 4.04 |
| **17** | 4.57 | 3.73 | 4.04 |
| **18** | 4.57 | 3.47 | 4.04 |
| **19** | 4.57 | 3.47 | 4.04 |
| **20** | 4.57 | 3.43 | 4.04 |
| **21** | 4.57 | 3.43 | 4.04 |
| **22** | 4.57 | 2.91 | 4.04 |
| **23** | 4.57 | 2.91 | 4.04 |
| **24** | 4.57 | 2.81 | 4.04 |
| **25** | 4.57 | 2.81 | 4.04 |
| **NA** | 7.63 | 4.48 | 9.84 |

Appendix 3) **Monitored volume**

**Table A3**: Maximal detection distance $D_{max}$ and effective beam area (and volume) depends on the sensitivity settings (threshold $P_{r_{min,dBm}}$ and $STC$) assuming a typical object size of 15cm-diameter, transmitted power $P_t$ of 20 kW, and the antenna diagram provided by the manufacturer.

| $P_{r_{thresh}}$ [dBm] | $D_{STC}$ [m] | 0.002 m² RCS | | | 0.02 m² RCS | | |
|---|---|---|---|---|---|---|---|
| | | $D_{max}$ | Total area | Total volume | $D_{max}$ | Total area | Total volume |
| -93 | 300 | 747 | 106692 | 13604635 | 1375 | 359324 | 82030323 |
| -90 | 300 | 621 | 74012 | 7914088 | 1149 | 251136 | 48263623 |
| -87 | 300 | 514 | 50905 | 4539960 | 959 | 174954 | 28290276 |
| -83 | 300 | 398 | 30163 | 2072093 | 752 | 107968 | 13848747 |
| -93 | 500 | 747 | 98239 | 12054358 | 1375 | 344685 | 78445031 |
| -90 | 500 | 621 | 64465 | 6315161 | 1149 | 240013 | 45818300 |
| -87 | 500 | 514 | 36326 | 2448002 | 959 | 165937 | 26455878 |
| -83 | 500 | 0 | 0 | 0 | 752 | 99417 | 12271716 |

Appendix 4) **Influence of site identity on the RCS distributions**

Using 0.90-quantile of the RCS distribution, for Passerines only and finite WBF:

```
> lme2 <- lme(sqrt_rcs_cm ~ wff_2Hz.of, random= ~ 1|siteID.f, data=t.RCS,
+              control=list(maxIter = 100))
> summary(lme2)
Linear mixed-effects model fit by REML
 Data: t.RCS
       AIC      BIC    logLik
  395.4264 435.8037 -184.7132

Random effects:
 Formula: ~1 | siteID.f
        (Intercept)  Residual
StdDev:   0.1729352 0.6565083

Fixed effects: sqrt_rcs_cm ~ wff_2Hz.of
                 Value  Std.Error  DF   t-value p-value
(Intercept)    4.058476 0.07348146 155  55.23129  0.0000
wff_2Hz.of.L  -2.075781 0.16412707 155 -12.64740  0.0000
```

The between-site variance (0.17 ± 0.65) is about 20 times smaller than the averaged site value (Intercept 4.06 ± 0.07) and 10 times smaller than the decrease in RCS per two-Hertz (-2.08 ± 0.16).

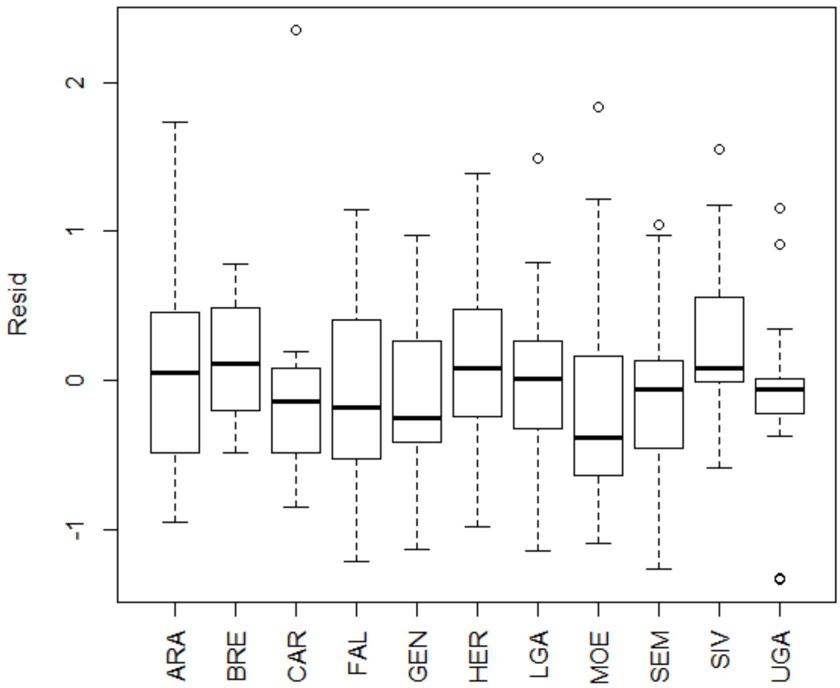


Figure A3: Between site variance of the square-root RCS corrected for the wingbeat frequency (sample size indicated on top).

Appendix 5) **R-Functions**

## funMinRCS

```
#*-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-*#
# original function snippet from Dominik Kleger, SwissBird Radar
TS = -93 # dBm as for Pr_min
Hmax = 300 # m as for STCdist
Psend = 22 # kW as for Pt
Again = 20 # dBi as for G0
funMinRCS <- function(TS=numeric(), Hmax=numeric(), Psend=numeric(), Again=numeric()){
  min_rcs   <-   (10^(TS/10)   *   10^-3   *   Hmax^4   *   (4*pi)^3)/((Psend*10^3)   *   (10^(Again/10))^2   *
(3*10^8/(9.4*10^9))^2)
  out <- min_rcs
}
```

## funMTRfactor

```
#*-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-**-*#
# original function snippet from Dominik Kleger, SwissBird Radar
funMTRfactor = function(height, # distance of the object [m]
                        rcs, # reference RCS in m2
                    waveguideAttenuation, # Attenuation of the transmitted and received power by the waveguide
[dB]
                        stc_level, # min dBm value possible for a given height, as for Pr_min_stc
                        Psend # in kW transmit power as for Pt
){

  # transform from kW to W
  transmitPower = Psend * 1000

  # MR1 specific parameters
  lut_phi_table = seq(0,90,5) # antenna diagram angle in Grad
  # diagram for "20dBiMR1"
  lut_lev_table = c(20, 19.5, 17, 10, 6, 0, -3, -10, -13, -17, -20, -20, -19, -19, -23, -30, -21, -25, -30)
   # antenna diagram Gain in dBi

  #- using flatten spline at phi=0
  xout <- unique(c(rev(seq(0, 90, 0.1)*-1), seq(0, 90, 0.1))) # use "unique" to avoid duplicated "0"
  int_res = spline(x = c(rev(lut_phi_table*(-1)),lut_phi_table), y = c(rev(lut_lev_table), lut_lev_table),
   xout = xout) # interpolate antenna diagram table
  #  plot(int_res$x,  int_res$y, ylab="level", xlab="phi", xlim=c(-100,100), col="green", type="l")
  #  points(lut_phi_table, lut_lev_table)
  #  abline(v=90)
  lut_lev = int_res$y[which(int_res$x >= 0)]
  lut_phi = int_res$x[which(int_res$x >= 0)]

  lut_lev_norm = lut_lev-lut_lev[1]
  antennaGain = 10^((lut_lev[1]-waveguideAttenuation)/10)
  f = 9.4e9 # electromagnetic wave frequency [Hz] or 9.4 GHz
  c = 3e8 # light speed
  # --> waveLength = c/f (see below in formula gainSTC)

  # ==================================================
  receiveLevelSTC = stc_level # alternatively use max(TS-40*log10(height/Hmax),  TS)
  receivePowerSTC = 10^(receiveLevelSTC/10)*1e-3
  gainSTC = sqrt(  (rcs*transmitPower*antennaGain^2*(c/f)^2) / ((4*pi)^3*height^4*receivePowerSTC)  )
  levelSTC = -10*log10(gainSTC)
  # values smaller than smallest antenna gain value -> set to value slightly higher than smallest antenna
   gain value
```

```
  index <- which(levelSTC <= lut_lev_norm[length(lut_lev_norm)])
  levelSTC[index] = lut_lev_norm[length(lut_lev_norm)] + 0.1
  # values bigger than biggest antenna gain value -> set value to zero
  index <- which(levelSTC >= lut_lev_norm[1])
  levelSTC[index] = 0

  # compute phiSTC
  phiSTC <- lapply(levelSTC, FUN=function(x){phiSTC = lut_phi[length(lut_lev_norm[lut_lev_norm > x])]})
  index <- which(levelSTC >= 0)
  phiSTC[index] <- 0
  index <- which(phiSTC < 0)
  phiSTC[index] <- 0
  phiSTC <- unlist(phiSTC)

  # get half-range
  halfRangeSTC = height*tan(phiSTC/180*pi) # convert to m
  # get full horizontal distance
  RangeSTC = 2*halfRangeSTC # m
  # get MTR-factor
  MTRFactor = 1000*(1/RangeSTC) # convert to "targets per meter" and then to "targets per km"
  MTRFactor[!is.finite(MTRFactor)] <- 0
  # ==================================================

  return( data.frame("mtrf"=MTRFactor, "RangeSTC"=RangeSTC, "halfRangeSTC"=halfRangeSTC) )
}
# end function body
```