Do species **revisit the same places** in successive seasons?
A **new metric** can help us find out.

Using the earth mover's distance to assess changes in species' spatial distribution

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INTRO

To identify changes in spatial distribution across a given region (e.g., a country), it helps to have a measure of how similar the distribution was in (say) successive years. We advocate the use of the **earth mover's distance** (**EMD**) for monitoring data. Advantages of this metric include its **meaningful interpretation** and the **availability of tools** that facilitate its calculation for bird monitoring data **in R**.

~~EARTH~~ BIRD MOVER'S DISTANCE?

The **average distance an individual would have to travel** if we were to turn this year's distribution of counts across monitored sites (**Table 1**) into that from the last year **with minimum effort**.

CALCULATION

We need an **optimal flight plan**: one that **minimizes the total kilometrage** the birds need to fly to turn one spatial distribution into the other (**Figure 1, Table 2**). In operations research, this is known as the **transportation problem**. Several **polynomial-time** algorithms exist, some of them implemented **in R**. We used the **emdist** package, combined with **geosphere** to calculate site distances based on their latitude and longitude (**Figure 2**).

APPLICATION EXAMPLE

Figure 3 presents the Czech IWC data for the Great Cormorant that show a **change in spatial distribution** between 2017 and 2018; the change is reflected by a **bump in EMD values**. **Figure 4** shows a long-term time series of EMD values of six waterbird species based on Czech IWC data over the last 20 years.

LIMITATIONS

- EMD is certainly not the average distance between an individual's location in 2021 and 2022: this would require data on marked individuals. (EMD is an estimate of its lower bound, though.)
- Relatedly, **total abundance** of species **affects EMD** to a certain degree. This needs to be noted especially in interspecies comparisons.
- Incomplete and **time-varying monitoring coverage adds noise**.
- EMD is inherently **restricted to** a given **monitoring region**.
- EMD calculation may get time-consuming. In a species with over 500 occupied monitoring sites, our computational time was under 20 sec. In larger datasets, approximation by Euclidean distance may help.

EXTENSIONS

It is straightforward to **extend EMD beyond year-to-year comparisons**. Examples include (i) yearly deviations from long-term average distributions or (ii) inter-species analyses.

Table 1: An example of monitoring data for EMD calculation

Site	Latitude (*lat*)	Longitude (*lon*)	Count in 2022 (*count*)	Count in 2021 (*lag_count*)
Láska (Love)	49° 6' 35.460'' N	14° 44' 54.6792'' E	160	80
Prkenný (Wooden)	49° 6' 43.956'' N	14° 47' 10.0176'' E	0	108
Klec (Cage)	49° 5' 23.438'' N	14° 46‘ 00.4944'' E	28	0

Figure 1: Optimal flight plan for Table 1

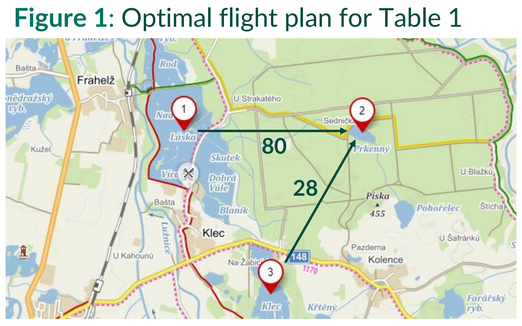


Table 2: Distances in the optimal flight plan

	1 → 2	3 → 2	Still	Total
Distance (km)	2.757	2.594	0	
Individuals	80	28	80	188
Total dist. (km)	220.56	72.63	0	293.19
EMD (avg. dist.)				**1.560**

Figure 2: R code that transforms data from Table 1 for use with **emdist::emd()**

```
calculate_emd <- function(df, max.iter = 1e5) {
   # Filter and standardize monitoring data for both years
   df <- df %>%
      filter(!is.na(count) & !is.na(lag_count)) %>%  # Keep only sites observed in both years
      filter(count > 0 | lag_count > 0) %>%  # Drop sites with 0s in both years
      mutate(  # Standardize counts into probability distributions
         count     = count     / sum(count),
         lag_count = lag_count / sum(lag_count)
      )
   A <- df %>% select(count,     lat, lon) %>% as.matrix()  # Input for emdist::emd()
   B <- df %>% select(lag_count, lat, lon) %>% as.matrix()  # Ditto
   # Calculate the EMD
   emdist::emd(A, B, max.iter=max.iter, dist=function(x, y) geosphere::distGeo(y[1:2], x[1:2]))
}
```

Figure 3: Spatial distribution and EMD for the Great Cormorant (IWC, Czechia, 2017–2019)

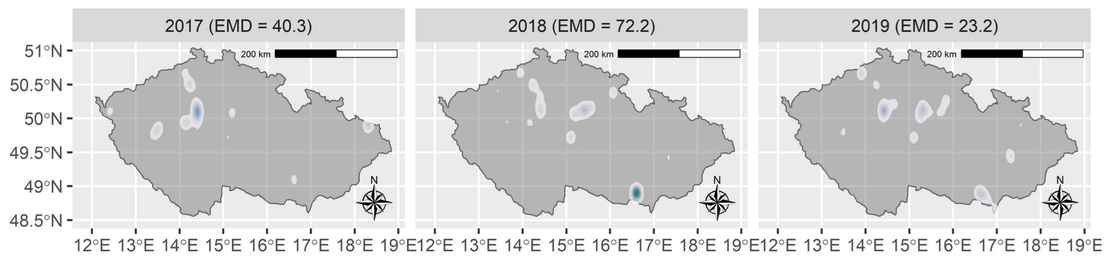
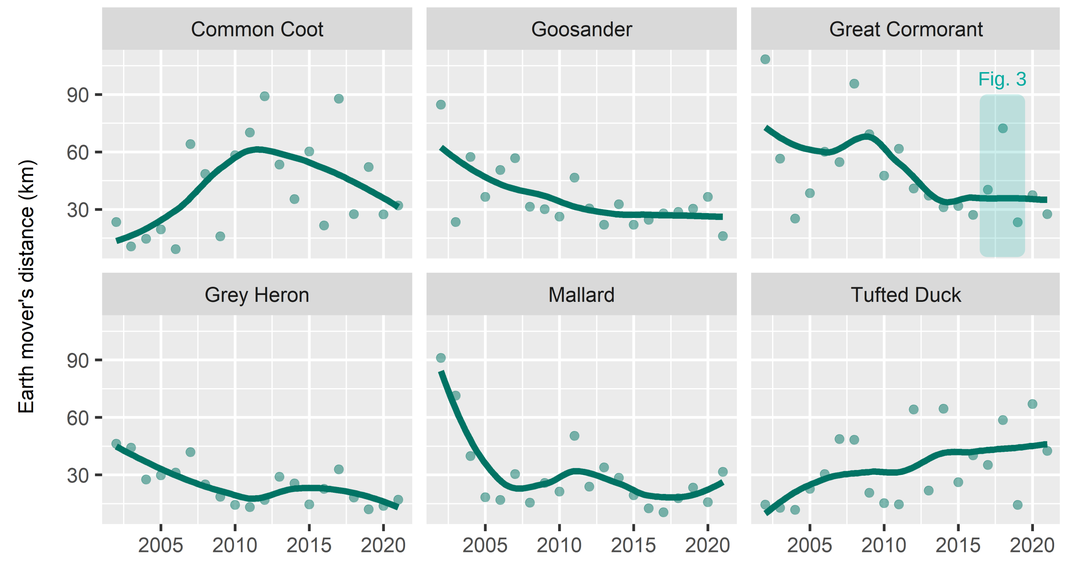


Figure 4: EMD values for selected waterbird species (IWC, Czechia, 2001–2021)



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