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Stochastic simulations reveal few green wave surfing populations among spring migrating herbivorous waterfowl

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Tracking seasonally changing resources is regarded as a widespread proximate mechanism underpinning animal migration. Migrating herbivores, for example, are hypothesized to track seasonal foliage dynamics over large spatial scales. Previous investigations of this green wave hypothesis involved few species and limited geographical extent, and used conventional correlation that cannot disentangle alternative correlated effects. Here, we introduce stochastic simulations to test this hypothesis using 222 individual spring migration episodes of 14 populations of ten species of geese, swans and dabbling ducks throughout Europe, East Asia, and North America. We find that the green wave cannot be considered a ubiquitous driver of herbivorous waterfowl spring migration, as it explains observed migration patterns of only a few grazing populations in specific regions. We suggest that ecological barriers and particularly human disturbance likely constrain the capacity of herbivorous waterfowl to track the green wave in some regions, highlighting key challenges in conserving migratory birds.

1

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fi

Dataset

Branta leucopsis

Anser albifrons

Cygnus cygnus *Cygnus columbianus*

Anser cygnoides *Anser fabalis*

Anser serrirostris

Anser brachyrhynchus

Anser albifrons flavirostris

Anas platyrhynchos *Anas acuta*

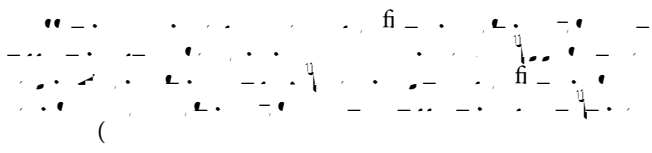
Method evaluation

fi

fi

fi

fi



.....

A handwritten musical score consisting of ten staves. The notation includes various musical symbols such as notes, rests, and dynamic markings. The score is written in a cursive, handwritten style. The first staff begins with a treble clef and a key signature of one flat. The notation includes notes, rests, and dynamic markings such as *mf* and *f*. There are several instances of parentheses and other symbols interspersed throughout the score, possibly indicating phrasing or performance instructions. The handwriting is somewhat dense and difficult to read in some places.

A handwritten musical score consisting of ten staves. The notation includes various musical symbols such as notes, rests, and dynamic markings. The word "fi" is written above the first staff, and "ff" appears on the seventh and tenth staves. There are also some parentheses and other markings scattered throughout the score. The handwriting is somewhat dense and appears to be a working draft or a personal manuscript.

A handwritten musical score consisting of ten staves. The notation includes various musical symbols such as notes, rests, and dynamic markings. The score is written in black ink on a white background. The notation is dense and appears to be a complex piece of music. The staves are numbered 1 through 10. The notation includes various note values, rests, and dynamic markings such as f and ff . There are also some markings in parentheses, such as (u) and $(-)$. The score is written in a style that suggests it is a personal or working manuscript.

• $\frac{1}{2} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) = \frac{1}{2} m v \frac{dv}{dt} = \frac{1}{2} m v a$
• $\frac{1}{2} m v a = \frac{1}{2} m v \frac{dv}{dt} = \frac{1}{2} m \frac{d}{dt} \left(\frac{1}{2} v^2 \right)$

p / $\frac{1}{2} m v^2 = \frac{1}{2} m \frac{d}{dt} \left(\frac{1}{2} v^2 \right) = \frac{1}{2} m v a$

Handwritten mathematical notes, possibly a proof or derivation, involving various symbols and expressions. The text is dense and difficult to decipher due to the handwriting and the presence of many small, illegible characters and symbols. Some recognizable elements include parentheses, dots, and what appears to be a summation symbol.

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