Deriving spatially explicit direct and indirect interaction networks from animal movement data

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Abstract

Quantifying spatiotemporally explicit interactions within animal populations facilitates the understanding of social structure and its relationship with ecological processes. Data from animal tracking technologies (Global Positioning Systems ["GPS"]) can circumvent longstanding challenges in the estimation of spatiotemporally explicit interactions, but the discrete nature and coarse temporal resolution of data mean that ephemeral interactions that occur between consecutive GPS locations go undetected. Here, we developed a method to quantify individual and spatial patterns of interaction using continuous-time movement models (CTMMs) fit to GPS tracking data. We first applied CTMMs to infer the full movement trajectories at an arbitrarily fine temporal scale before estimating interactions, thus allowing inference of interactions occurring between observed GPS locations. Our framework then infers indirect interactions – individuals occurring at the same location, but at different times– while allowing the identification of indirect interactions to vary with ecological context based on CTMM outputs. We assessed the performance of our new method using simulations and illustrated its implementation by deriving disease-relevant interaction networks for two behaviorally differentiated species, wild pigs (Sus scrofa) that can host African Swine Fever and mule deer (Odocoileus hemionus) that can host Chronic Wasting Disease. Simulations showed that interactions derived from observed GPS data can be substantially underestimated when temporal resolution of movement data exceeds 30-minute intervals. Empirical application suggested that underestimation occurred in both interaction rates and their spatial distributions. CTMM-Interaction method, which can introduce uncertainties, recovered the majority of true interactions. Our method leverages advances in movement ecology to quantify fine-scale spatiotemporal interactions between individuals from lower temporal resolution GPS data. It can be leveraged to infer dynamic social networks, transmission potential in disease systems, consumer-resource interactions, information sharing, and beyond. The method also sets the stage for future predictive models linking observed spatiotemporal interaction patterns to environmental drivers.

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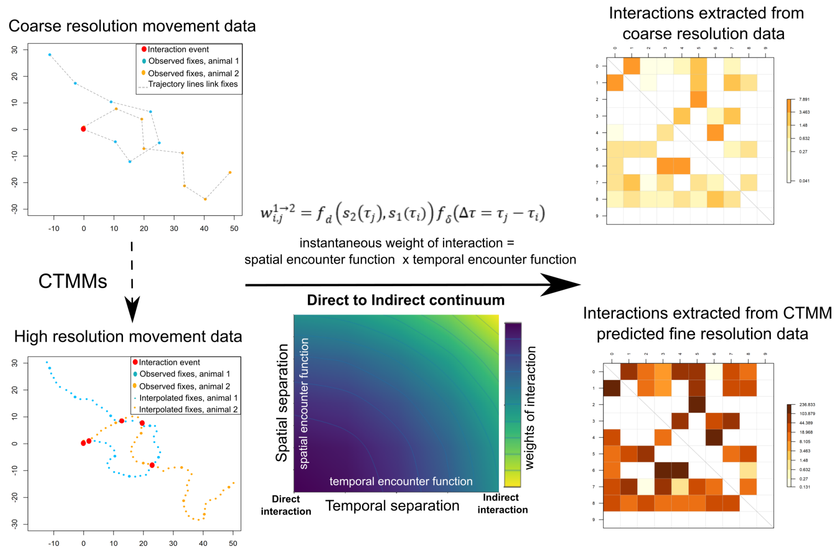
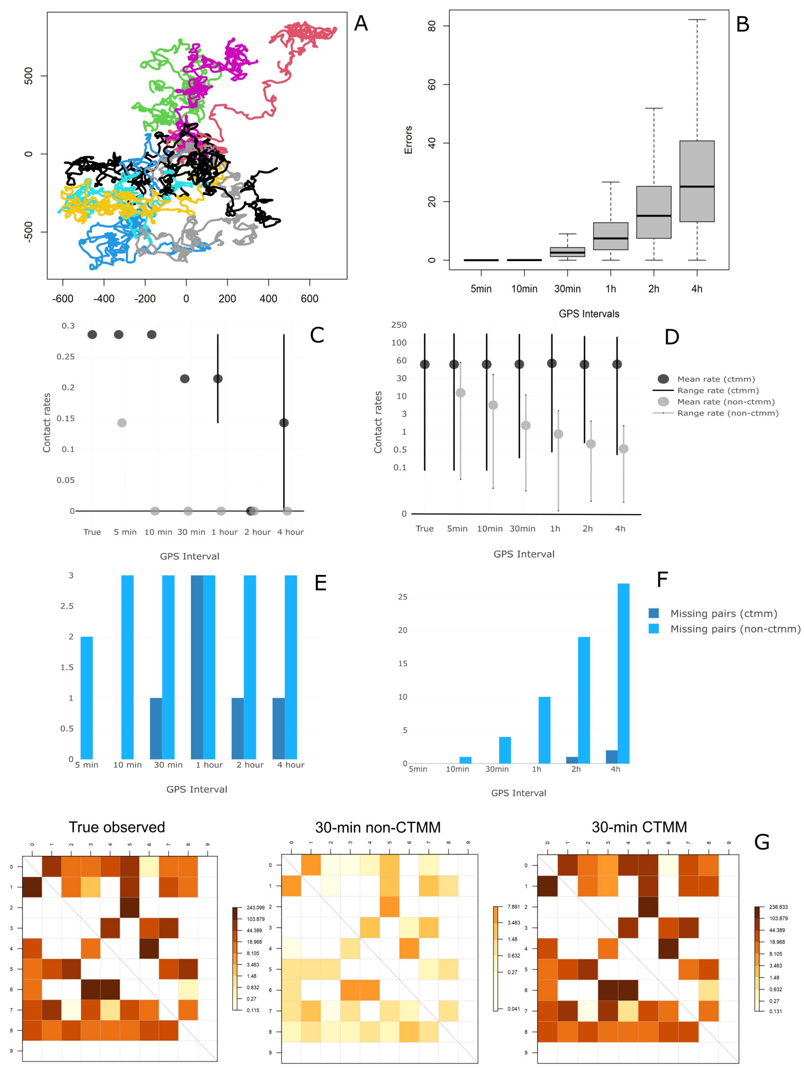
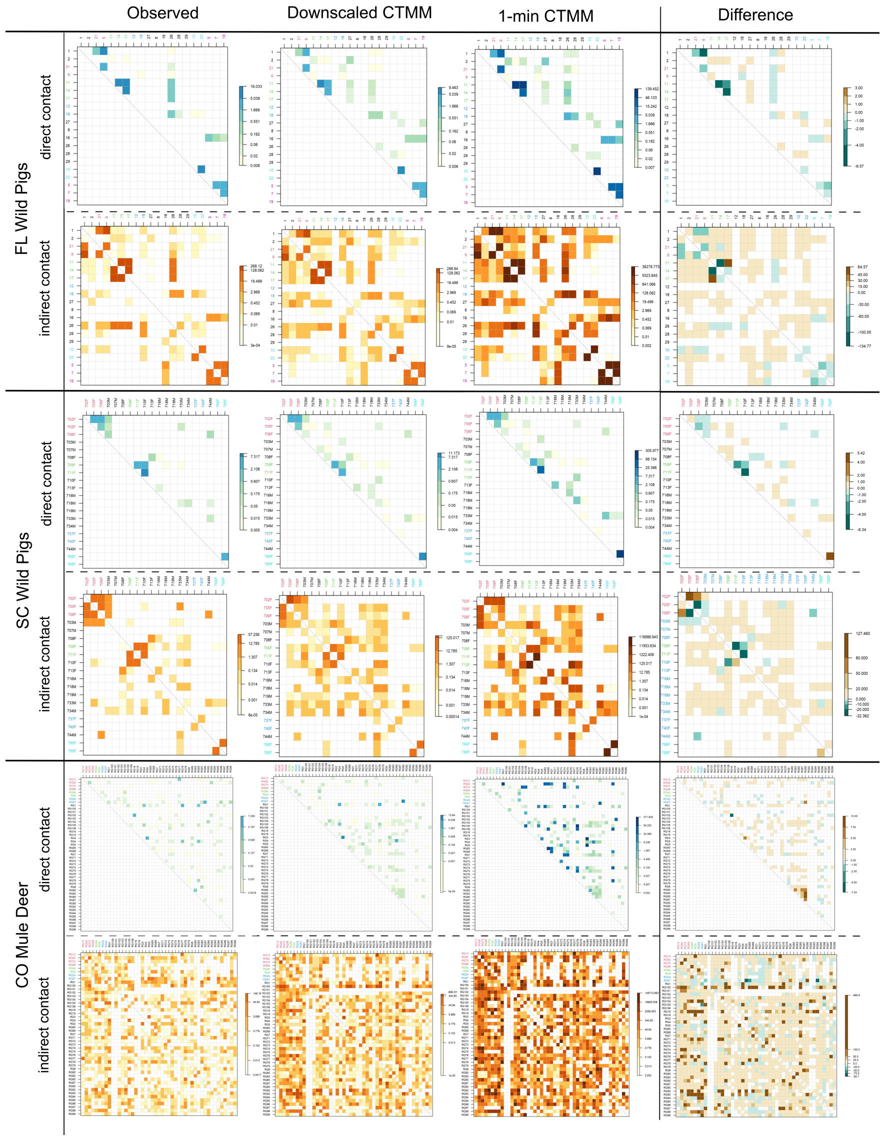
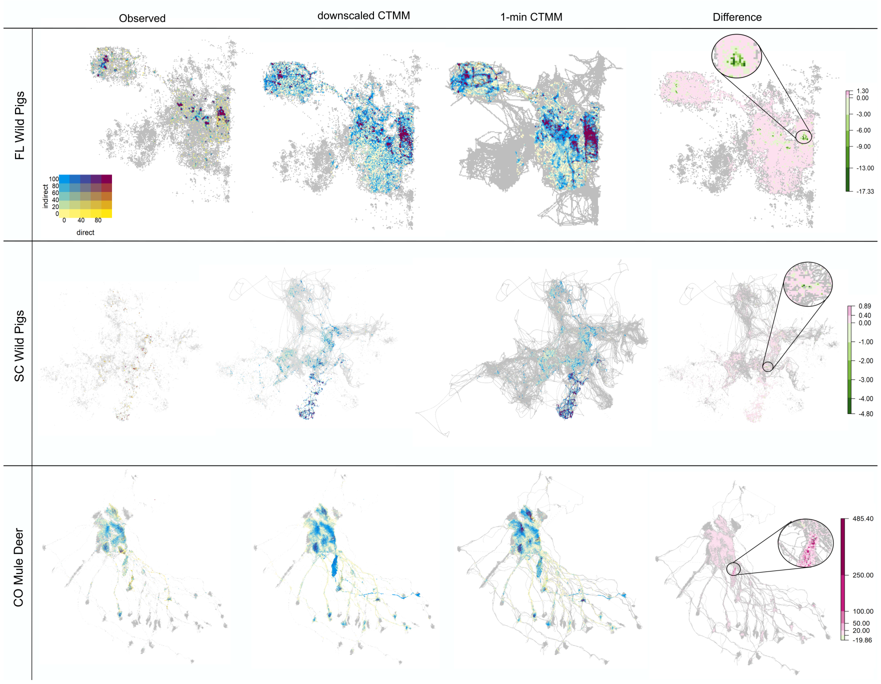
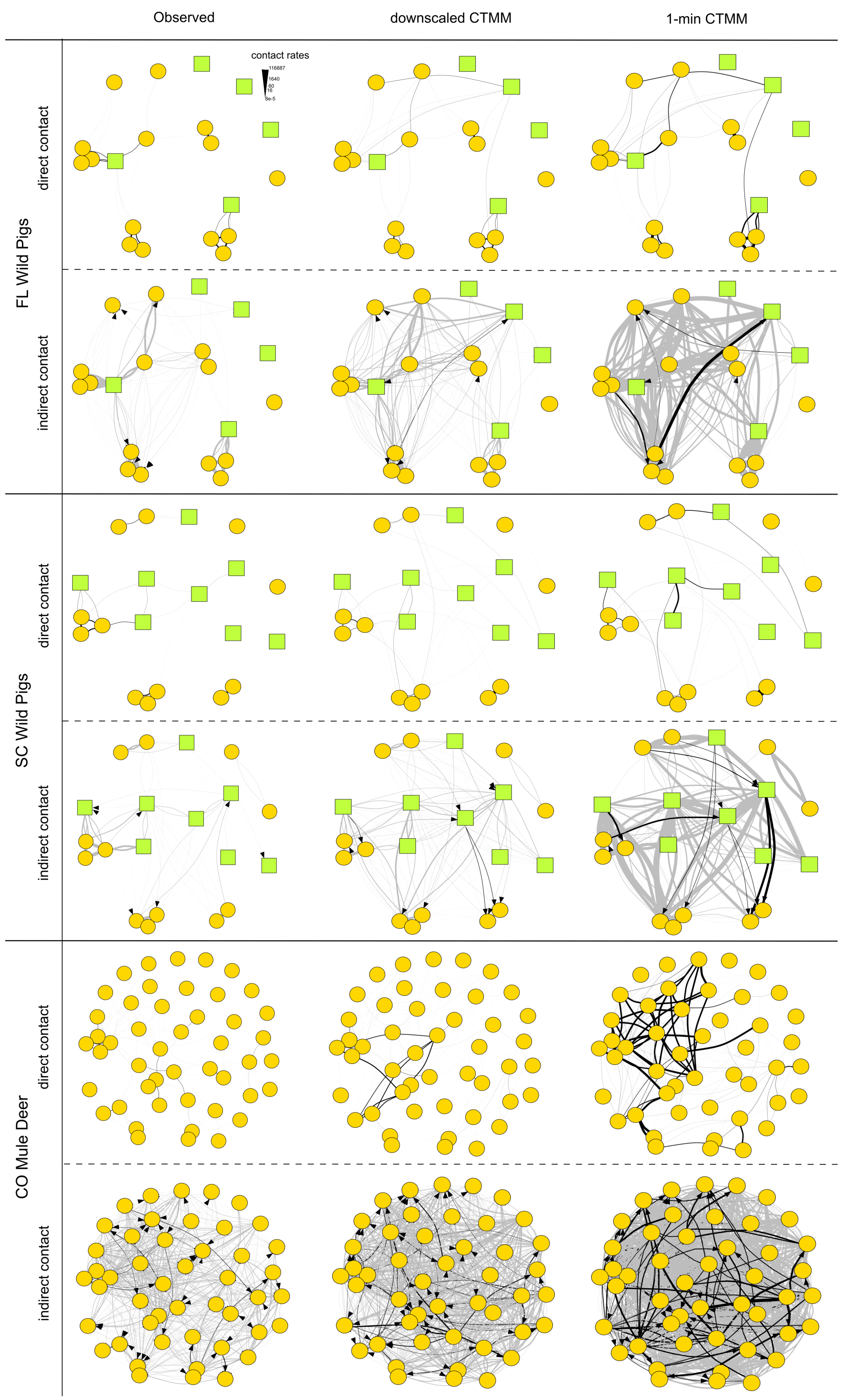



A
B
Errors
5min
10min
30min
1h
2h
4h
GPS Intervals
C
Contact rates
True
5 min
10 min
30 min
1 hour
2 hour
4 hour
GPS Interval
D
Mean rate (ctmm)
Range rate (ctmm)
Mean rate (non-ctmm)
Range rate (non-ctmm)
Contact rates
GPS Interval
E
GPS Interval
F
Missing pairs (ctmm)
Missing pairs (non-ctmm)
GPS Interval
True observed
30-min non-CTMM
30-min CTMM
G


Observed
Downscaled CTMM
1-min CTMM
Difference
FL Wild Pigs
SC Wild Pigs
CO Mule Deer
direct contact
indirect contact


Observed
downscaled CTMM
1-min CTMM
Difference
FL Wild Pigs
SC Wild Pigs
CO Mule Deer
indirect
direct
100
80
60
40
20
0
0
40
80
1.30
0.00
-3.00
-6.00
-9.00
-13.00
-17.33
0.89
0.40
0.00
-1.00
-2.00
-3.00
-4.00
-4.80
485.40
250.00
100.00
50.00
20.00
-19.86



Observed
downscaled CTMM
1-min CTMM
contact rates
116887
1640
60
16
8e-5
FL Wild Pigs
SC Wild Pigs
CO Mule Deer
direct contact
indirect contact