Supplemental Information for:

Ecosystem service flows from a migratory species: Spatial subsidies of the northern pintail

Appendix S1. Per Capita Contributions Equations and Proportional Dependence

For migratory species, the per capita contribution of a migratory region can be defined as the number of individuals in the entire population that are generated from a single individual occupying the region during the season, or anniversary date, \( T \), after one year (Fig. 1). The time interval over which the contribution is evaluated is one year for any given region and season. One annual cycle is divided into seasons in which habitats are occupied during the origin \( o \), intermediate \( i \), or destination, \( d \) time periods.

We first calculate per capita contributions from individuals following a specific pathway. For instance, after the breeding season, individuals migrate from a breeding habitat \( o \) (origin) to a non-breeding habitat \( i \) (intermediate), and, after the non-breeding season, individuals migrate from a non-breeding habitat \( i \) to a breeding habitat \( d \) (destination). Resident cohorts that remain in one habitat year-round can be accounted for by specifying \( o=i=d \). Since a cohort of pintails have a stopover during spring migration, we consider the pintails to migrate between three types of habitats: breeding, wintering and spring stopover habitats. Thus, we account for two intermediate steps \( i_1 \) and \( i_2 \), in the following equations.

First, we define adult survival probability \( A^{oid} \) and per-capita juvenile recruitment \( J^{oid} \) for a single pathway \( oid \) (migratory route) during their annual cycle. In the following equations, each vital rate can be specified separately for each migratory route \( oid \), and the superscript \( a \) represents parameters for adults, while \( j \) represents parameters for juveniles. While most of the equations are the same regardless of anniversary date, the equations for juvenile recruitment (Eqns 2 - 4) vary according to anniversary date. The probability of adult survival is the same regardless of the anniversary date:

\[
A^{oid} = S_o S_{oi} S_{i1} S_{i2} S_{id} \quad \text{(eqn 1)}
\]

Here, a single subscript would represent habitat survival, for example \( s_o^a \) represents the adult survival probability for any individual using habitat \( o \), and double subscripts represent survival along the transition between habitats, for example \( s_{oi1}^a \) represents the survival probability for adults transitioning between habitats \( o \) and \( i_1 \).

Unlike adult survival, the calculation of juvenile survival depends on which season is considered for the anniversary date in the annual cycle. For a breeding season anniversary date, the per-capita recruitment of juveniles along pathway is

\[
J^{oid} = S_o r_o S_{oi1} S_{i1} S_{i2} S_{id} \quad \text{(eqn 2)}
\]

where \( r_o \) represents the number of juveniles produced per adult that survive in habitat \( o \). If breeding occurs in the season immediately following the season, or origin, then
and if breeding occurs in the last season of the year for a given season, then

\[ J^{old} = s^{old}_0 s^{old}_{0i_1} s^{old}_{i_1i_2} s^{old}_{i_2i_2} r_i \]  

(eqn 3)

\[ J^{old} = s^{old}_0 s^{old}_{0i_1} s^{old}_{i_1i_2} s^{old}_{i_2i_2} r_i S^{old}_{i_2} \]  

(eqn 4)

In Mattsson et al. (2012), juveniles born during the breeding season transition to adults in the next season (during winter). Therefore, juvenile vital rates are equivalent to adult vital rates, except for the migration survival immediately after the breeding season.

From the individual pathway survival and recruitment contributions we can calculate the per capita contribution of region \( o \), defined as follows:

\[ C^{o} = \sum_{i_1=1}^{m} \sum_{i_2=1}^{m} \sum_{d=1}^{m} (A^{old} + J^{old}) p_{0i_1} p_{i_1i_2} p_{i_2d} \]  

(eqn 5)

Here \( p_{0i_1} \) represents the probability of an individual transitioning from habitat \( o \) to one of \( n \) intermediate destinations indexed by \( i_1 \). Similarly, \( p_{i_1i_2} \) and \( p_{i_2d} \) represent transition probabilities between intermediate and destination locations.

In the formulation here, no distinction is made for survival differences between sexes. However, in the model by Mattsson et al. (2012) males have a higher survival rate than females. Thus, \( C^{o} \) will need to be calculated independently for each sex. This results in per capita contributions for males and females at each of the \( n \) nodes during each of the three seasons \( T \). We will denote this as \( C^{o\alpha}_T \) and \( C^{o\alpha_f}_T \) for the females and males respectively.

Next we calculate the proportional dependence. For node \( o \) and season \( T \), the seasonal proportional dependence is defined as
\[
d_{o,T} = \frac{N_{o,T}^Q C_T^Q + N_{o,T}^\sigma C_T^\sigma}{\sum_{r=1}^{m} (N_{r,T}^Q C_T^Q + N_{r,T}^\sigma C_T^\sigma)}
\]

(eqn 6)

where \(N_{o,T}^Q\) and \(C_T^Q\) represent the female equilibrium population and per capita contribution respectively for origin habitat \(o\) during anniversary date \(T\). Similarly, \(N_{o,T}^\sigma\) and \(C_T^\sigma\) for males. The denominator normalizes the seasonal proportional dependence values so that \(\sum_{o=1}^{m} d_{o,T} = 1\). To calculate the annual proportional dependence for habitat \(A\), we average the seasonal values given in eqn 6:

\[
D_{SA} = \frac{1}{3} \sum_{T=1}^{3} d_{A,T}
\]

(eqn 7)