**Appendix A**

## Sub-models corresponding to processes in the ‘Process overview and scheduling’ part of the ODD protocol

In the following the details of the simulation processes are presented in order of execution, and when necessary the formulas involved in the calculations and the reference parameter values are presented. The literature used to support the choice of parameter values is provided in the main text

*Update field types and energy content*

If the habitat type of a field does not change between two consecutive periods, the habitat biomass, grass length or grain density remains the same as on the last day of the previous period. If the habitat type changes between two consecutive periods, the field updates biomass and initial grass length or grain density as described in Table 1 in the main text.

*Goose arrival*

The temporal variation in the number of pink-footed geese on the study site was assessed based on counts of geese on the roost sites in the years 2005–2012. It was modelled using a 4th-order polynomial fit (H. Baveco, unpubl. manuscript). Goose numbers peak on 30th of April and equal approximately 43 650 (equalling 2183 super-geese). From the start of the simulation until 30th of April, the calculated number of modelled individuals arrive each day with a certain initial energy store (Table 1), which was estimated by scoring abdominal profiles (API; Madsen and Klaassen 2006) of neck-banded geese in the field and accurately matches the values reported in Drent et al. (2003) and Madsen et al. (1997). Number of geese entering the model on each particular date was fixed across simulations. All the arriving geese start from a randomly chosen roost within the study area.

*Grass growth*

The increase in grass biomass is based on the study by Bjerke et al. (2014). In our model, the increase in compressed sward height (CSH) is period-specific (Table 1) but independent of the grazing pressure.

*Intake rate and habitat depletion*

If a field was occupied by a super-goose during a time step, the biomass on this field was depleted according to the rules below. The total dry grass biomass (GB) of the compressed sward height (CSH (m)) was calculated as follows for each field of area A (m2):

(A1)

where 16.4 is a conversion from sward height into its biomass (Johansen and Högling 2003).

On grass fields, the dry grass biomass decreases as GB – 20 N × IRgrass due to grazing. Here the 20 represents the number of geese per super-goose (N). The intake rate (IRgrass) is a function of sward height. IRgrass is calculated based on an equation adapted from Baveco et al*.* (2011) (Table 1):

(A2)

Here b1-3 are regression coefficients, tc is cropping time (h) and Rmax is the maximum rate of chewing (g h-1).

The decrease in grain/stubble biomass (SB) due to geese grazing is calculated as SB – 20 N \* IRgrain and stubble , where IRgrain and stubble is estimated based on a type 2 functional response (H. Baveco, unpubl. manuscript):

(A3)

Here *a* is an attack rate (m2 h-1) and H handling time (h g-1) (Table 1).

Due to lack of data about intake rate on potato fields, we assume that potato fields are never depleted (since this has never been observed in nature) and that metabolisable energy intake rate is biomass-independent and equal to 879.5 kJ h-1 (M. Chudzińska, unpubl. manuscript). When geese are on ploughed fields, they neither gain energy nor deplete the field.

Because each super-goose performs all the actions as described in section *Process overview and scheduling* before the same actions are performed by the next super-goose, if there is more than one super-goose on the same field, some of the super-geese may obtain a metabolised energy intake close to 0 in a particular time step if the field has already been almost depleted by the other super-geese. However, since the intake rate is a function of grass length or grain density, fields are never entirely depleted. The order that the super-geese forage in is randomised at each step.

*Updating energetics*

The net energy intake rate (NEI) is the difference between the metabolisable energy intake rate (ME) and energy expenditure (EE). The energy expenditure does not differ between roost sites or between fields (M. Chudzińska et al, unpubl. manuscript, Table 1). Geese energy expenditure increases when flying from a previous to a given location. The time required for that flight is subtracted from the time the goose spends on a given field. In order to calculate the time geese were engaged in flying we used 50 km h-1 as an average flight speed (Green et al. 2002, Fox et al. 2003, Baveco et al. 2011, Hawkes et al. 2011).

Metabolised energy intake is calculated based on an equation suggested by Stock and Hofeditz (1997):

(A4)

where j are different habitat types, IRj is the habitat-specific intake rate (g DW h-1) (equations A2 and A3), GF,j and GD,j are the habitat-specific gross energy content of food and droppings (kJ [gorg DW]–1), respectively, DRj is the habitat specific dropping production rate (h–1) and mj habitat-specific average ash-free mass of one dropping (g) (Table 1).

The behaviour of individuals is often determined by the behaviour of a flock and the flock status of a bird (Inglis and Lazarus 1981, Tombre et al. 2005, Amano et al. 2006, Ladin et al. 2011). The number of vigilant birds differs in relation to flock size, position of a bird in a flock hierarchy and location of a bird in a flock (Black et al. 1992, Kotrschal et al. 1993). To incorporate general flock behaviour, the time a super-goose dedicates for feeding (tf) and being vigilant during one time step is a random value between the maximum and minimum feeding time observed in the fields (Table 1). At the end of this procedure, ME is reduced according to proportion of time geese spent on actual feeding based on assumption that while vigilant geese do not gain any energy.

*Leaving a field*

There are four field leaving rules. Geese leave the fields if any of the following rules apply.

Leaving rule 1:

The giving-up time, that is, period of time after which animals should leave a patch has been discussed in many studies (Charnov 1976, Amano et al. 2006, Nolet et al. 2006, Railsback and Johnson 2011). In this model, we use a giving-up time suggested by Bernstein et al. (1988) and Charnov (1976), which states that an animal should leave a given patch when the net energy intake obtained at this patch drops below the expected energy intake of all other patches, which is based on animal’s previous experience (termed marginal value theorem). In our model, the expected gain rate is updated every time step using a linear operator model with current net energy intake rate (MEt – EEt), weighted by the memory factor (α):

(A5)

where calculations of ME and EE are as described in the *Updating energetics* section of this appendix and the value of α was parameterised as described in *Parameterisation* section in the main text and shown in Table 1. The role of the memory factor is to regulate the adjustment of γ to the previous experience (Bernstein et al. 1988). A super-goose abandons a field and move to a new one if the current gain rate (MEt – EEt) falls below the expected gain rate at time t (γt).

Leaving rule 2:

Geese should feed as long as it takes them to fill their guts (time of the first passage), and stop feeding until the food in the gut is processed (retention time) (Bednekoff and Houston 1994). When following this rule, the geese thus leave a field if they feed continuously for an amount of time equal to time of the first passage. Time of the first passage has been estimated to be between one and four hours for geese feeding on graminoids (Dorozunska 1963, Marriot 1970, Burton et al. 1979) and we therefore calibrated this value (see *Parameterisation* section and Table 1 in the main text). For geese the mean retention time is 2–3 h for grass (Burton et al. 1979) and probably less than 2-3 h for grain, which is digested faster than grass due to its lower cellulose content (Demment and Van Soest 1985). Geese at the study area prefer to rest on roost sites rather than staying on fields, probably to avoid disturbances (M. Chudzińska, unpubl. manuscript). In our model, geese consequently process food on roost sites.

Leaving rule 3:

Geese also leave a field if they are exposed to a disturbance event. The probability of disturbance differs among patch types (roost or field) and varies with field size (Table 1). If there is more than one super-goose on the disturbed field, all geese leave that field simultaneously. A study by Holm (1994) showed that brent geese (*Branta bernicla*) do not start feeding immediately after arriving to a field after being disturbed and in consequence a reduction of the time spent feeding and the metabolised energy intake has to be taken into account. Therefore, when disturbed, geese have their metabolised energy intake multiplied by a random number between 0 and 1, mimicking a situation in which geese can be disturbed at any point of the time step, causing them to obtain only a fraction of the energy they would have obtained had they not been disturbed. The reduction is the same for all the super-geese present at the same field. The cumulative time geese spent feeding since they were last on a roost site is also multiplied by the same value. The effect of disturbance differs between foraging decision rules (*Geese foraging decision* section in the main text) and with distance between the field where geese were disturbed and the closest roost site.

Leaving rule 4:

Geese leave the fields at sunset set as afternoon civil twilight (Astronomical Applications Department of the U.S. Naval Observatory, http://aa.usno.navy.mil)

*Leaving the model*

Duriez et al. (2009) suggested that pink-footed geese depart Mid-Norway when they have accumulated enough body stores and conditions at the next stopover site are suitable. Therefore, geese leave the model to continue their migration further north if they obtain energy storage equivalent to API 4 ± 0.25 (Table 1; Drent et al., 2003; Madsen et al., 1997) but not earlier than 7th of May ± 5 days. Duriez et al. (2009) suggested that geese use the number of growing degree days (GDD) as a cue to indicate that conditions are suitable at the next stopover site. For the years 2004-2014 geese left Mid-Norway around 7th May, when the GDD exceeded 950 ºC (Duriez et al. 2009). Using 1st January as a starting data, daily GDD were calculated as:

Here Ti is the average daily temperature at day *i* (source: the European Climate Assessment & Dataset (ECA&D, www. ecad.eu, metadata for 2004-2014)) and -5ºC is a temperature threshold which triggers vegetation development in Mid-Norway (van der Graaf 2006). If Ti – (-5) < 0, GDD was set to 0.

Geese also leave the model if their energy stores fall below 9620 kJ, equivalent to starvation mass of API 0 (Madsen and Klaassen 2006) (Table 1).

**Appendix B**

Results of Sobol’ sensitivity analysis for foraging decision rule 1 (FDR 1-random)

For FDR 1-random, the average DNEI over the four periods varied between -62 and +43% of the average value estimated by FDR 1-random with the use of final parameter’s settings. The sum of the main and the total effect indices are comparable (Si = 0.98, STi = 1.01) and therefore the model is largely additive (Fig. B.1). Similarly to FDR 3-asocial learning, probability of disturbance on large fields and global disturbance were responsible for the bulk of the variance (approx. 39 and 60% of the variation of the DNEI respectively, Fig. B.1). The variation in time spent on roost sites during daytime was smaller than the variation in DNEI (-30 +4% of the average time geese spent on roost during daytime estimated by FDR 1-random with the final parameterisation). In contrast to the results for FDR 3-asocial learning and similarly to the results of FDR 1-random for DNEI, probability of disturbance on large fields and global disturbance had the highest contribution to the variance (approx. 40 and 57% of the variation of the time spend on roost respectively, Fig. B.1). The values of Si and STi for each parameter as well as their sum are comparable (Si = 0.98, STi = 1.06, Fig. B.1). When the probability of disturbance on all fields (“Global disturbance”) was increased by approximately 100%, the mean DNEI for all four periods decreased by 51% in comparison to DNEI estimated by FDR 1-random with the use of the final parameter’s settings. Simulations with almost no disturbance in FDR 1-random resulted in the increase of the mean DNEI over the four periods by 31% in comparison to DNEI estimated by FDR 1-random with the best parameterisation. The changes in global disturbance had no large effects on the amount of time geese spent on roost sites during daytime; the mean value over four periods for the models with increased or decreased disturbance was equal to the mean value for all simulations and was equal to 24%.

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Figure B.1. Results of the sensitivity analysis based on Sobol’ method for the two patterns: pattern 1 - daily net energy intake (DNEI) and pattern 2 – time geese spend on roost during daylight (roost) for foraging decision rules 1 (random search) that best described foraging behaviour of pink-footed geese during their spring-stagi

ng stopover site in Mid-Norway. Open circles show first-order sensitivity index values (Si), i.e. main effects. Black squares show total sensitivity index values (STi), i.e. total (main and all interaction) effects. Bars show bootstrapped 95% confidence intervals of corresponding sensitivity indices.

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