2023

Balmeanach Wind Farm

Modelling the Impacts of Wind Farm Mortality on White-tailed Eagles

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CONTENTS

Executive Summary

The Model

1.1. A national rather than a regional population model is the appropriate scale for modelling white-tailed eagles (*Haliaeetus albicilla*). Nonetheless, the potential impacts of additional mortality are modelled at two smaller scales: Skye and NHZ 6.

1.2. Models were constructed using the R statistical programming language using an adapted Population Projection Matrix (PPM) approach augmented by a sequence of year specific (cohort) calculations.

1.3. Models are built around six age classes (five juvenile/sub-adult and one adult class). Sub-adults are individuals less than the usual first age of breeding (although there may be a small number that breed earlier). Only the adult class is assumed to fledge young in these models.

1.4. As in Evans *et al*. (2009) an equal sex ratio at birth is assumed and use survival rates from Table 8 in Samsom *et al*. (2016). Productivity on Skye was assumed to be 0.38 (0.76 for both sexes), based on SRMS data 2014-20. Productivity in NHZ 6 was assumed to be 0.4 (0.8 for both sexes), based on SRMS data 2014-20.

1.5. A generic sigmoidal curve is used to simulate the effect of density dependence on productivity and survival. As a population approaches the carrying capacity parameter values are slowly reduced. Once past the carrying capacity the rate of decrease increases to minimum of 45% of the original value.

1.6. In their Appendix 2 Sansom *et al*. (2016) report that *"… the predicted maximum number of breeding pairs would vary between around 28 (Skye) to 125 (Argyll excluding Mull…). As Mull was used as a baseline scenario, the predictions for Mull were close to the observed current population size.*". Further, in their Table A2-3 the predicted maximum number of pairs is 21 for Mull and 30 for Skye. In order to provide a precautionary buffer, these models assume larger maximum population sizes (carrying capacities) of 40 for Skye and 80 for NHZ 6.

1.7. Stochastic noise is added each year to simulate the effects of between-year variability in survival and reproductive rates. Limits are applied to prevent values becoming too large.

1.8. Collision mortality was added each year of the simulation according to an age class specific rate, expressed as a percentage of the number of pairs (0, 2, 4, 8, 10%). As the population increased so did the number of wind farm related deaths. This models a situation in which activity around wind farms increases as the population increases. Each mortality scenario was simulated 1,000 times.

1.9. The impact of wind farm mortality, for a long-lived species such as the white-tailed eagle, is partly dependent on the age classes of the birds killed. Generally, killing adults has a larger impact. In order to model these three scenarios are run. The first assumes that all mortality is to sub-adults, in the second collision mortality is split evenly between sub-adults and adults. Finally, all collision mortality is assumed to be adults.

1.10. Sub-adult mortality is split between age classes in proportion to their numbers.

1.11. Models were run with and without density dependence and with three age class mortality scenarios. Each model (combination of region, mortality rate and presence or absence of density dependence) is simulated 1,000 times with a 30-year projection.

NHZ 6 Results

1.12. Starting values are 0.4 females fledged per pair, 16,14, 12, 10 & 8 sub-adult females plus 39 adult females and a carrying capacity of 80 pairs.

1.13. All results show that the effect of additional mortality is much greater when there is no density dependence and when the collisions are mainly to adults.

1.14. Differences in the population trajectories, in the absence of density dependence, are large but they cannot be considered to be biologically meaningful or feasible. For example, the median population size, in absence of any collision mortality, was 545 pairs (range 337 - 843 pairs).

1.15. The most extreme modelled scenario was 10% adult mortality, equivalent to killing approximately 35 adults (both sexes) per year. There is no realistic scenario in which this is possible and even this extreme scenario predicts a median year 30 population of 80 pairs, which is considerably larger than the combined maximum population of 51 pairs for Skye and Mull estimated by Sansom *et al*. (2016).

1.16. When there is density dependence the effect of additional mortality is much reduced but the effect of killing adults, rather than sub-adults, remains. In the presence of density dependence, an additional 4% adult mortality, or ~14 white-tailed eagles (both sexes) per year after 30 years, has a negligible impact compared with the control of 0 deaths. The most extreme modelled scenario was a 10% mortality, restricted to adult birds. Even when ~30 adults (both sexes) are killed each year the median NHZ 6 population was ~69 pairs (range 52 to 79 pairs). Given that Sansom *et al*. (2016) estimated a maximum combined population of 51 pairs for Skye and Mull, a median estimate of 69 pairs cannot be considered a significant impact.

1.17. In year 0, when there were assumed to be 39 pairs plus 60 sub-adult females, the initial additional wind farm deaths of females would be 0, 2, 4, 6, 8 & 10 females per year at 0, 2, 4, 6, 8 & 10 % levels of additional mortality. The total killed would be double this assuming an equal sex ratio. It is reasonable to assume that the majority of collision deaths would be sub-adults as only a small number of pairs could be directly affected by the wind farms. Even assuming an equal ratio of deaths, collision mortality had to be more than 4% before the impact on the number of pairs was apparent and, even then, it was only a reduction of 2.6 pairs from an assumed cap of 80 pairs.

1.18. In the absence of density dependence, the numbers killed (both sexes) each year after 30 years depends on how mortality is partitioned between sub-adults and adults. If all mortality is sub-adult the numbers are 0, 41, 67, 80, 87 & 88 while, if all mortality is to adults, the numbers are 0, 30, 43, 44, 41 & 35 in year 30.

Skye Results

1.19. Starting values are 0.38 females fledged per pair, 7, 6, 5, 4 & 3 sub-adult females plus 25 adult females and a carrying capacity of 40 pairs.

1.20. Differences in the population trajectories, in the absence of density dependence, are large but they cannot be considered to be biologically meaningful or feasible. For example, the median population size, in absence of any collision mortality, was 270 pairs (range 157 - 422 pairs). There is no situation in which Skye could support even the minimum scenario of 157 pairs.

1.21. The most extreme, and ecologically unrealistic, modelled scenario was 10% adult mortality, equivalent to killing approximately 17 adults (both sexes) per year. Even this extreme scenario predicts a median year 30 population of 38 pairs, which is considerably larger than the maximum population of 30 pairs for Skye estimated by Sansom *et al*. (2016). The minimum modelled year 30 population was 25 pairs, which is the same as the current population.

1.22. When there is density dependence the effect of additional mortality is much reduced but the effect of killing adults, rather than sub-adults, remains.

1.23. In the presence of density dependence, an additional 4% mortality of adults, or ~6 white-tailed eagles (both sexes) per year after 30 years, has a negligible impact compared with the control of 0 deaths. The most extreme modelled scenario was a 10% mortality, restricted to adult birds. Even when ~15 adults (both sexes) are killed each year the median Skye population was ~33 pairs (range in 1,000 simulations 23 to 38). Given that Sansom *et al*. (2016) estimated a maximum population of 30 pairs for Skye, a median estimate of 33 pairs cannot be considered a significant impact.

1.24. In year 0, there were assumed to be 25 pairs plus 25 sub-adult females, so initial additional wind farm deaths of females would be 0, 1, 2, 3, 4 & 5 females per year at 0, 2, 4, 6, 8 & 10 % levels of additional mortality. The total killed would be double this assuming an equal sex ratio.

1.25. It is reasonable to assume that the majority of collision deaths would be sub-adults as only a small number of pairs could be directly affected by the wind farms. Even assuming an equal ratio of deaths, collision mortality had to be more than 4% before the impact on the number of pairs was apparent and, even then, it was only a reduction of 1.4 pairs from an assumed cap of 40 pairs.

1.26. In the absence of density dependence, the numbers killed (both sexes) each year after 30 years depends on how mortality is partitioned between sub-adults and adults. If all mortality is sub-adult the numbers are 0, 19, 31, 38, 41 & 42 while, if all mortality is to adults, the numbers are 0, 14, 20, 21, 19 & 17 in year 30. Because of the impacts of the additional mortality on the population trajectories, if all mortality is adults the number killed at the 10% rate is less than that at a 4% rate.

Conclusions

1.27. None of the 30,000 modelled scenarios resulted in population extinction nor were any of the year 30 population totals lower than the starting values, even at the highest mortality rates.

1.28. As noted in Samsom *et al*. (2016) the effect of killing even large numbers of white-tailed eagles is to slow the rate of population expansion and delay the date at which the carrying capacity is reached.

1.29. Predicted mortality from the Balmeanach wind farm is 1.34 individuals per year.

1.30. The assumed NHZ 6 starting population in the models is 120 sub-adults and 78 adults. Depending on the ages of the birds killed 1.3 deaths represents 1.1% of the sub-adults, 1.7% of the adults or 0.7% of all birds. This scale of mortality is not predicted to have a significant impact.

1.31. The assumed Skye starting population in the models is 50 sub-adults and 50 adults. Depending on the ages of the birds killed 1.3 deaths represents 2.6% of the sub-adults, 2.6% of the adults or 1.3% of all birds. This scale of mortality is also not predicted to have a significant impact.

1.32. The issue of cumulative assessment is complicated by the temporal differences between the already operational and consented wind farms. There are no wind farms in NHZ 6 apart from those on Skye. The wind farms included in a cumulative assessment are the operational Ben Aketil and Edinbane wind farms, plus the consented Ben Sca, Beinn Mheadhonach and Glen Ullinish schemes.

1.33. The cumulative predicted mortality from the two operational wind farms was 0.11 per annum while the consented Ben Sca (0.5 per annum), Ben Mheadhonach (0.3 per annum) and Glen Ullinish (1.2 per annum) winds farm have a combined predicted mortality of 2.1 per annum. Therefore, adding in the predicted mortality from the Balmeanach wind farm of 1.3 individuals per year gives a cumulative total of 3.4 birds per year.

1.34. The assumed NHZ 6 starting population in the models is 120 sub-adults and 78 adults. Depending on the ages of the birds killed the cumulative collision mortality of 3.4 birds per year represents 2.8% of the sub-adults, 4.4% of the adults or 1.7% of all birds. This scale of mortality is not predicted to have a significant impact although there would be a delay in reaching the carrying capacity.

1.35. The impact, without density dependence operating, looks large but the median year 30 population, with 6% annual adult mortality is predicted to be 174 pairs (range 111-269 pairs). Even the minimum of 111 pairs is larger than any realistic white-tailed eagle population size for NHZ 6.

1.36. The assumed Skye starting population in the models is 50 sub-adults and 50 adults. Depending on the ages of the birds killed the cumulative collision mortality of 3.4 birds per year represents 6.8% of the sub-adults, 6.8% of the adults or 3.4% of all birds.

1.37. The worst-case scenario is that all collisions would be adults and the population is not predicted to reach its carrying capacity within 30 years. However, the prediction of between 34 and 37 pairs (range 26 - 38 pairs) is still a significant increase from the present and well above the maximum predicted Skye population in in Samsom *et al*. (2016). There is no prediction of a population decline.

1.38. A more realistic scenario is that the collision mortality will be split between sub-adults and adults. If an equal split is assumed the prediction of between 36 and 37 pairs (range 29 - 40 pairs).

1.39. The impact, without density dependence operating, looks large but the median year 30 population, with 6% annual adult mortality is predicted to be 82 pairs (range 49 - 130 pairs). Even the minimum of 49 pairs is larger than any realistic maximum.

1.40. The overall effect of the levels of additional wind farm mortality modelled in this report is to reduce the year at which the population reach their carrying capacities. There is no threat to the integrity of the white-tailed eagle populations at even the highest rate of modelled mortality.

Background

1.41. The potential impacts, on white-tailed eagle's future population trajectories, arising from a range of collision mortality scenarios, are investigated using population modelling approaches.

1.42. Robust population modelling of these populations requires estimates of four key population parameters:

1) Number of occupied ranges.
2) Average number of young fledged per pair.
3) Proportion of young birds surviving each year.
4) Proportion of range holding birds dying each year.

1.43. In addition, it is useful to know the between-year variability of the above and if there is any evidence of trends and density dependence.

1.44. Usually items 1 and 2 are the only parameters whose values are known with a reasonable degree of confidence but, for white-tailed eagles, items 3 and 4 are also reasonably well known but it is unclear how, if at all, avian influenza has affected them.

Model Extent

1.45. A national rather than a regional population model is the appropriate scale for modelling white-tailed eagles. The rationale for a national, rather than a regional model, is based on the findings of Whitfield *et al*. (2009) who examined natal dispersal rates in the Scottish population meaning that it is very unlikely that birds breeding on Skye and the Hebrides are isolated from other populations. A model restricted to the Skye or the Western Seaboard Natural Heritage Zone (NHZ 6) would be conservative. Nonetheless, the potential impacts of additional mortality are modelled at the two smaller scales: Skye and NHZ 6.

Population Modelling Approaches

1.46. The models were constructed using the R statistical programming language (v3.6.1) and the Popbio library (v2.6, Stubben & Milligan, 2007). The model uses an adapted Population Projection Matrix (PPM), or Leslie matrix, which is augmented by a sequence of year specific (cohort) calculations and adjustments. This approach is used because it is simpler to incorporate additional wind farm related mortality. The models are implemented in R and some of the more novel aspects are described in detail below.

1.47. The models are built around six age classes (five juvenile/sub-adult and one adult class). Sub-adults are defined in these models as individuals less than the usual first age of breeding (although there may be a small number that breed earlier). Only the adult class is assumed to fledge young in these models.

Sources of Evidence

1.48. The most recent, and comprehensive, data on the Scottish white-tailed eagle population is from Scottish Raptor Monitoring Scheme (SRMS) data between 2012 and 2020.

1.49. Evans *et al*. (2009) lists three reproductive values for Scotland, with an additional value in the text (**Table 1**). It is clear from those data that productivity increased apparently as a consequence of more breeding by wild-bred, rather than released, birds. More recent SRMS data suggest a figure of 0.8, while Samsom *et al*. 2016 use a figure of 0.67. The mean national productivity between 2010 and 2020 (SRMS data) is 0.798.

Years	Productivity	Fledged brood size
2003-07	0.76	
2001-07	0.70	1.44
1993–2000	0.61	1.48
1982–92	0.38	1.61

Table 1. Productivity values from Evans *et al*. (2009)

1.50. As in Evans *et al*. (2009) these models assume an equal sex ratio at birth. Thus, in the subsequent analyses, it is assumed that females are 50% of the total fledged and that breeding does not begin until birds are at least five years old.

1.51. Evans *et al*. (2009) lists annual age-specific survival rates for both released and wild bred individuals. As with productivity, wild bred birds performed much better. If pre-adult age classes are combined, the probability of reaching recruitment age (>4 years) for a wild-bred bird was 53% compared to 37% for a released bird (Evans *et al*., 2009). The estimate shown in Sansom *et al*. (2016) is slightly lower at 51%. The models described below use survival rates from Samsom *et al*. (2016). These are similar to those for wild bred birds in Evans *et al*. (2009) but the first three survival rates are higher at 0.874 while the survival rate between years 3-4 is lower at 0.855. Adult survival is slightly lower at 0.961.

Origin	0–1	1–2	2–3	3–4	4+
Released	0.736 ± 0.077	0.726 ± 0.091	0.790 ± 0.091	0.922 ± 0.058	0.942 ± 0.022
Wild bred	0.819 ± 0.051	0.821 ± 0.065	0.857 ± 0.065	0.951 ± 0.038	0.966 ± 0.014

Table 2. Age-specific survival rates (± se) from Evans *et al*. (2009) plus mean values.

1.52. The number of breeding pairs of white-tailed eagles has been increasing quite rapidly in recent years. For example, nationally there were 42 pairs in 2007 but at least 123 pairs by 2020. The most recent estimate of the empirical annual rate of population growth (1997-2007) was 9.7% (Table 6 of Evans *et al*., 2009). Sansom *et al*. (2016), using a Vortex model predicted a mean annual growth rate of 8.6% (range: 8.0%-9.2%), but this appears to have been a slight underestimate based on a comparison with empirical data (see their Figure 10).

Model Structure

1.53. The default PPM (no wind farm mortality and no density dependence) model for the white-tailed eagles is shown below. Row 1 is the productivity (fledging rate) per age class. Only adults are assumed to fledge young at the rate of 0.4 females per pair per year. The five columns are the five age classes: s0 (fledged-1), s1 (1-2), s2 (2-3), s3 (3-4), s4 (4-5) and adults are 5+ years old. Survival rates are those for wild bred birds listed in Samsom *et al*. (2016). The figures in each column, from the second row down, are the annual survival rates for the age classes.

s0	s1	s2	s3	S4	adult
0.000	0.000	0.000	0.000	0.000	**0.40*0.961**
0.874	0.000	0.000	0.000	0.000	0.000
0.000	**0.874**	0.000	0.000	0.000	0.000
0.000	0.000	**0.874**	0.000	0.000	0.000
0.000	0.000	0.000	**0.855**	0.000	0.000
0.000	0.000	0.000	0.000	**0.961**	**0.961**

1.54. The expected rate of increase, *r*, from the above PPM with no additional mortality is 0.0983 or 9.83% per year, i.e., the number of pairs is expected to increase by 9.8% each year. This is similar to the empirical value of 9.7% given in Table 6 of Evans *et al*. (2009) and higher than the modelled value in Sansom *et al*. (2016) which appears to have been an underestimate when compared with empirical data. As in Sansom *et al*. (2016), there are no density-dependent effects in the above model. It was assumed that the population continues growing at a rate determined by the combination of survival and productivity rates used in the scenarios. Sansom *et al*. (2016), using data up to 2014 on both Mull and Skye, did not find that the number of fledglings produced per territorial pair was significantly associated with the total number of pairs on the islands. They interpreted this to mean that, in 2014, the breeding performance was not density dependent. Therefore, both islands, and by extrapolation the NHZ, should not experience density dependence until the population exceeds, perhaps by some margin, the number of pairs in 2014.

1.55. As expected, the model is most sensitive to adult survival (adult survival 0.538). All other parameters have relatively small elasticity values of 0.0769.

Density Dependence

1.56. A generic sigmoidal curve (**Figure 1**) is used to simulate the effect of density dependence on productivity and survival. The same curve is used for the fledging rate and all survival rates. As the population approaches the carrying capacity parameter values are slowly reduced. Once past the carrying capacity the rate of decrease increases to minimum of 45% of the original value. For example, assume a carrying capacity of 500 and a current population of 600 (100 above the carrying capacity), a ratio of 1.2 on the x-axis. From **Figure 1** the growth rate and survival rates would be reduced to 65% of their default values. A fledging rate of 0.22 would become 0.143 and an 80% survival rate would become 52.0%. Density dependence is applied as an R function (**Box 1**).

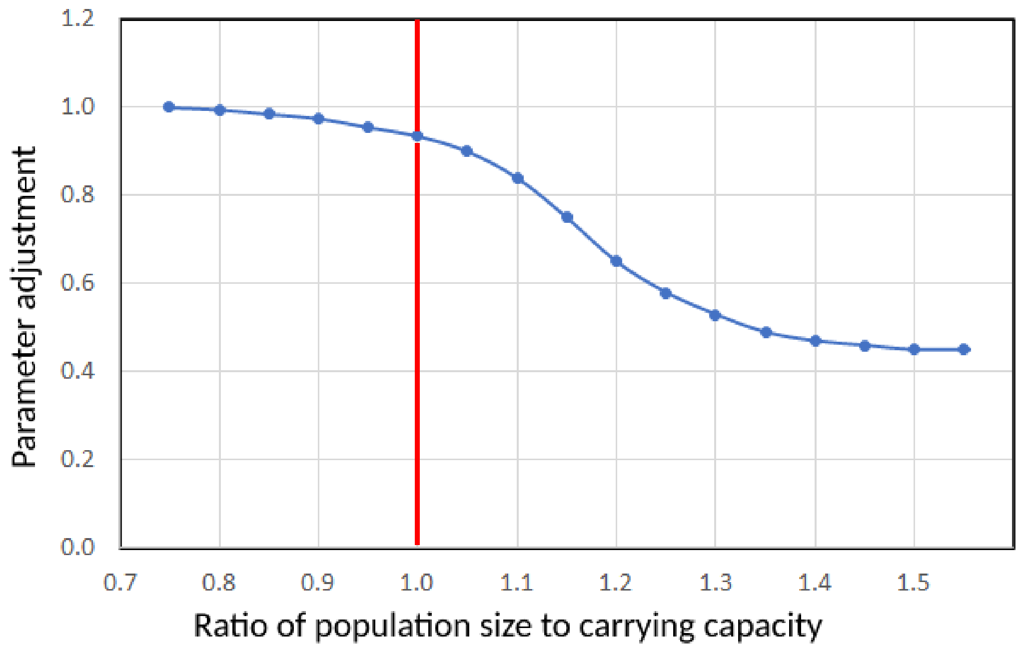

Figure 1. Effect of density-dependence on growth rate and survival. The red line shows a point at which the population is at its carrying capacity. The blue line shows the amount of adjustment to the parameter's value.

1.57. In their Appendix 2 Sansom *et al*. (2016) report that "*Multiplying the number of km² squares with suitable habitat at each threshold level with the corresponding densities of breeding white-tailed eagles around Loch Frisa on Mull …, the results suggested that across the Scottish regions, the predicted maximum number of breeding pairs would vary between around 28 (Skye) to 125 (Argyll excluding Mull…). As Mull was used as a baseline scenario, the predictions for Mull were close to the observed current population size.*". Further, in their Table A2-3 the predicted maximum number of pairs is 21 for Mull and 30 for Skye. In order to provide a precautionary buffer, these models assume larger maximum population sizes (carrying capacities) of 40 for Skye and 80 for NHZ 6.

Box 1. R Density dependence function (dd.adj).

Four values are passed to the function: 1 param (current fledging rate or survival rate); 2 pop (current population size), 3 pop.max (carrying capacity) and 4 DD (True or False, no changes are made to the parameters if DD is false)

```
dd.ratio<-
c(0.995,0.985,0.975,0.955,0.935,0.900,0.840,0.750,0.650,0.580,0.530,0.490,0.470,0
.460) # for ratios between 0.8 and 1.45
dd.adj<-function(param,pop,pop.max,DD){
# If DD is false x = 0 and param remains unchanged otherwise round ratio to 0.05
ifelse(DD,x<-round((pop/pop.max)/0.05)*0.05,x<-0)
if(x<0.8) y<-1        #if the popn is <80% of carrying capacity leave it unchanged
if(x>1.45) y<-0.55    #if the popn is >145% of carrying capacity reduce to 45%
# between 80% and 145% of the carrying capacity reduce the parameter by a value
# extracted from dd.ration
if(x>0.75 && x<1.5){
  indx<-(x-0.75)/0.05
  y<-dd.ratio[indx]}
return(param*y)
}}
```

Incorporating Wind Farm Mortality

1.58. A PPM is normally projected over a long period of time, typically 30 years, but it is possible to project forward by just 1 year. Doing this provides mechanisms by which:

- Random (stochastic) noise can be added to each parameter each year.
- Birds can be added (for a re-introduction model) or removed (for additional mortality events) at a known rate for each age class.

1.59. Stochastic noise is added each year to simulate the effects of between-year variability in survival and reproductive rates by sampling from normal distributions (see **Box 2**). The mean is the default value, e.g., a 0.22 fledging rate, and the standard deviation is a percentage of the mean. In these models the standard deviation is 5% so with a mean annual survival rate of 0.8 the standard deviation would be 0.04. Limits are applied to prevent values becoming too large (**Box 2**).

Box 2. R function to add noise to parameters.

p.list is a list of 6 parameters (four sub-adult survival rates covering years 1 to 4, an adult survival rate and the fledging rate). Random values are reduced to maximum values if they exceed a cap, for example a random variate of the adult survival could be >1 by chance. For example, the (females only) fledging rate is the minimum of 0.5 or a random variate based on the assumed fledging rate. This means that the fledging rate cannot be larger than 0.5 (1.0 for both sexes). The function returns the list of six random values.

```
params.r<-function(p.list,std){
      p.list[1]<-min(0.85,rnorm(1,m=p.list[1],sd=p.list[1]*std))
      p.list[2]<-min(0.87,rnorm(1,m=p.list[2],sd=p.list[2]*std))
      p.list[3]<-min(0.92,rnorm(1,m=p.list[3],sd=p.list[3]*std))
      p.list[4]<-min(0.98,rnorm(1,m=p.list[4],sd=p.list[4]*std))
      p.list[5]<-min(0.995,rnorm(1,m=p.list[5],sd=p.list[5]*std))
      p.list[6]<-min(0.5,rnorm(1,m=p.list[6],sd=p.list[6]*std))
return(p.list)}
```

1.60. Collision mortality was added at each year of the 30-year simulation according to a pre-set age class specific rate, expressed as a percentage of the number of pairs (0, 2, 4, 8, 10%). Therefore, as the population increased so did the number of wind farm related deaths. This is intended to model a situation in which activity around wind farms increases as the population increases. Each mortality scenario was simulated 1,000 times over a 30-year projection.

1.61. Because stochastic noise was added to the population parameters the actual collision mortality figure could vary between years within a simulation but, over all of the simulations, the average numbers killed would be close to the defined level.

1.62. The impact of wind farm mortality, for a long-lived species such as the white-tailed eagle, is partly dependent on the age classes of the birds killed. Generally, killing adults has a larger impact on the population. In order to model this three scenarios are run. The first assumes that all mortality is to sub-adult birds, in the second scenario collision mortality is split evenly between sub-adults and adults. Finally, all collision mortality is assumed to be adults.

1.63. Any sub-adult mortality is split between the sub-adult age classes in proportion to their numbers. For example, if 20% of sub-adults were in the second-year class and 30 birds were predicted to be killed, the number of birds in the second-year age class would be reduced by 30 x 0.874 * 0.2 = 5.2.

1.64. **Box 3** shows the code for one year of a 30-year simulation (there were 1,000 30-year simulations).

Box 3. Applying wind farm mortality.

```
#p.imm and p.Ad are the proportions of collisions in the sub-adult (immature) and
adult age classes. Mortality is split between sub-adults and adults depending on the
value of p.Imm.
p.Imm <-0.5
p.Ad  <-1 - p.Imm

#obtain some random values for the parameters for this year, std is 0.05
s.params<-params.r(params,std)
#the next six lines apply density dependent reductions if required.
#the order is sub-adult survival (s1.ran, etc), adult survival (v.ran) and
#the fledging rate (f.ran). Note these are applied to the random values in s.params
and not the default values in params
s1.ran<-dd.adj(s.params[1],pop.proj[i,7],car.cap,Dens.Dep)
s2.ran<-dd.adj(s.params[2],pop.proj[i,7],car.cap,Dens.Dep)
s3.ran<-dd.adj(s.params[3],pop.proj[i,7],car.cap,Dens.Dep)
s4.ran<-dd.adj(s.params[4],pop.proj[i,7],car.cap,Dens.Dep)
v.ran<-dd.adj(s.params[5],pop.proj[i,7],car.cap,Dens.Dep)
f.ran<-dd.adj(s.params[6],pop.proj[i,7],car.cap,Dens.Dep)
#create the PPM matrix (wte) with the new values
wte<-matrix(c(0,0,0,0,0,f.ran, s1.ran,0,0,0,0,0, 0,s2.ran,0,0,0,0,
0,0,s3.ran,0,0,0, 0,0,0,s4.ran,0,0, 0,0,0,0,v.ran,v.ran), nrow=6, byrow=TRUE)
#project population forward to next year (2) using the current age structure (n)
p<-pop.projection(wte,n,2)
#find the numbers of sub-adults (n[1]) and adults (n[2])
n<-p$stage.vectors[,2]
# remove the appropriate number of individuals from each class based on the level of
mortality and the proportion of individuals in that age class.
n.sa<-n[-6]                              # remove adults to leave only sub.ads
sub.ads<-sum(n.sa)                       # number of SAs
n.sa.p<-n.sa/sub.ads                     # proportions in each age class
n.sa.killed<-sub.ads*(p.Imm*mortality)   # find number of SA killed
n.sa.kill.age<-n.sa.killed * n.sa.p      # split up the deaths by age class
n[1:5]<-n.sa-n.sa.kill.age               # SAs after mortality
n.ad.killed<- n[6]*(p.Ad*mortality)      # adults killed
n[6]<-n[6]- n.ad.killed                  # adults after mortality
#store the results
pop.proj[i+1,1]<-i
pop.proj[i+1,2:7]<-n
#the adjusted values of n[1]…n[6] are the age structure for the projection to the
following year
```

1.65. Models were run for two regions (NHZ 6 and Skye). In each region the same levels of additional mortality were applied (0, 2, 4, 6, 8, 10%). Models were run with and without density dependence and with three age class mortality scenarios. Each model (combination of region, mortality rate and presence or absence of density dependence) is simulated 1,000 times with a 30-year projection.

1.66. Productivity on Skye was assumed to be 0.38 (0.76 for both sexes), based on SRMS data 2014-20. Productivity in NHZ 6 was assumed to be 0.4 (0.8 for both sexes), based on SRMS data 2014-20.

1.67. Results are presented in tabular form in **Appendix 1** with the minimum, maximum and median values for the number of pairs and population growth rates (λ) at the end of the projections. The first and third quartiles are also shown. These results are summarised graphically as boxplots (**Appendix 2**).

1.68. In addition, population trajectories are shown for 300 simulations (**Figures 2** – **7**). The number of simulations is reduced to 300 from 1,000 to help with the interpretation of the graph.

Results

NHZ 6

1.69. Starting values are 0.4 females fledged per pair; 16,14, 12, 10 & 8 sub-adult females plus 39 adult females and a carrying capacity of 80 pairs.

1.70. Detailed results are in **Appendices 1** and **2** and example trajectories are in **Figures 2**, **3** and **4**.

1.71. All results show that the effect of additional mortality is much greater when there is no density dependence and when the collisions are mainly to adults.

1.72. Differences in the population trajectories, in the absence of density dependence, are large but they cannot be considered to be biologically meaningful or feasible. For example, the median population size, in absence of any collision mortality, was 545 pairs (range 337 - 843 pairs). There is no situation in which NHZ 6 could support even the minimum scenario of 337 pairs. The most extreme modelled scenario was 10% adult mortality, equivalent to killing approximately 35 adults (both sexes) per year. There is no realistic scenario in which this is possible as it would be impossible to have this many adults close to the turbines. Even this extreme scenario predicts a median year 30 population of 80 pairs, which is considerably larger than the combined maximum population of 51 pairs for Skye and Mull estimated by Sansom *et al*. (2016). The minimum modelled year 30 population was 49 pairs, close to the Sansom *et al*. (2016) estimate of 51 pairs.

1.73. When there is density dependence the effect of additional mortality is much reduced but the effect of killing adults, rather than sub-adults, remains. In the presence of density dependence, an additional 4% adult mortality, or ~14 white-tailed eagles (both sexes) per year after 30 years, has a negligible impact compared with the control of 0 deaths (**Appendices 1** and **2**; **Figures 2** - **4**). The most extreme modelled scenario was a 10% mortality, restricted to adult birds. Even when ~30 adults (both sexes) are killed each year the median NHZ 6 population was ~69 pairs (range in 1,000 simulations 52 to 79). Given that Sansom *et al*. (2016) estimated a maximum combined population of 51 pairs for Skye and Mull, a median estimate of 69 pairs cannot be considered a significant impact.

1.74. In year 0, when there were assumed to be 39 pairs plus 60 sub-adult females, the initial additional wind farm deaths of females would be 0, 2, 4, 6, 8 & 10 females per year at 0, 2, 4, 6, 8 & 10 % levels of additional mortality. The total killed would be double this assuming an equal sex ratio, i.e., 0, 4, 8, 12, 16 & 20 per year. It is reasonable to assume that the majority of collision deaths would be sub-adults as only a small number of pairs could be directly affected by the wind farms. Even assuming an equal ratio of deaths, collision mortality had to be more than 4% before the impact on the number of pairs was apparent and, even then, it was only a reduction of 2.6 pairs from an assumed cap of 80 pairs.

1.75. In the absence of density dependence, the numbers killed (both sexes) each year after 30 years depends on how mortality is partitioned between sub-adults and adults (**Appendices 1** & **2**; **Figures 2** - **4**). If all mortality is sub-adult the numbers are 0, 41, 67, 80, 87 & 88 while, if all mortality is to adults, the numbers are 0, 30, 43, 44, 41 & 35 in year 30. Note that if all mortality is to adult birds the number killed at the 10% rate is less than that at a 4% rate; this is because of the impacts of the additional mortality on the population trajectories.

Skye

1.76. Starting values are 0.38 females fledged per pair; 7, 6, 5, 4 & 3 sub-adult females plus 25 adult females and a carrying capacity of 40 pairs.

1.77. Detailed results are in **Appendices 1** and **2** and example trajectories are in **Figures 5**, **6** and **7**.

1.78. As with the NHZ 6 results, all results show that the effect of additional mortality is much greater when there is no density dependence and when the collisions are mainly to adults.

1.79. Differences in the population trajectories, in the absence of density dependence, are large but they cannot be considered to be biologically meaningful or feasible. For example, the median population size, in absence of any collision mortality, was 270 pairs (range 157 - 422 pairs). There is no situation in which Skye could support even the minimum scenario of 157 pairs. The most extreme modelled scenario was 10% adult mortality, equivalent to killing approximately 17 adults (both sexes) per year. There is no realistic scenario in which this is possible as it would be impossible to have this many adults close to the turbines. Even this extreme scenario predicts a median year 30 population of 38 pairs, which is considerably larger than the combined maximum population of 30 pairs for Skye estimated by Sansom *et al*. (2016). The minimum modelled year 30 population was 25 pairs, which is the same as the current population.

1.80. When there is density dependence the effect of additional mortality is much reduced but the effect of killing adults, rather than sub-adults, remains. In the presence of density dependence, an additional 4% mortality of adults, or ~6 white-tailed eagles (both sexes) per year after 30 years, has a negligible impact compared with the control of 0 deaths (**Appendices 1** and **2**; **Figures 5** - **7**). The most extreme modelled scenario was a 10% mortality, restricted to adult birds. Even when ~15 adults (both sexes) are killed each year the median Skye population was ~33 pairs (range in 1,000 simulations 23 to 38). Given that Sansom *et al*. (2016) estimated a maximum population of 30 pairs for Skye, a median estimate of 33 pairs cannot be considered a significant impact.

1.81. In year 0, when there were assumed to be 25 pairs plus 25 sub-adult females, the initial additional wind farm deaths of females would be 0, 1, 2, 3, 4 & 5 females per year at 0, 2, 4, 6, 8 & 10 % levels of additional mortality. The total killed would be double this assuming an equal sex ratio, i.e., 0, 2, 4, 6, 8 & 10 per year. It is reasonable to assume that the majority of collision deaths would be sub-adults as only a small number of pairs could be directly affected by the wind farms. Even assuming an equal ratio of deaths, collision mortality had to be more than 4% before the impact on the number of pairs was apparent and, even then, it was only a reduction of 1.4 pairs from an assumed cap of 40 pairs.

1.82. In the absence of density dependence, the numbers killed (both sexes) each year after 30 years depends on how mortality is partitioned between sub-adults and adults (**Appendices 1** and **2**; **Figures 5** - **7**). If all mortality is sub-adult the numbers are 0, 19, 31, 38, 41 & 42 while, if all mortality is to adults, the numbers are 0, 14, 20, 21, 19 & 17 in year 30. Note that if all mortality is to adult birds the number killed at the 10% rate is less than that at a 4% rate; this is because of the impacts of the additional mortality on the population trajectories.

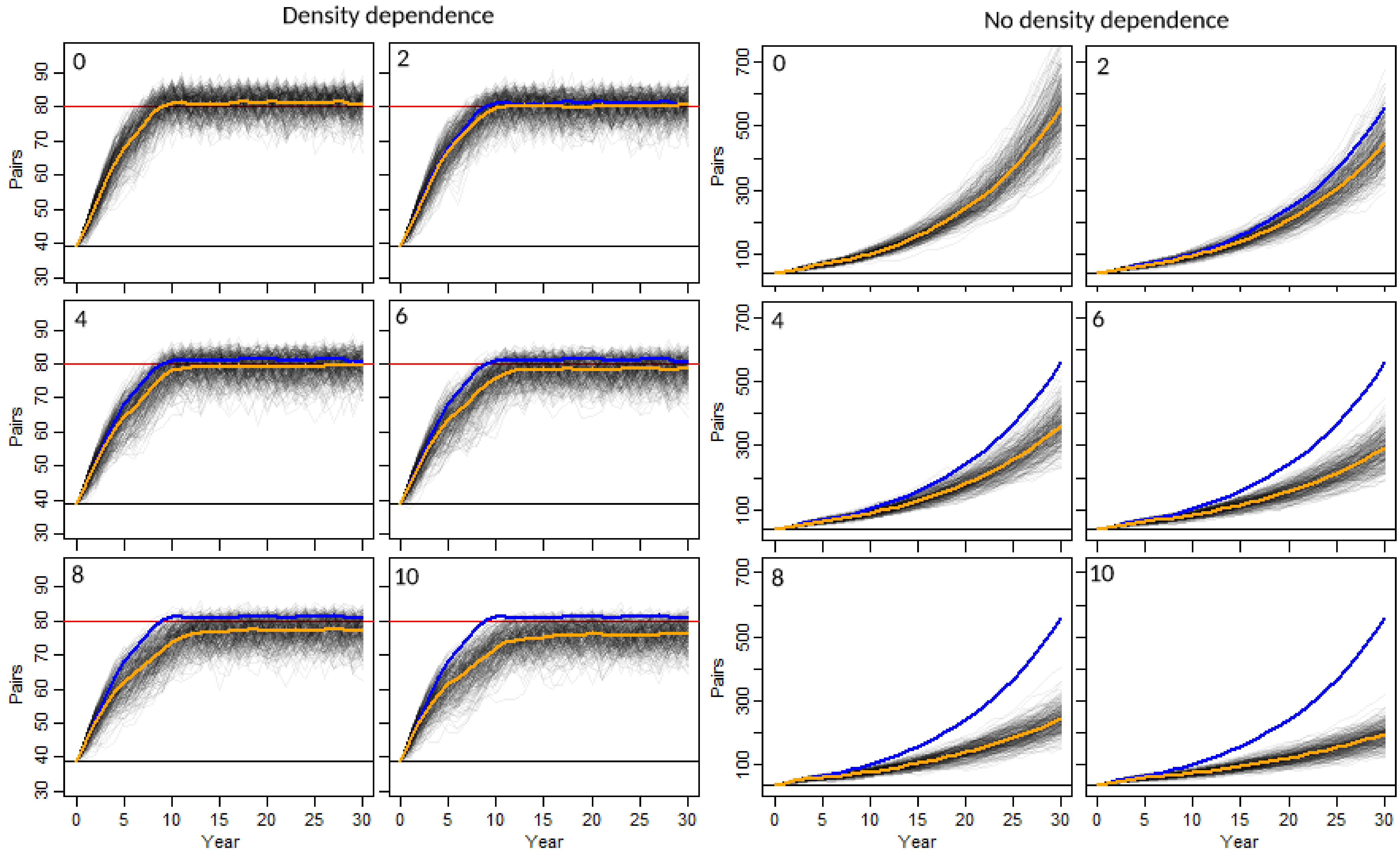

Figure 2. NHZ 6: example population trajectories at different levels of additional mortality (all sub-adult), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

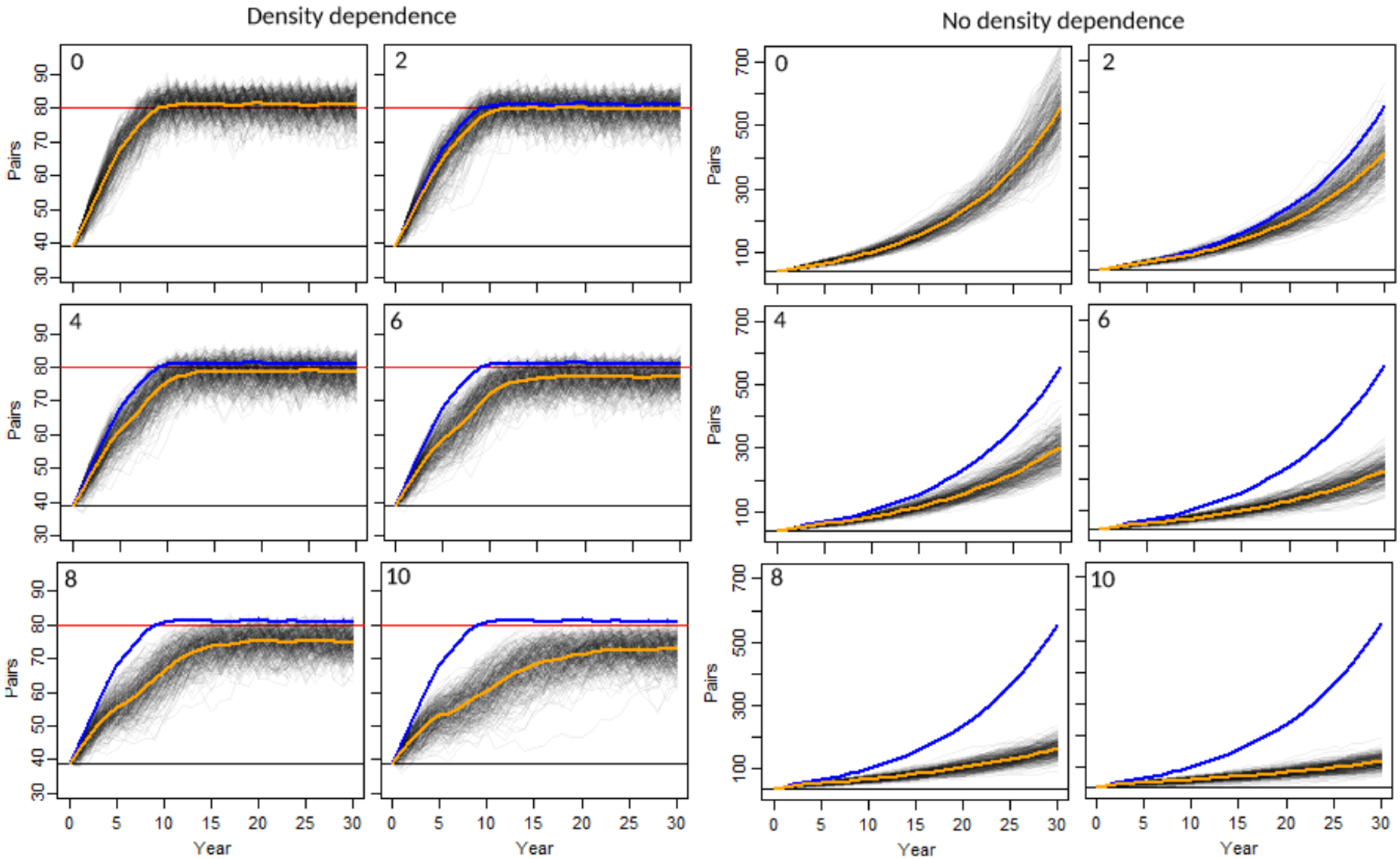

Figure 3. NHZ 6: example population trajectories at different levels of additional mortality (split between adults and sub-adults), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

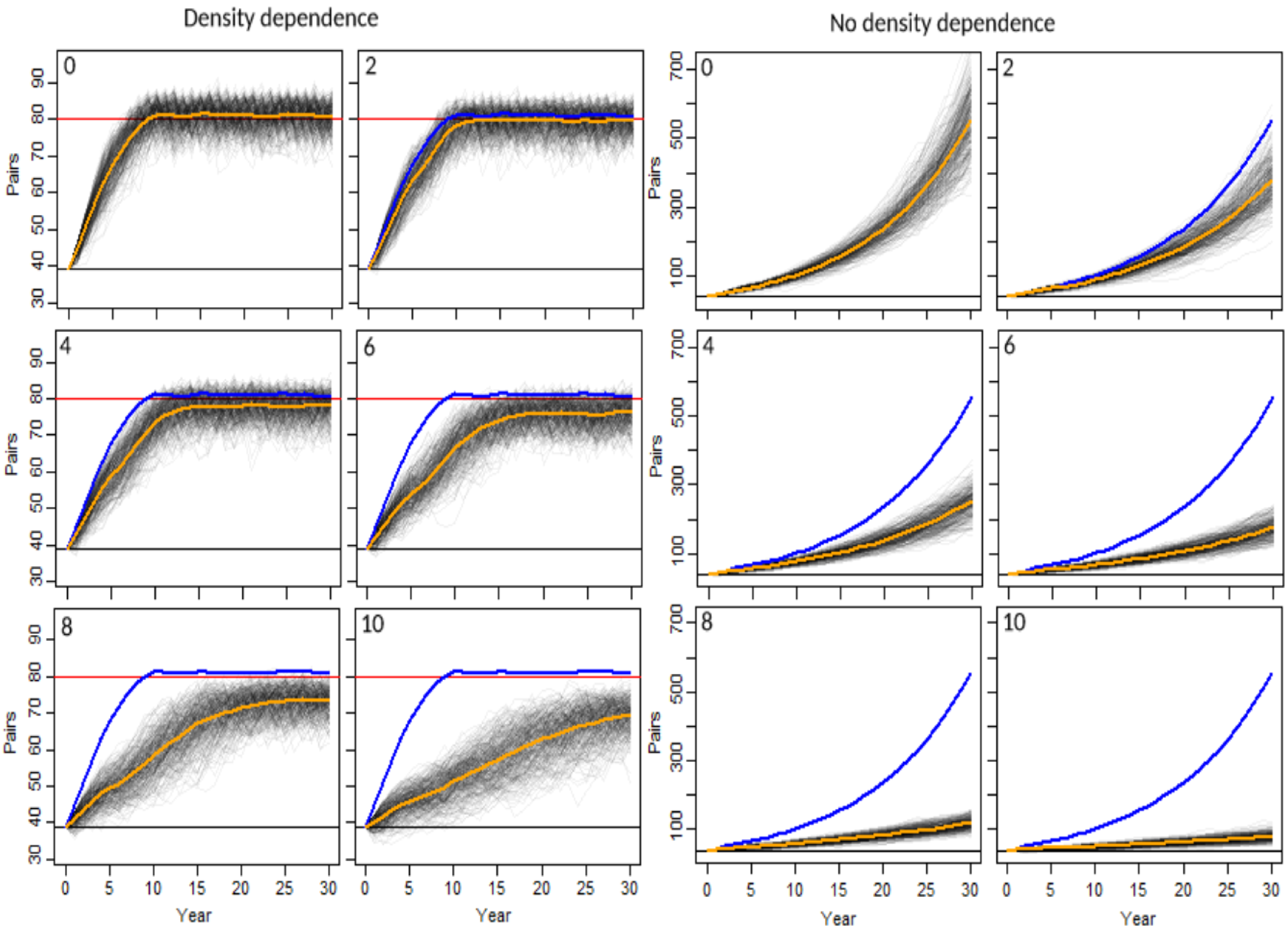

Figure 4. NHZ 6: example population trajectories at different levels of additional mortality (all adults), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

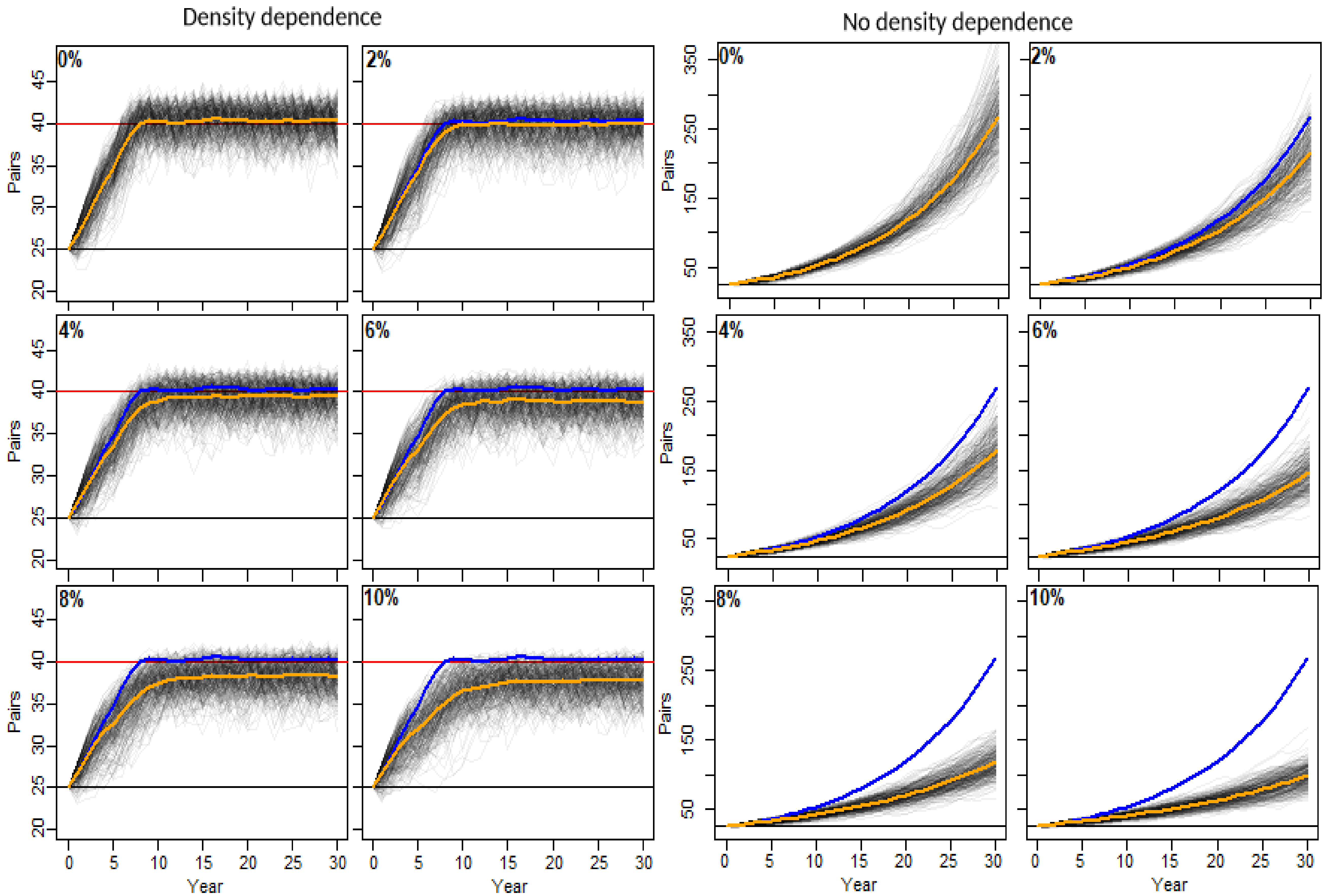

Figure 5. SKYE: example population trajectories at different levels of additional mortality (all sub-adults), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

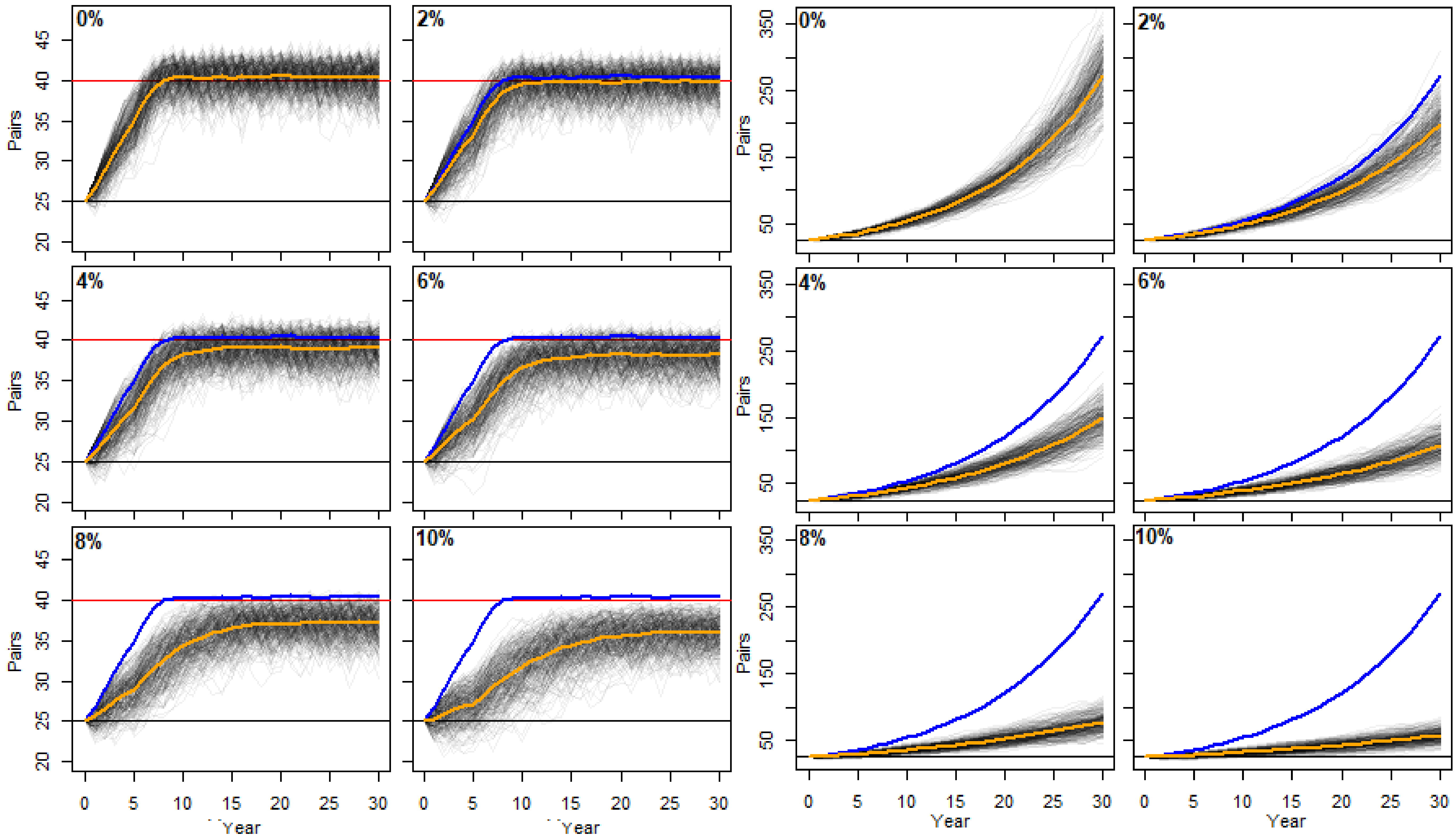

Figure 6. SKYE: example population trajectories at different levels of additional mortality (split between adults and sub-adults), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

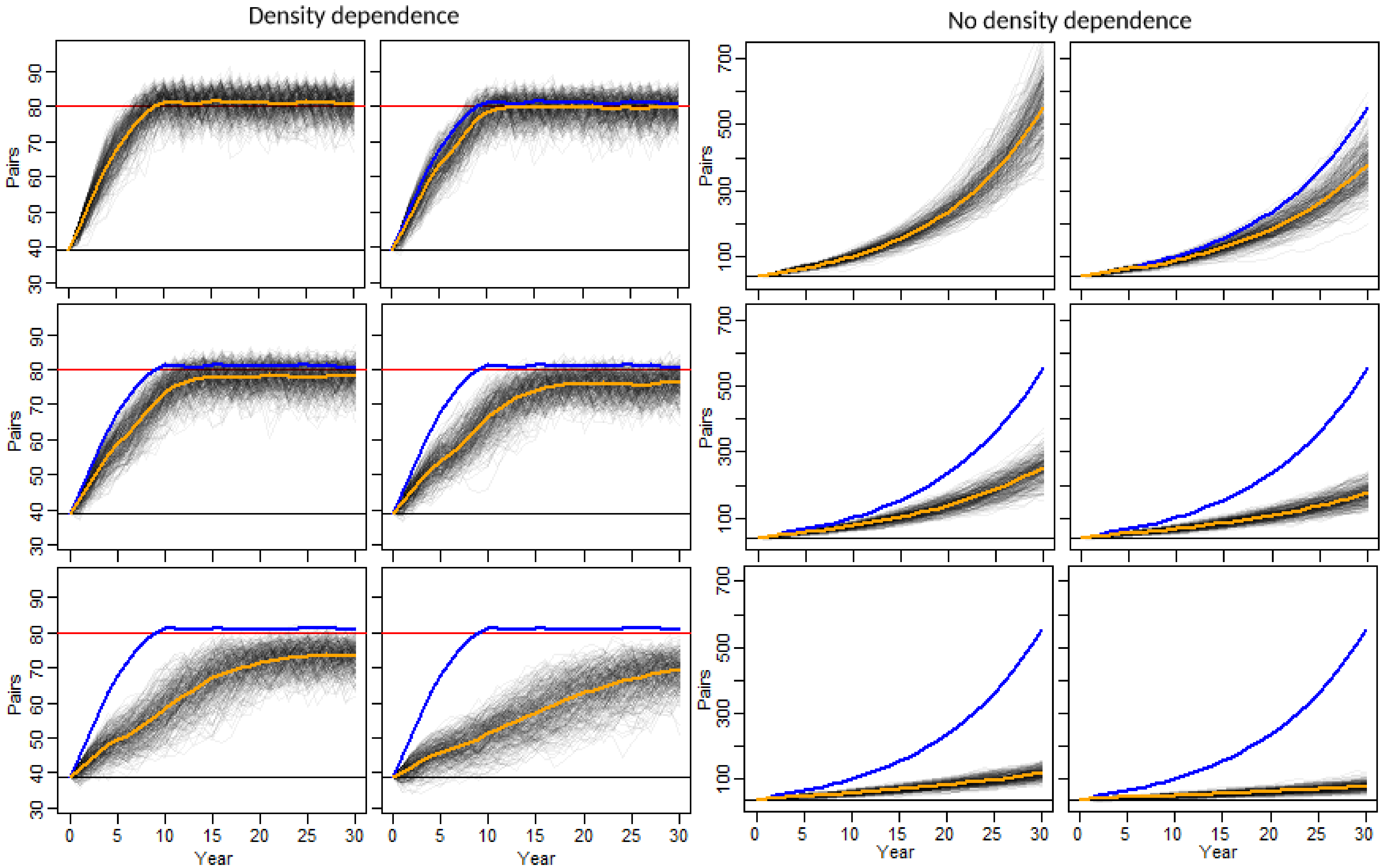

Figure 7. SKYE: example population trajectories at different levels of additional mortality (all adults), with and without density dependence. The solid blue line is the population trajectory in the absence of stochastic noise (fixed values). The orange line is the median trajectory of the 300 simulations. The horizontal red line is the assumed carrying capacity.

Conclusions

1.83. None of the modelled scenarios resulted in population extinction.

1.84. 30-year population totals lower than the starting values were not seen, even at the highest mortality rates. Indeed, the minimum numbers of pairs after 30 years from 30,000 simulations (6 levels of mortality with and without density dependence and three levels of partitioning mortality) were 48 and 51 for NHZ 6 population (10% adult mortality with and without density dependence respectively). For the Skye population the minimums were 23 and 25 under the same scenarios as the NHZ 6 simulations. The starting populations were 39 and 25 respectively. The lower quartiles for the same scenarios were 66 and 77 pairs (NHZ 6) and 52 and 54 pairs for Skye.

1.85. As noted in Samsom *et al*. (2016) the effect of killing even large numbers of white-tailed eagles is to slow the rate of population expansion and delay the date at which the carrying capacity is reached (see **Figures 2** - **7**). The greater impact of killing more adults than sub-adults is also clear in **Figures 2** - **7**.

1.86. The predicted mortality from the Balmeanach wind farm is 1.3 individuals per year, although this might be considered as a pessimistic estimate since it would require immediate replacement of birds killed by the wind farm.

1.87. The assumed NHZ 6 starting population in the models is 120 sub-adults and 78 adults. Depending on the ages of the birds killed this represents 1.1% of the sub-adults, 1.7% of the adults or 0.7% of all birds. As shown in **Figures 2** – **4** and **Appendices 1** and **2**, this scale of mortality is not predicted to have a significant impact.

1.88. The assumed Skye starting population in the models is 50 sub-adults and 50 adults. Depending on the ages of the birds killed this represents 2.6% of the sub-adults, 2.6% of the adults or 1.3% of all birds. As shown in **Figures 5** - **7** and **Appendices 1** and **2**, this scale of mortality is also not predicted to have a significant impact.

1.89. The issue of cumulative assessment is complicated by the temporal differences between the already operational and consented wind farms. There are no wind farms in NHZ 6 apart from those on Skye. The wind farms that need to be included in a cumulative assessment are the operational Ben Aketil and Edinbane wind farms, plus the consented Ben Sca, Beinn Mheadhonach and Glen Ullinish schemes. Based on previous ES data, the cumulative predicted mortality for white-tailed eagles from the two operational wind farms was estimated to be 0.11 per annum while the consented Ben Sca (0.5 per annum), Ben Mheadhonach (0.3 per annum) and Glen Ullinish (1.2 per annum) winds farms have a combined predicted mortality of 2.1 per annum. Therefore, adding in the predicted mortality from the Balmeanach wind farm of 1.3 individuals per year gives a cumulative total of 3.4 birds per year.

1.90. The assumed NHZ 6 starting population in the models is 120 sub-adults and 78 adults. Depending on the ages of the birds killed the cumulative collision mortality of 3.4 birds per year represents 2.8% of the sub-adults, 4.4% of the adults or 1.7% of all birds. As shown in **Figure 4** and **Appendices 1** and **2**, this scale of mortality is not predicted to have a significant impact although there would be a delay in reaching the carrying capacity. The impact, without density dependence operating, looks large (**Figure 4**) but the median year 30 population, with 6% annual adult mortality is predicted to be 174 pairs (range 111-269 pairs) which is far in excess of any realistic white-tailed eagle population size for NHZ 6. Even the minimum of 111 pairs is larger than any realistic maximum.

1.91. The assumed Skye starting population in the models is 50 sub-adults and 50 adults. Depending on the ages of the birds killed the cumulative collision mortality of 3.4 birds per year represents 6.8% of the sub-adults, 6.8% of the adults or 3.4% of all birds. The worst-case scenario is that all collisions would be all adults and in **Figure 7** the population is not predicted to reach its carrying capacity within 30 years. However, the prediction of between 34 and 37 pairs (range 26 - 38 pairs) is still a significant increase and well above the maximum predicted Skye population in in Samsom *et al*. (2016). There is no prediction of a population decline. A more realistic scenario is that the collision mortality will be split between sub-adults and adults. If an equal split is assumed the prediction of between 36 and 37 pairs (range 29 - 40 pairs).

1.92. The impact, without density dependence operating, looks large (**Figure 7**) but the median year 30 population, with 6% annual adult mortality is predicted to be 82 pairs (range 49 - 130 pairs) which is far in excess of any realistic white-tailed eagle population size for Skye. Even the minimum of 49 pairs is larger than any realistic maximum.

1.93. Note: the population growth rate with density dependence and no mortality is lower than that without density dependence (7.6% compared with 8.2%) because density dependence prevented further population expansion after approximately 21 years. The overall growth rate is based on the number of pairs after 25 years compared with the number of pairs in year 0.

1.94. The overall effect of the levels of additional wind farm mortality modelled in this report is to reduce the year at which the population reach their carrying capacities. There is no threat to the integrity of the white-tailed eagle populations at even the highest rate of modelled mortality. This is the same conclusion reached by Samsom *et al*. (2016).

1.95. Thus, despite potentially limiting the overall population size, the modelled additive mortality levels would not cause a population decline or extinction (across either population) and would only reduce the rate at which population growth occurs.

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Appendix 1 - Summary of the simulation results

NHZ 6 Population - **Density dependence operating with a carrying capacity of 80 pairs.**

	% mortality	Population Growth rate						Year 30 Population Size (Pairs)						Sub-adults killed (year 30)						Adults Killed (year 30)					
		Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max
All sub-adult	0	1.019	1.023	1.025	1.024	1.026	1.028	66.4	78.5	81.4	80.9	83.9	89.4												
	2	1.018	1.023	1.024	1.024	1.025	1.027	65.3	77.9	80.9	80.3	83.1	88.2	3.3	3.7	3.8	3.8	3.9	4.2						
	4	1.019	1.023	1.024	1.024	1.025	1.027	67.4	77.1	79.9	79.4	82.3	87.2	6.4	7.2	7.4	7.4	7.6	8.2						
	6	1.017	1.022	1.023	1.023	1.024	1.027	65.7	75.6	78.6	78.2	81.0	86.4	9.4	10.6	10.8	10.8	11.1	12.2						
	8	1.017	1.022	1.023	1.023	1.024	1.026	63.1	75.0	78.0	77.4	80.3	85.8	12.7	13.7	14.0	14.0	14.3	15.3						
	10	1.015	1.021	1.022	1.022	1.023	1.025	63.5	73.5	76.4	76.0	79.0	83.9	15.3	16.7	17.0	17.0	17.4	18.6						
50:50 mortality	0	1.019	1.023	1.024	1.024	1.025	1.028	67.2	78.7	81.4	81.1	83.9	89.8												
	2	1.018	1.023	1.024	1.024	1.025	1.027	65.6	77.3	80.4	79.9	82.8	89.8	1.7	1.9	1.9	1.9	2.0	2.1	1.3	1.6	1.6	1.6	1.7	1.8
	4	1.017	1.022	1.024	1.023	1.025	1.027	62.1	75.7	78.8	78.3	81.4	87.3	3.5	3.8	3.8	3.8	3.9	4.2	2.5	3.1	3.2	3.2	3.3	3.6
	6	1.017	1.022	1.023	1.023	1.024	1.026	63.2	74.8	77.6	77.2	79.9	85.2	5.0	5.6	5.7	5.7	5.8	6.2	3.9	4.6	4.8	4.8	4.9	5.3
	8	1.014	1.021	1.022	1.022	1.023	1.025	60.7	72.8	75.5	75.2	77.9	84.0	6.9	7.4	7.5	7.5	7.6	8.3	5.1	6.1	6.3	6.3	6.5	7.0
	10	1.013	1.020	1.021	1.021	1.022	1.024	60.0	70.3	73.3	72.9	75.7	81.6	8.2	9.0	9.2	9.2	9.4	10.2	6.3	7.4	7.7	7.7	8.0	8.6
All adult mortality	0	1.019	1.023	1.025	1.024	1.026	1.028	68.0	78.4	81.5	80.9	83.9	89.6												
	2	1.018	1.023	1.024	1.024	1.025	1.028	67.5	77.5	80.5	79.9	82.9	89.3							2.8	3.2	3.3	3.3	3.4	3.6
	4	1.016	1.022	1.023	1.023	1.024	1.026	63.1	75.6	78.4	78.0	80.8	86.1							5.3	6.3	6.5	6.5	6.7	7.2
	6	1.015	1.021	1.022	1.022	1.024	1.026	60.8	73.6	76.4	76.0	79.0	84.3							7.8	9.4	9.8	9.7	10.1	10.8
	8	1.014	1.020	1.021	1.021	1.022	1.025	58.9	70.8	73.7	73.3	76.1	82.8							10.3	12.3	12.8	12.7	13.2	14.4
	10	1.010	1.017	1.019	1.019	1.020	1.023	52.0	65.9	69.2	68.8	72.0	78.7							11.5	14.6	15.4	15.3	16.0	17.5

NHZ 6 Population - Density dependence is not operating.

% mortality		Population Growth rate						Year 30 Population Size (Pairs)						Sub-adults killed (year 30)						Adults Killed (year 30)					
		Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max
All sub-adult	0	1.072	1.085	1.088	1.088	1.092	1.102	336.6	495.0	545.1	554.8	610.5	843.5												
	2	1.064	1.078	1.081	1.081	1.084	1.094	268.4	398.8	440.0	443.9	486.2	656.7	12.3	19.1	20.8	21.0	22.8	30.3						
	4	1.056	1.070	1.074	1.074	1.077	1.089	206.8	321.5	359.5	363.3	398.1	561.4	21.1	30.2	33.6	33.9	37.3	51.3						
	6	1.051	1.064	1.067	1.067	1.070	1.083	177.8	262.2	289.5	294.0	322.4	467.3	25.2	36.4	40.0	40.6	44.7	59.7						
	8	1.042	1.057	1.060	1.060	1.064	1.077	137.7	213.0	238.6	241.3	265.0	391.9	25.8	39.2	43.5	43.9	48.0	68.7						
	10	1.035	1.050	1.054	1.054	1.058	1.071	111.6	175.5	196.8	199.3	220.5	324.5	25.5	39.8	44.3	44.8	49.4	72.0						
50:50 mortality	0	1.071	1.085	1.088	1.088	1.092	1.104	327.0	493.6	546.2	552.9	607.7	883.1												
	2	1.064	1.075	1.078	1.078	1.082	1.092	265.5	366.8	405.8	409.9	450.9	614.2	6.4	8.9	9.8	9.9	10.8	14.3	5.4	7.4	8.2	8.3	9.1	12.4
	4	1.050	1.064	1.068	1.068	1.071	1.084	173.0	269.9	297.4	300.0	329.4	484.4	8.8	13.3	14.5	14.6	16.0	22.4	7.1	11.0	12.1	12.2	13.4	19.8
	6	1.039	1.054	1.058	1.057	1.061	1.074	124.0	197.4	219.1	221.1	243.2	353.8	9.9	14.7	16.3	16.4	17.8	25.4	7.7	12.2	13.6	13.7	15.0	21.9
	8	1.030	1.044	1.047	1.047	1.051	1.064	97.3	144.7	161.3	162.2	178.0	265.1	10.4	14.6	16.1	16.2	17.7	25.5	8.1	12.1	13.4	13.5	14.8	22.1
	10	1.022	1.033	1.037	1.037	1.040	1.050	74.8	106.1	118.4	118.7	130.6	175.6	9.1	13.4	14.9	14.9	16.3	21.0	7.9	11.2	12.5	12.5	13.7	18.5
All adult mortality	0	1.070	1.085	1.088	1.088	1.091	1.102	315.6	495.4	547.9	550.9	601.8	836.3												
	2	1.060	1.072	1.075	1.075	1.079	1.090	232.4	340.6	375.4	378.0	413.6	585.8							9.5	13.9	15.3	15.4	16.9	23.9
	4	1.047	1.060	1.063	1.063	1.066	1.075	158.5	234.1	258.2	258.8	282.1	372.2							13.2	19.5	21.5	21.6	23.5	31.0
	6	1.035	1.047	1.050	1.050	1.053	1.064	111.1	157.5	174.2	175.0	192.1	269.1							14.2	20.1	22.2	22.3	24.5	34.3
	8	1.018	1.034	1.037	1.037	1.040	1.051	66.0	107.3	117.0	118.2	129.3	181.8							11.5	18.7	20.4	20.6	22.5	31.6
	10	1.007	1.021	1.024	1.024	1.027	1.037	48.8	72.7	79.6	80.2	87.6	118.9							10.8	16.2	17.7	17.8	19.5	26.4

Skye Population - Density dependence operating with a carrying capacity of 40 pairs.

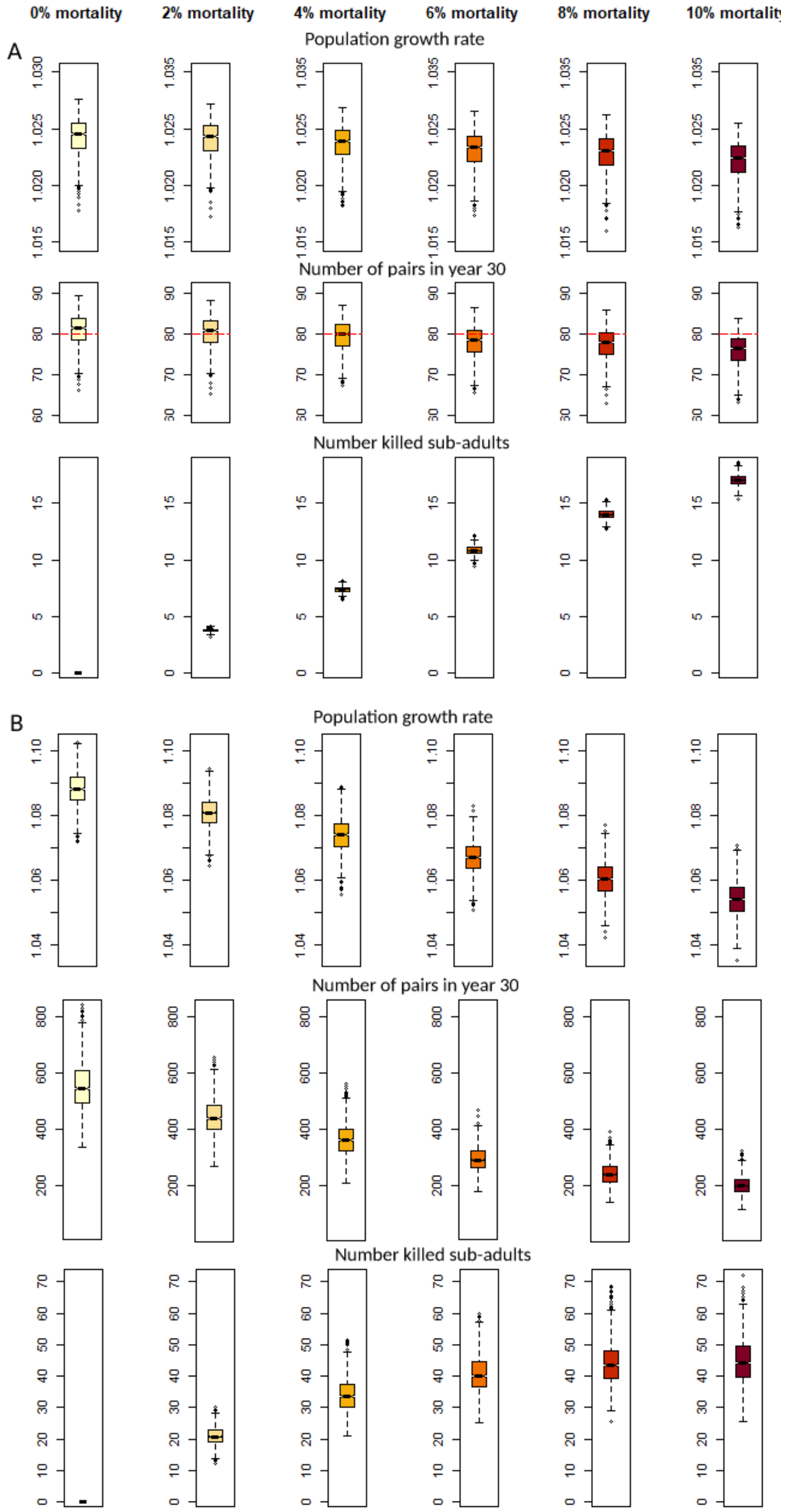
	% mortality	Population Growth rate						Year 30 Population Size (Pairs)						Sub-adults killed (year 30)						Adults Killed (year 30)					
		Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max	Min	1stQ	Med.	Mean	3rdQ	Max
All sub-adult	0	1.011	1.015	1.016	1.016	1.017	1.019	34.4	39.1	40.6	40.4	41.9	44.3												
	2	1.010	1.014	1.016	1.015	1.017	1.019	33.3	38.5	40.0	39.8	41.3	44.4	1.6	1.8	1.8	1.8	1.9	2.0						
	4	1.008	1.014	1.015	1.015	1.016	1.019	32.0	38.2	39.6	39.4	40.8	43.7	3.1	3.5	3.5	3.5	3.6	3.9						
	6	1.008	1.014	1.015	1.015	1.016	1.018	31.4	37.7	39.1	39.0	40.4	42.7	4.6	5.0	5.2	5.1	5.3	5.7						
	8	1.008	1.013	1.014	1.014	1.015	1.017	31.6	37.1	38.5	38.3	39.8	42.2	6.1	6.6	6.7	6.7	6.8	7.6						
	10	1.007	1.013	1.014	1.014	1.015	1.017	30.5	36.5	38.0	37.8	39.3	41.4	7.0	7.9	8.1	8.1	8.3	8.8						
50:50 mortality	0	1.010	1.015	1.016	1.016	1.017	1.019	33.4	39.2	40.6	40.4	41.8	44.4												
	2	1.009	1.014	1.016	1.015	1.017	1.019	32.4	38.6	40.0	39.8	41.3	44.6	0.8	0.9	0.9	0.9	0.9	1.0	0.7	0.8	0.8	0.8	0.8	0.9
	4	1.008	1.014	1.015	1.015	1.016	1.018	31.4	37.7	39.2	39.1	40.5	43.0	1.6	1.8	1.8	1.8	1.9	2.0	1.3	1.5	1.6	1.6	1.7	1.8
	6	1.007	1.013	1.014	1.014	1.015	1.017	31.2	37.0	38.4	38.2	39.7	42.1	2.4	2.7	2.7	2.7	2.8	3.0	1.9	2.3	2.4	2.4	2.5	2.6
	8	1.005	1.012	1.013	1.013	1.015	1.017	29.4	36.1	37.5	37.3	38.7	41.4	3.3	3.5	3.6	3.6	3.6	3.9	2.5	3.0	3.1	3.1	3.2	3.4
	10	1.004	1.011	1.012	1.012	1.013	1.016	28.6	34.8	36.2	36.0	37.4	40.4	3.8	4.2	4.3	4.3	4.4	4.8	3.0	3.7	3.8	3.8	3.9	4.3
All adult mortality	0	1.006	1.015	1.016	1.016	1.017	1.019	30.1	39.0	40.6	40.3	41.7	44.5												
	2	1.010	1.014	1.016	1.015	1.016	1.019	33.8	38.4	39.8	39.6	41.0	43.7							1.4	1.6	1.6	1.6	1.7	1.8
	4	1.008	1.013	1.015	1.015	1.016	1.018	31.9	37.4	38.9	38.7	40.2	42.6							2.7	3.1	3.2	3.2	3.3	3.6
	6	1.008	1.013	1.014	1.014	1.015	1.017	31.4	36.4	37.7	37.6	38.9	41.8							4.0	4.6	4.8	4.8	5.0	5.3
	8	1.007	1.011	1.012	1.012	1.014	1.016	30.5	35.0	36.4	36.2	37.6	39.9							5.3	6.1	6.3	6.3	6.5	6.9
	10	0.997	1.008	1.010	1.010	1.011	1.014	23.2	32.0	33.6	33.4	35.1	38.3							5.1	7.1	7.5	7.4	7.8	8.5

Skye Population - Density dependence not operating.

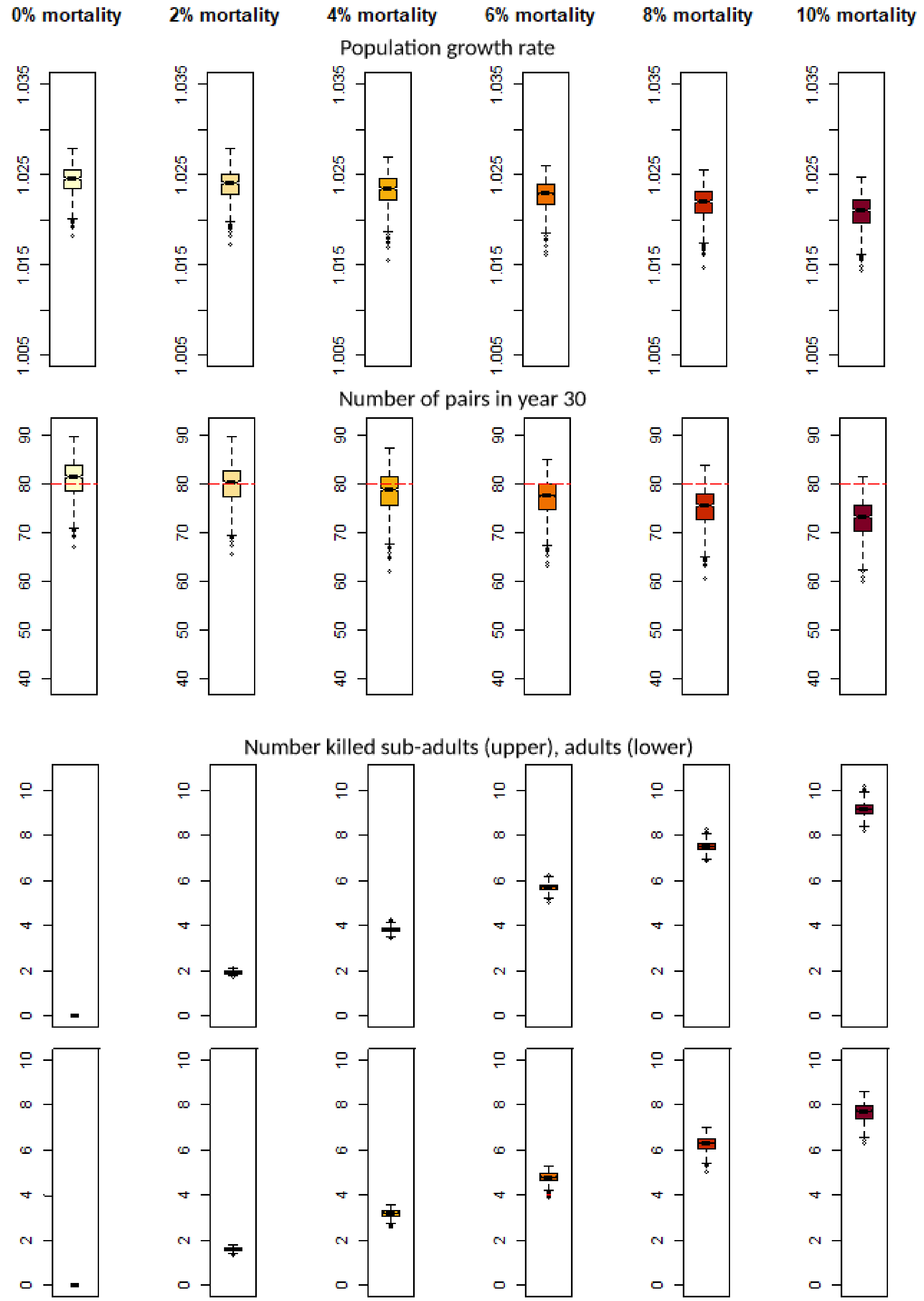
	% mortality	Population Growth rate						Year 30 Population Size (Pairs)						Sub-adults killed (year 30)						Adults Killed (year 30)					
		Min	1stQ	Median	Mean	3rdQ	Max	Min	1stQ	Median	Mean	3rdQ	Max	Min	1stQ	Median	Mean	3rdQ	Max	Min	1stQ	Median	Mean	3rdQ	Max
All sub-adult	0	1.061	1.076	1.079	1.079	1.082	1.094	157.7	245.3	270.1	271.7	295.5	422.6												
	2	1.057	1.068	1.072	1.072	1.075	1.090	138.6	194.7	216.8	217.5	238.0	370.7	6.0	8.9	9.8	9.9	10.8	15.8						
	4	1.048	1.062	1.065	1.065	1.068	1.080	104.8	158.3	176.1	177.8	194.7	278.4	9.8	14.2	15.7	15.9	17.4	25.3						
	6	1.040	1.055	1.059	1.058	1.062	1.073	82.5	128.5	145.3	145.8	161.5	224.0	10.5	17.0	19.1	19.3	21.2	30.6						
	8	1.032	1.048	1.052	1.052	1.055	1.066	65.1	106.2	118.7	119.3	131.3	183.1	11.2	18.6	20.6	20.8	22.9	31.3						
	10	1.031	1.042	1.046	1.045	1.049	1.063	62.5	87.5	98.3	99.1	109.2	164.3	12.6	18.8	21.0	21.2	23.4	32.8						
50:50 mortality	0	1.063	1.075	1.079	1.079	1.083	1.096	166.7	240.4	266.7	269.9	297.2	441.0												
	2	1.050	1.065	1.069	1.069	1.072	1.082	113.5	176.4	197.2	198.5	219.4	293.6	2.7	4.1	4.6	4.6	5.1	7.1	2.3	3.6	4.0	4.0	4.4	5.9
	4	1.043	1.055	1.059	1.059	1.062	1.073	89.8	130.8	145.6	146.9	161.7	222.9	4.3	6.2	6.9	6.9	7.5	10.3	3.7	5.3	5.9	6.0	6.6	9.1
	6	1.032	1.045	1.048	1.048	1.052	1.062	64.7	95.3	106.9	107.5	118.1	160.1	4.7	6.8	7.6	7.6	8.3	11.7	4.0	5.9	6.6	6.7	7.3	9.9
	8	1.023	1.035	1.038	1.038	1.042	1.051	49.8	70.9	78.3	79.0	86.8	116.5	4.6	6.8	7.5	7.5	8.2	11.2	4.1	5.9	6.5	6.6	7.2	9.7
	10	1.010	1.024	1.028	1.028	1.031	1.041	34.1	51.9	57.5	57.7	63.2	85.7	4.1	6.3	6.9	6.9	7.6	9.9	3.6	5.5	6.1	6.1	6.6	9.0
All adult mortality	0	1.060	1.075	1.079	1.079	1.082	1.095	150.6	240.6	265.0	267.8	292.6	432.2												
	2	1.046	1.063	1.066	1.066	1.069	1.079	100.1	163.6	181.2	181.7	199.0	265.7							4.1	6.7	7.4	7.4	8.1	10.8
	4	1.036	1.050	1.053	1.053	1.056	1.067	72.8	110.6	122.2	123.2	134.0	185.3							6.1	9.2	10.2	10.3	11.2	15.4
	6	1.023	1.036	1.040	1.040	1.043	1.055	49.3	74.4	82.1	82.9	90.6	130.1							6.3	9.5	10.5	10.6	11.6	16.6
	8	1.010	1.024	1.027	1.027	1.030	1.038	33.3	50.9	56.3	56.6	61.6	78.9							5.8	8.8	9.8	9.8	10.7	13.7
	10	1.000	1.011	1.014	1.014	1.017	1.029	25.2	34.4	38.0	38.2	41.6	60.5							5.6	7.6	8.5	8.5	9.2	13.4

Appendix 2 - Graphical summaries of the simulation results

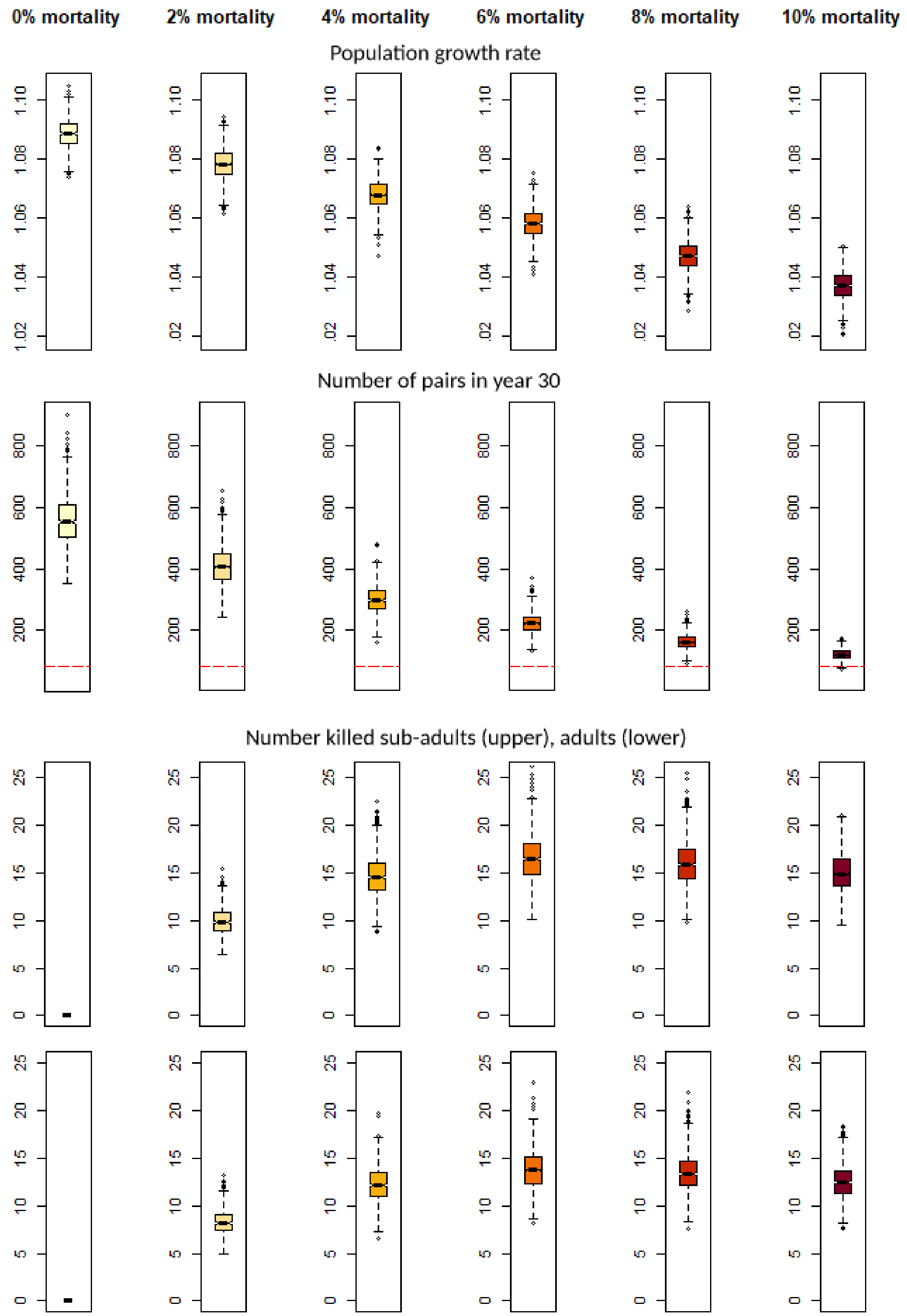
NHZ 6: sub-adult only collision mortality boxplots. A with density dependence, B without. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line) and row 3 the numbers killed in year 30.



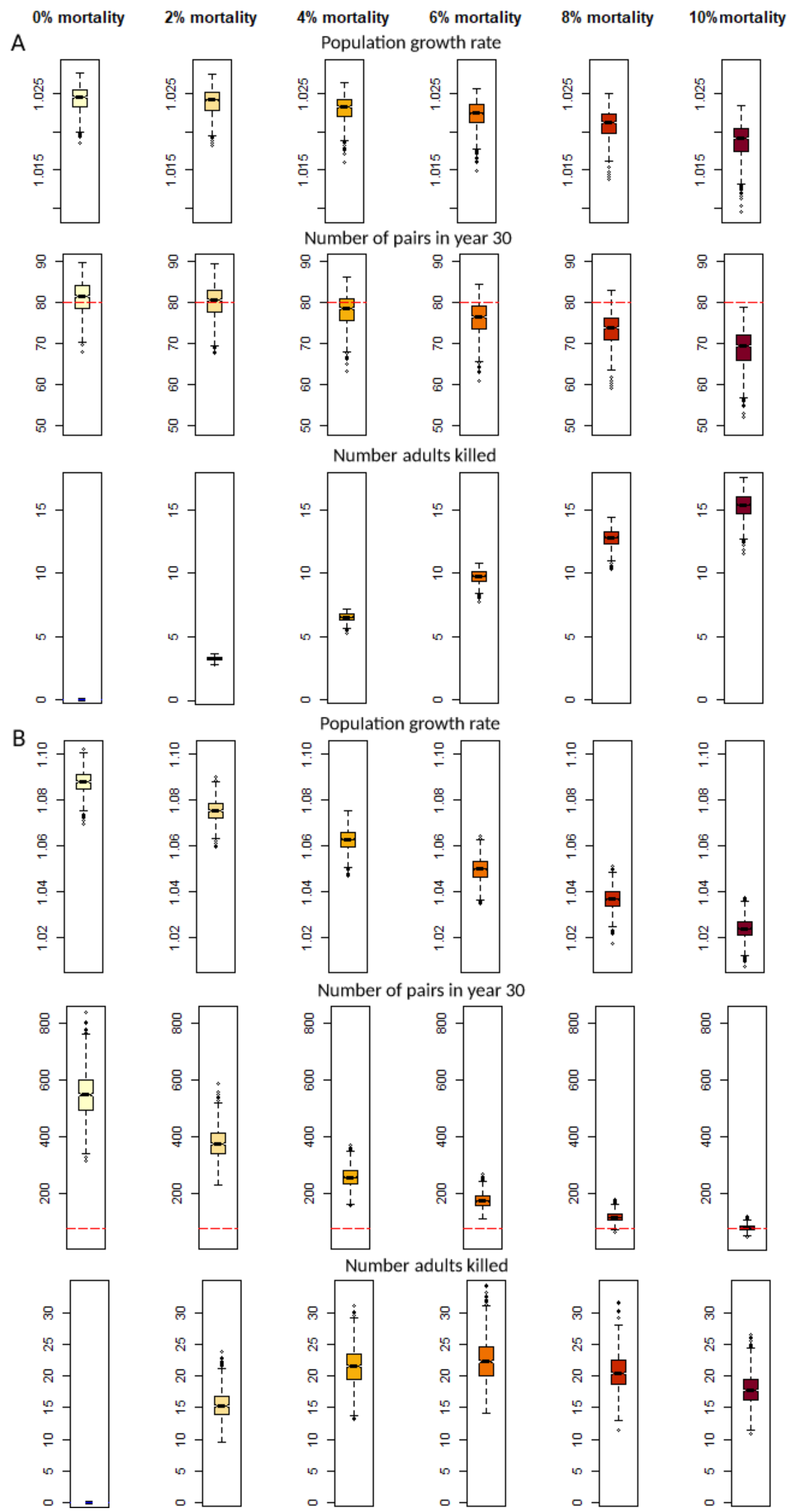
NHZ 6: collision mortality shared 50:50 between adults and sub-adult boxplots, with density dependence operating. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line); row 3 the numbers of sub-adults killed in year 30 and row 4 is the numbers of adults killed in year 30.



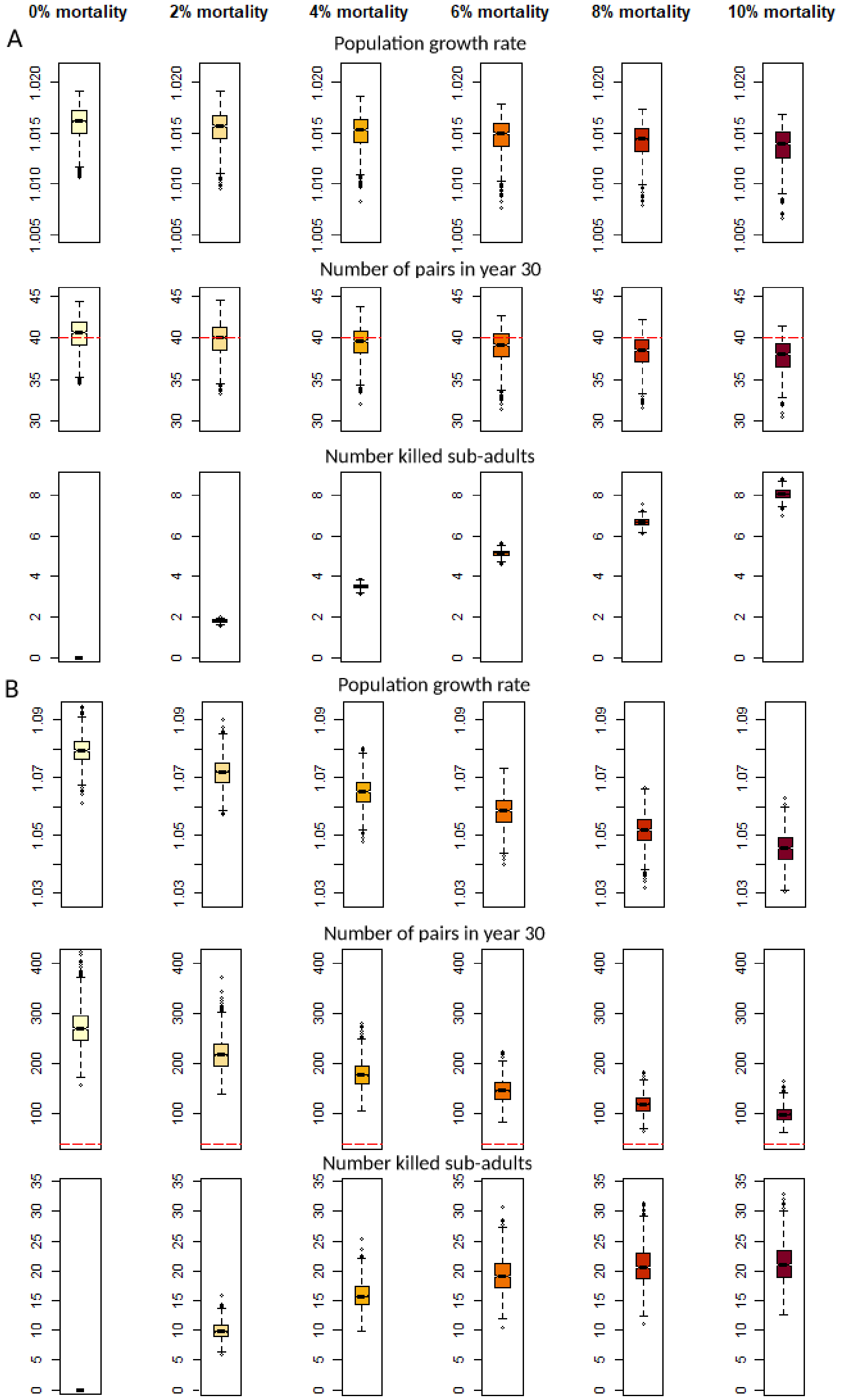
NHZ 6: collision mortality shared 50:50 between adults and sub-adult boxplots, with NO density dependence operating. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line); row 3 the numbers of sub-adults killed in year 30 and row 4 is the numbers of adults killed in year 30.



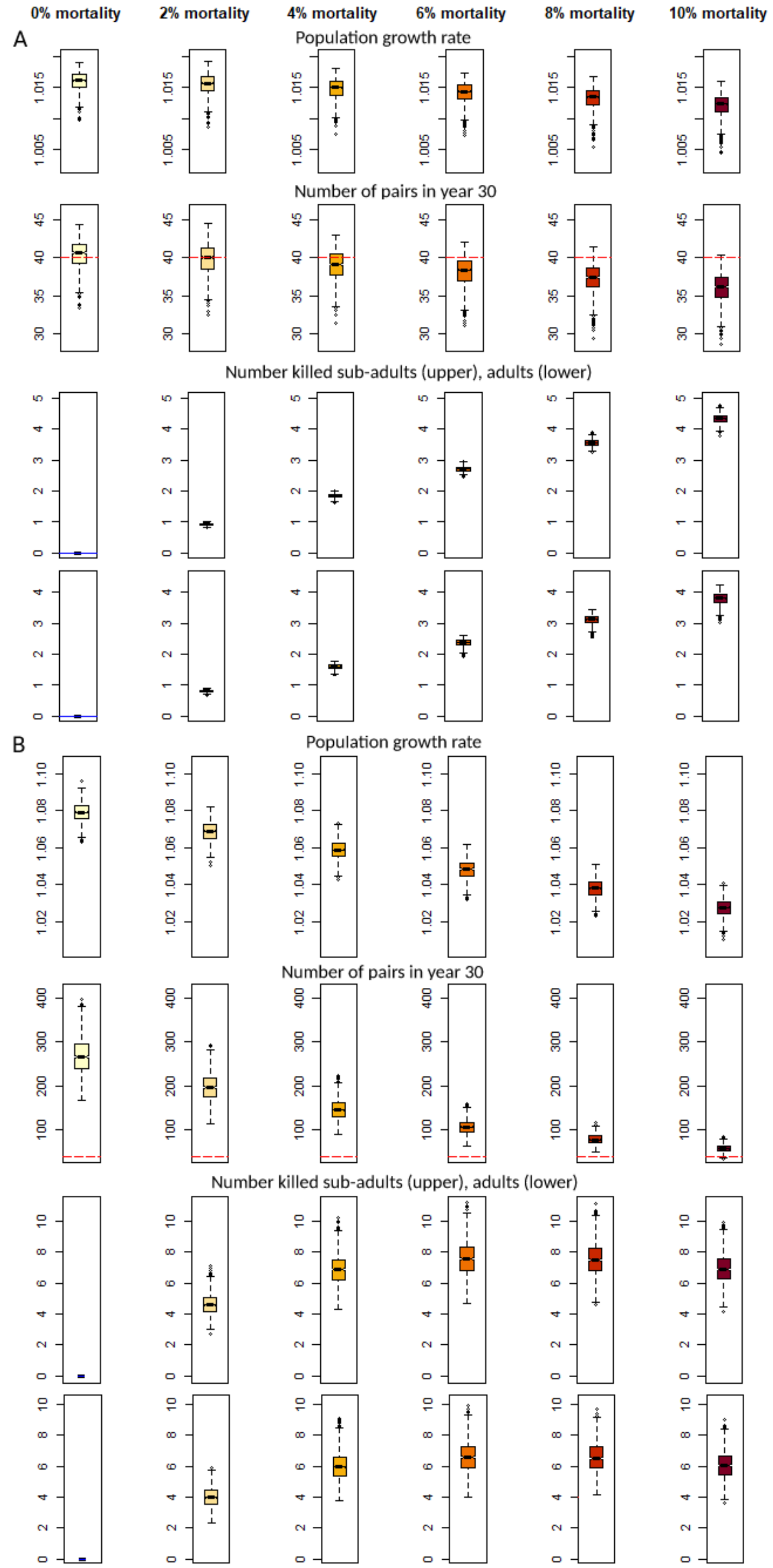
NHZ 6: adult only collision mortality boxplots. A with density dependence, B without. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line) and row 3 the numbers killed in year 30.



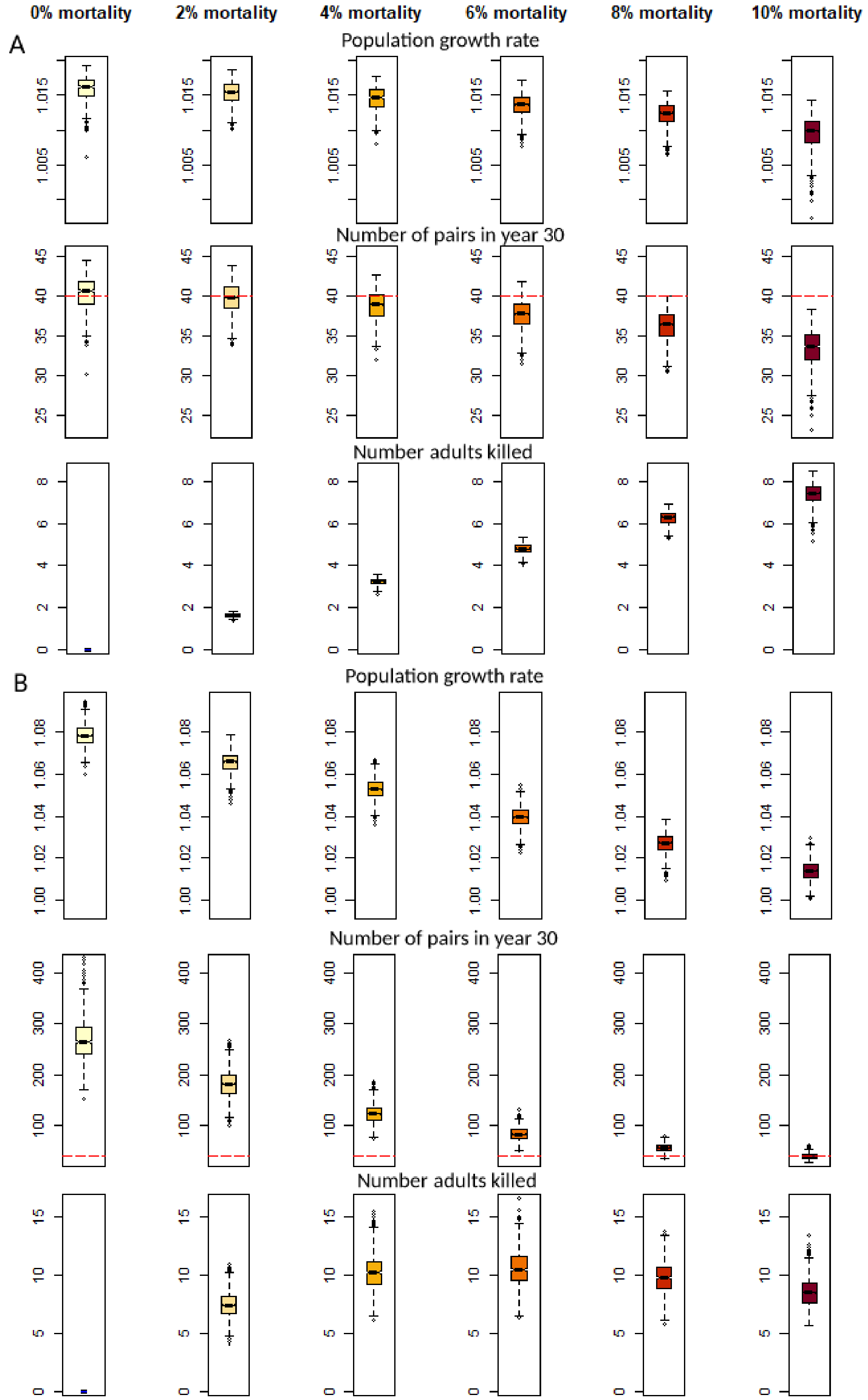
Skye: sub-adult only collision mortality boxplots. A with density dependence, B without. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line) and row 3 the numbers killed in year 30.



Skye: collision mortality shared 50:50 between adults and sub-adult boxplots. A with density dependence operating, B without density dependence. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line); row 3 the numbers of sub-adults killed in year 30 and row 4 is the numbers of adults killed in year 30.



Skye: adult only collision mortality boxplots. A with density dependence, B without density dependence. Row 1 is the population growth rate; row 2 the population sizes in year 30 (with carrying capacity – dashed red line) and row 3 the numbers killed in year 30.



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