Supplemental Information:

Contrasting phenological and demographic responses of Atlantic Puffin (*Fratercula arctica*) and Razorbill (*Alca torda*) to climate change in the Gulf of Maine

Heather L Major\*1, Sarah E Durham1, Natalia Fana1, Joy E Rivers1, and Antony W Diamond2

1 Department of Biological Sciences, University of New Brunswick, Saint John, New Brunswick E2L 4L5, Canada

2 Department of Biology, University of New Brunswick, Fredericton, New Brunswick, E3B 5A3, Canada

\*hmajor@unb.ca

Table S1. Candidate models assessing change in Atlantic Puffin hatch date, reproductive success, and hatch success at Machias Seal Island, New Brunswick between 1995 – 2020 (1995 – 2019 for reproductive success and hatch success).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Model Predictors** | **k** | **AICc** | **ΛAICc** | **ω*i*** |
| **Hatch Date** *ARMA correlation structure: ~1|Year, p=1,q=1* | Year | 5 | 10614.95 | 0.00 | 0.61 |
| Null | 4 | 10615.80 | 0.86 | 0.39 |
| **Reproductive Success** *Models weighted by # active nests* | Year | 2 | 281.96 | 0.00 | 0.75 |
| Null | 1 | 284.19 | 2.23 | 0.25 |
| **Hatch Success** *Models weighted by # of nests with eggs* | Null | 2 | 171.12 | 0.00 | 0.61 |
| Year | 1 | 171.99 | 0.87 | 0.39 |

Table S2. Summary results of model-averaged Atlantic Puffin hatch date, reproductive success, hatch success, and year at Machias Seal Island, New Brunswick between 1995 – 2020 (1995 – 2019 for reproductive success and hatch success). Important parameters are in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Parameter** | **Estimate** | **Unconditional SE** | **Relative Importance** |
| **Hatch Date** | (Intercept) | -121.714 | 323.69 |  |
| **Year** | **0.243** | **0.140** | **0.61** |
| **Reproductive Success** | (Intercept) | 23.545 | 18.351 |  |
| **Year** | **-0.015** | **0.007** | **0.75** |
| **Hatch Success** | (Intercept) | 18.531 | 18.749 |  |
| **Year** | **-0.014** | **0.008** | **0.61** |

Table S3. Candidate models assessing change in Razorbill hatch date, reproductive success, and hatch success at Machias Seal Island, New Brunswick between 1995 – 2020 (1995 – 2019 for reproductive success and hatch success).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Model Predictors** | **k** | **AICc** | **ΛAICc** | **ω*i*** |
| **Hatch Date** *ARMA correlation structure: ~1|Year, p=5,q=1* | Year | 9 | 6815.99 | 0.00 | 0.59 |
| Null | 8 | 6816.68 | 0.69 | 0.41 |
| **Reproductive Success** *Models weighted by # active nests* | Year | 2 | 153.22 | 0.00 | 1.00 |
| Null | 1 | 167.00 | 13.78 | 0.00 |
| **Hatch Success** *Models weighted by # of nests with eggs* | Year | 2 | 146.08 | 0.00 | 1.00 |
| Null | 1 | 159.32 | 13.24 | 0.00 |

Table S4. Summary results of model-averaged Razorbill hatch date, reproductive success, hatch success, and year at Machias Seal Island, New Brunswick between 1995 – 2020 (1995 – 2019 for reproductive success and hatch success). Important parameters are in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Parameter** | **Estimate** | **Unconditional SE** | **Relative Importance** |
| **Hatch Date** | (Intercept) | 378.919 | 229.701 |  |
| **Year** | **-0.172** | **0.100** | **0.59** |
| **Reproductive Success** | (Intercept) | 61.573 | 15.504 |  |
| **Year** | **-0.031** | **0.008** | **1.00** |
| **Hatch Success** | (Intercept) | 65.108 | 16.547 |  |
| **Year** | **-0.032** | **0.008** | **1.00** |

Table S5. Spearman rank correlation coefficients for all environmental variables included in our candidate models evaluating the relationships between Atlantic Puffin phenology, productivity, and fledgling body condition (puffins only) between 1996 – 2020. Correlation coefficients >0.70 are highlighted in grey, these were considered important and not included in any candidate models together.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Prey Quality | NAO | Winter SST | Spring SST | Summer SST | Spring Air Temperature | Spring Precipitation | Summer Air Temperature | Summer Precipitation |
| Prey Quality |  |  |  |  |  |  |  |  |  |
| NAO | 0.22 |  |  |  |  |  |  |  |  |
| Winter SST | 0.13 | 0.36 |  |  |  |  |  |  |  |
| Spring SST | 0.19 | 0.09 | 0.75 |  |  |  |  |  |  |
| Summer SST | -0.13 | -0.21 | 0.73 | 0.77 |  |  |  |  |  |
| Spring Air Temperature | 0.02 | -0.33 | 0.67 | 0.83 | 0.95 |  |  |  |  |
| Spring Precipitation | 0.37 | -0.56 | 0.13 | 0.21 | 0.42 | 0.52 |  |  |  |
| Summer Air Temperature | 0.01 | -0.32 | 0.68 | 0.84 | 0.94 | 0.99 | 0.53 |  |  |
| Summer Precipitation | 0.54 | -0.54 | -0.12 | 0.14 | 0.20 | 0.36 | 0.92 | 0.37 |  |

Table S6. Spearman rank correlation coefficients for all environmental variables included in our candidate models evaluating the relationships between Razorbill phenology, productivity, and fledgling body condition (puffins only) between 1996 – 2020. Correlation coefficients >0.70 are highlighted in grey, these were considered important and not included in any candidate models together.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Prey Quality | NAO | Winter SST | Spring SST | Summer SST | Spring Air Temperature | Spring Precipitation | Summer Air Temperature | Summer Precipitation |
| Prey Quality |  |  |  |  |  |  |  |  |  |
| NAO | -0.41 |  |  |  |  |  |  |  |  |
| Winter SST | 0.82 | -0.37 |  |  |  |  |  |  |  |
| Spring SST | 0.58 | -0.16 | 0.59 |  |  |  |  |  |  |
| Summer SST | 0.31 | -0.33 | 0.53 | 0.79 |  |  |  |  |  |
| Spring Air Temperature | 0.38 | -0.43 | 0.47 | 0.83 | 0.81 |  |  |  |  |
| Spring Precipitation | 0.24 | -0.54 | 0.13 | 0.15 | 0.01 | 0.52 |  |  |  |
| Summer Air Temperature | 0.35 | -0.41 | 0.50 | 0.81 | 0.79 | 0.99 | 0.50 |  |  |
| Summer Precipitation | 0.43 | -0.43 | 0.21 | -0.01 | -0.28 | 0.25 | 0.87 | 0.24 |  |

Table S7. List of *a priori* candidate model sets evaluating the relationships between puffin and Razorbill phenology, productivity, and fledgling body condition (puffins only) 1) between 1995 – 2020 (hatch success to 2019) and at Machias Seal Island, New Brunswick, Canada and 2) with environmental conditions. Models with a “1” were run for puffins only, those with a “2” were run for Razorbills only.

1) 1995 – 2020 (Hatch success 1995-2019)

|  |
| --- |
| Phenology – Hatch Date |
| NULLYearSpeciesYear + Species + Year × Species |
| Phenology – Fledge Date (puffins only) |
| NULLYear |
| Productivity |
| NULLYearSpeciesYear + Species + Year × Species |
| Productivity – Hatch Success |
| NULLYearSpeciesYear + Species + Year × Species |
| Productivity – Fledge Success |
| NULLYearSpeciesYear + Species + Year × Species |
| Fledgling Body Condition Index (puffins only) |
| NULLYear |

2) Environmental Conditions:

|  |
| --- |
| Phenology – Hatch Date |
| NULLOccupancyWinter SSTSpring SSTOccupancy + Winter SSTOccupancy + Spring SST2Occupancy + Winter SST + Spring SST2Winter SST + Spring SSTNAONAO + OccupancyNAO + Winter SSTNAO + Spring SST2NAO + Winter SST + Spring SSTNAO + Occupancy + Winter SSTNAO + Occupancy + Spring SST2NAO + Occupancy + Winter SST + Spring SST |
| Productivity – Hatch Success |
| NULLSpring SSTWinter SSTSpring Air TemperatureSpring Precipitation2Spring SST + Winter SSTWinter SST + Spring Air Temperature + Spring PrecipitationSpring Air Temperature + Spring PrecipitationSpring SST + Spring PrecipitationWinter SST + Spring Precipitation2Spring SST + Winter SST + Spring PrecipitationWinter SST + Spring Air TemperatureNAONAO + Spring Air Temperature + Spring PrecipitationNAO + Spring Air TemperatureNAO + Spring PrecipitationNAO + Spring SSTNAO + Spring Precipitation + Spring SST |
| Productivity – Fledge Success |
| NULLHatch DateSummer Air TemperatureSummer PrecipitationPrey QualityHatch Date + Summer Air TemperatureHatch Date + Summer PrecipitationHatch Date + Prey QualityHatch Date + Summer Air Temperature + Summer PrecipitationHatch Date + Summer Air Temperature + Prey QualitySummer Air Temperature + Summer PrecipitationSummer Air Temperature + Prey QualitySummer Air Temperature + Summer Precipitation + Prey QualitySummer Precipitation + Prey Quality |
| Fledgling Body Condition Index (puffins only) |
| NULLSummer SSTSummer Air TemperatureSummer PrecipitationPrey QualityFledge DateSummer SST + Summer PrecipitationSummer Air Temperature + Summer PrecipitationSummer SST + Prey QualitySummer SST + Fledge DateSummer SST + Fledge Date + Prey QualitySummer SST + Summer Precipitation + Prey QualitySummer SST + Summer Precipitation + Fledge DateSummer SST + Summer Precipitation + Prey Quality + Fledge DateSummer Air Temperature + Prey QualitySummer Air Temperature + Fledge DateSummer Air Temperature + Prey Quality + Fledge DateSummer Air Temperature + Summer Precipitation + Prey QualitySummer Air Temperature + Summer Precipitation + Fledge DateSummer Air Temperature + Summer Precipitation + Prey Quality + Fledge DateSummer Precipitation + Prey QualitySummer Precipitation + Fledge DateSummer Precipitation + Prey Quality + Fledge DatePrey Quality + Fledge Date |