**Supplementary File 1**

**Windborne migration amplifies insect-mediated pollination services**

**Supplementary file 1a.** Mass migration events of *E. balteatus* across the Bohai Strait observed by the searchlight trapping on BH Island during 2003–2018.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **Dates** | **Captured no.** | **Year** | **Dates** | **Captured no.** |
| 2003 | 3-Jun | 40  | 2010 | 30-May | 48  |
| 4-Jun | 50  | 1-Jun | 220  |
| 5-Jun | 45  | 6-Jun | 72  |
| 7-Jun | 136  | 14-Jun | 96  |
| 2004 | 15-May | 350  | 15-Jun | 66  |
| 29-May | 56  | 2-Sep | 1431  |
| 7-Jun | 51  | 5-Sep | 129  |
| 8-Oct | 60  | 11-Sep | 89  |
| 2005 | 26-May | 84  | 2011 | 18-May | 357  |
| 6-Jun | 49  | 6-Jun | 112  |
| 7-Sep | 270  | 22-Aug | 81  |
| 8-Sep | 96  | 23-Aug | 389  |
| 2006 | 19-May | 172  | 2012 | 23-May | 185  |
| 3-Jun | 265  | 27-May | 50  |
| 22-Aug | 183  | 5-Jun | 330  |
| 16-Sep | 120  | 20-Aug | 104  |
| 17-Sep | 68  | 9-Sep | 86  |
| 22-Sep | 128  | 2013 | 3-Jun | 129  |
| 30-Sep | 54  | 25-Aug | 61  |
| 3-Oct | 49  | 2014 | 21-May | 1018  |
| 2007 | 20-May | 79  | 29-May | 426  |
| 1-Sep | 185  | 29-Jun | 84  |
| 2-Sep | 86  | 2015 | 27-May | 59  |
| 6-Sep | 73  | 7-Jun | 67  |
| 10-Sep | 77  | 15-Jul | 184  |
| 2008 | 22-May | 105  | 24-Aug | 304  |
| 24-May | 248  | 27-Aug | 80  |
| 7-Jun | 134  | 4-Sep | 85  |
| 10-Jun | 116  | 2016 | 27-May | 65  |
| 1-Sep | 132  | 30-May | 49  |
| 2-Sep | 111  | 7-Jun | 548  |
| 8-Sep | 48  | 6-Oct | 120  |
| 2009 | 25-May | 204  | 23-Oct | 147  |
| 26-May | 3536  | 2017 | 26-May | 386  |
| 28-May | 688  | 27-May | 114  |
| 2-Jun | 70  | 2-Sep | 46  |
| 18-Sep | 112  | 2018 | 4-Sep | 52  |
| 21-Sep | 185  | 25-Sep | 60  |

**Supplementary file 1b.** Collection information for sample in the study.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Code | Collection location |  | Longitude(E) | Latitude(N) | Host plants | Collection date | Specimens |
| Isotope analysis | Population genetics | Feeding trails  |
| 1 | PE | Yunnan Province, Puer | SW | 100.972343 | 22.777323 | watermelon | 2018.04 | 36 | 30 | 30 |
| 2 | NC | Jiangxi Province, Nanchang | YzP | 115.95046 | 28.551604 | cotton | 2017.09 | 36 | 30 | 30 |
| 3 | WH | Hubei Province, Wuhan | 114.02919 | 30.58203 | cotton | 2017.09 | 36 | 40 | 30 |
| 4 | TZ | Jiangsu Province, Taizhou | 119.88116 | 32.31841 | wheat | 2018.04 | 36 | 35 | 30 |
| 5 | YZ | Jiangsu Province, Yangzhou | 119.43157 | 32.39463 | wheat | 2018.04 | 36 | 35 | 30 |
| 6 | YL | Shannxi Province, Yangling | NP | 108.08455 | 34.27221 | orchard | 2018.07 | 36 | 35 | 30 |
| 7 | XX | Henan Province, Xinxiang | 113.90598 | 35.3718 | wheat | 2017.05 | 36 | - | 30 |
| 8 | cotton | 2017.09 | 36 | 50 | 30 |
| 9 | XJ | Shangdong Province, Xiajin | 116.00175 | 36.94856 | cotton | 2017.09 | 36 | 30 | 30 |
| 10 | DY | Shangdong Province, Dongying | 118.63019 | 37.30696 | cotton | 2017.09 | - | - | 30 |
| 11 | YT | Shangdong Province, Yantai | 121.112409 | 35.3522 | cotton | 2017.09 | 36 | 30 | 30 |
| 12 | CZ | Hebei Province, Cangzhou | 116.67828 | 38.23891 | wheat | 2018.04 | 36 | - | 30 |
| 13 | YP | Shanxi Province, Yuanping | 112.711104 | 38.730472 | wheat | 2018.05 | - | 20 | 30 |
| 14 | LF | Hebei Province, Langfang | 116.68572 | 39.50311 | wheat | 2017.05 | - | - | 15 |
| 15 | cotton | 2017.09 | 18 | 30 | 15 |
| 16 | CF | Neimenggu Province, Chifeng | NE | 118.95927 | 42.26581 | cotton | 2017.09 | - | 30 | 30 |
| 17 | SY | Liaoning Province, Shenyang | 123.589285 | 41.846472 | cotton | 2017.09 | 32 | 50 | 30 |
| 18 | CC | Jilin Province, Changchun | 125.332429 | 43.829776 | cotton | 2017.09 | 41 | 30 | 30 |
| 19 | HB | Heilongjiang Province, Harbin | 126.542051 | 45.816446 | cotton | 2017.09 | 36 | 30 | 30 |
| 20 | SH | Xinjiang Province, Shihezi | NW | 86.07893 | 44.30653 | alfalfa | 2017.07 | - | 24 | 20 |
| 21 | CDI | Changdao, Shandong | CD | 125.717623 | 39.059202 | - | (2014-2018)spring  | 149 | 55 | 85 |
| 22 | CDII | Changdao, Shandong | CD | 125.717623 | 39.059202 | - | (2014-2018)Autumn | 149 | 55 | 85 |

**Supplementary file 1c.** Pollen carrying rate of the migratory *E. balteatus* hoverflies across Bohai Sea during 2014-2018.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sampling time | No. with pollen | No. adults examined | % with pollen  | No. taxa |
| Spring-summer migration stage | April | 7 | 42 | 17% | 28 |
| May | 101 | 367 | 28% |
| June | 59 | 174 | 34% |
| 　 | July | 1 | 29 | 3% | 1 |
| Autumn migration stage　 | August | 40 | 138 | 24% | 17 |
| September | 82 | 205 | 27% |
| October | 30 | 59 | 50% |
| 　 | Total | 320 | 1014 | 27% | 46 |

**Supplementary file 1d.** Quantitative PCR (qPCR) primers and conditions used in this study.

|  |  |  |
| --- | --- | --- |
|  | Primer | Primer sequence (5'to3') |
| *Cannabis sativa* | ITS2-F | TAGGCCAACCACAAGGCAAT |
| ITS2-R | CACTGCCAAAAGCGTGTTCA |
| ITS2-probe FAM | ATGGGAAGCCAGTCTCCGCC |
| *Humulus scandens* | ITS2-F  | GCACCGATACAATCGAAAAC |
| ITS2-R | TGGCCTAAATTCGAGTCATC |
| ITS2-probe FAM  | ACCGAATGTCGCGGCGATCG |
| *Helianthus annuus* | ITS2-F | GAGCATCTACTCTCAAGAAA |
| ITS2-R | CTAGTGGTGGTTGATAAGAC |
| ITS2-probe FAM  | TAAACGCACGACACGAGACG |

**Supplementary file 1e.** Key parameters within *E. balteatus* searchlight trapping on BH Island during 2003–2018.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **First capture dd/mm (no.)** | **Final capture dd/mm (no.)** | **Duration of capture (d)** | **Peak capture dd/mm (no.)** |
|
| 2003 | 01 Jun. (10) | 21 Sep. (4) | 113 | 07 Jun. (136) |
| 2004 | 14 May (10) | 18 Oct. (8) | 158 | 15 May (350) |
| 2005 | 13 May (3) | 04 Oct. (2) | 145 | 07 Sep. (270) |
| 2006 | 17 May (16) | 20 Oct. (14) | 157 | 03 Jun. (265) |
| 2007 | 02 May (2) | 11 Oct. (1) | 163 | 01 Sep. (185) |
| 2008 | 17 May (2) | 29 Sep. (3) | 136 | 24 May (248) |
| 2009 | 05 May (2) | 29 Sep. (37) | 148 | 26 May (3536) |
| 2010 | 21 May (1) | 13 Oct. (2) | 146 | 02 Sep. (1431) |
| 2011 | 03 May (1) | 21 Sep. (11) | 142 | 23 Aug. (389) |
| 2012 | 02 May (1) | 20 Oct. (1) | 172 | 05 Jun. (330) |
| 2013 | 02 May (7) | 10 Oct. (5) | 162 | 03 Jun. (129) |
| 2014 | 01 May (13) | 28 Sep. (1) | 151 | 21 May (1018) |
| 2015 | 28 Apr.(2) | 17 Oct. (1) | 173 | 24 Aug. (304) |
| 2016 | 30 Apr.(2) | 28 Oct. (1) | 182 | 07 Jun. (548) |
| 2017 | 23 May (1) | 22 Sep. (7) | 123 | 26 May (386) |
| 2018 | 04 May (1) | 28 Sep. (10) | 148 | 25 Sep. (60) |

**Supplementary file 1f.** The percentage of the total trajectories that ended in each region.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Region | Valid endpoints | Total valid endpoints |  Percentage |
| Apr.-Jul. | Shandong | 7546 | 9069 | 83.20652773 |
| Liaoning | 966 | 9069 | 10.65167053 |
| Jiangsu | 74 | 9069 | 0.815966479 |
| Hebei | 68 | 9069 | 0.749807035 |
| Aug.-Oct. | Liaoning | 3945 | 4945 | 79.77755308 |
| Hebei | 461 | 4945 | 9.322548028 |
| Shandong | 204 | 4945 | 4.125379171 |
| Tianjin | 62 | 4945 | 1.253791709 |

**Supplementary file 1g.** Results of analysis of molecular variance (AMOVA) test in different populations and regions of *E.balteatus* based on Cytb and18S-28S rRNA gene.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Source of variation | d.f. | Sum of squares | Variance components | Percentage of variation | Fixation Indices |
| Cytb | Among populations  | 17 | 16.8 | 0.012 Va | 1.84 | FST : 0.01844 P-value<0.02 |
| Within population | 512 | 327.117 | 0.6389 Vb | 98.16 |  |
| Total | 529 | 343.917 | 0.6509 |  |  |
| 18S-28S | Among populations  | 15 | 217.7 | 0.60342 Va | 11.12 | FST : 0.11121 P-value<0.01 |
| Within population | 244 | 1176.661 | 4.82238 Vb | 88.88 |  |
| Total | 259 | 1394.362 | 5.42581 |  |  |

**Supplementary file 1h.** Comparative assessment of the degree of taxonomic identification obtained through either molecular or morphology-based approaches, for 46 different types of pollen grains dislocated from *E. balteatus* long-distance migrants collected on Beihuang Island (Bohai Sea, northeastern China). For each type of pollen grain, the highest level of taxonomic identification is indicated and contrasted between molecular and morphology-based approaches.

|  |  |  |
| --- | --- | --- |
|  **Pollen Grain Type** | **Identified Plants** | **Molecular Identification** |
| 1 | *Ailanthus altissima* | *Ailanthus altissima* |
| 2 | *Cotinus coggygria* | *Cotinus coggygria* |
| 3 | *Forsythia suspensa*  | *Forsythia suspensa*  |
| 4 | *Prunus avium* | *Prunus avium* |
| 5 | Brassica L. | Sister to Brassica carinata/Brassica juncea/Brassica nigra |
| 6 | *Morus alba* | *Morus alba* |
| 7 | *Citrus sinensis* | *Citrus sinensis/Citrus maxima* |
| 8 | *Descurainia sophia* | *Descurainia sophia* |
| 9 | Euonymus L. | Sister to Euonymus alatus |
| 10 | Taraxacum L. | Sister to Taraxacum mongolicum |
| 11 | *Sedum japonicum* | *Sedum japonicum* |
| 12 | *Populus cathayana* | *Populus cathayana* |
| 13 | *Celastrus orbiculatus* | *Celastrus orbiculatus* |
| 14 | *Daucus carota* | *Daucus carota* |
| 15 | *Chenopodium album* | *Chenopodium giganteum/Chenopodium album* |
| 16 | *Castanea mollissima* | *Castanea mollissima* |
| 17 | *Amorpha fruticosa* | *Amorpha nana* |
| 18 | *Diospyros lotus* | *Diospyros lotus* |
| 19 | *Ziziphus jujuba* | *Ziziphus jujuba* |
| 20 | *Cirsium setosum* | *Cirsium setosum* |
| 21 | *Neoshirakia japonica* | *Neoshirakia japonica* |
| 22 | Flueggea L. | *Flueggea virosa* |
| 23 | *Maclura pomifera* | *Maclura pomifera* |
| 24 | Rumex L. | Sister to Rumex nepalensis/Rumex kandavanicus/Rumex ponticus |
| 25 | Euonymus L. | Sister to Euonymus myrianthus |
| 26 | *Schisandra chinensis* | *Schisandra chinensis* |
| 27 | *Eleusine indica* | *Eleusine indica* |
| 28 | *Actinidia kolomikta* | *Actinidia kolomikta* |
| 29 | *Cannabis sativa* | *Cannabis sativa* |
| 30 | *Humulus scandens* | *Humulus scandens* |
| 31 | *Helianthus annuus* | *Helianthus annuus* |
| 32 | *Persicaria orientalis* | *Persicaria orientalis* |
| 33 | *Adenophora trachelioides* | *Adenophora trachelioides* |
| 34 | *Gypsophila paniculata* | *Gypsophila paniculata* |
| 35 | Artemisia L. | *Artemisia sp. AD-H* |
| 36 | *Rubia cordifolia* | *Rubia cordifolia* |
| 37 | *Suaeda glauca* | *Suaeda glauca* |
| 38 | Artemisia L. | Sister to Artemisia japonica |
| 39 | Artemisia L. | Sister to Artemisia sieversiana |
| 40 | Artemisia L. | Sister to Artemisia annua |
| 41 | *Allium tuberosum* | *Allium tuberosum* |
| 42 | *Tripolium vulgare* | *Tripolium vulgare* |
| 43 | *Ambrosia trifida* | *Ambrosia trifida* |
| 44 | *Sorghum bicolor* | *Sorghum bicolor* |
| 45 | *Aster tataricus* | *Aster tataricus* |
| 46 | *Chrysanthemum zawadskii* | *Chrysanthemum zawadskii* |