Supplementary Tables:

Table S1: Pantala taxon sample, voucher and accession data. Additionally, we used the following COI NCBI samples: AB709105, EU332412, HM413487, HM413599, JN817426, KF57083, KR011198, KR080063-KR080133, KU641567-KU641599, KX054305-KX054315, KY947425, KY949462, KY947463, KY947481, MF358754-MF358756, MG885265, MH816998, MH816999, MK038726, and the 446 Pantala sequences ranging from LC326557-LC366762. We additionally used the following CytB NCBI samples: MK076418-MK076342. We additionally used the following 16S NCBI samples: LC194792, KF256865, AB127059, LC366373, LC366465, KJ730183, KJ730182, GU323081, EF631537, KC306714, AB708161, AB708160,, EF640450, GU323129, EF032732, MW256717. We additionally used the following H3 NCBI samples: AY870292, MT086571, MT086570, MT086561.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Voucher Name | Year collected | Country | Accession numbers | Country |
| 372Senegal\_Mbaye\_Mbaye | 2005 | Senegal: Mbaye Mbaye | 123456 | Senegal |
| 371Guinea\_Bissau\_Bambadinca | 2005 | Guinea Bissau: Bambadinca | 123456 | Guinea Bissau |
| 370Senegal\_Kidira | 2005 | Senegal: Kidira | 123456 | Senegal |
| JW\_MAL\_147 | 2017-2018 | Maldives | 123456 | Maldives |
| Pantala\_14\_Indian\_Ocean\_Hot\_tub | 2008 | Indian Ocean, on hot tub | 123456 | India |
| Pantala\_13\_Leonardville\_Maldives | 2017-2018 | Maldives: Leonardville | 123456 | Maldives |
| Pantala\_12\_Leonardville\_Maldives | 2017-2018 | Maldives: Leonardville | 123456 | Maldives |
| JW\_MAL\_149\_maldives | 2017-2018 | Maldives | 123456 | Maldives |
| JW\_MAL\_148\_maldives | 2017-2018 | Maldives | 123456 | Maldives |
| JW\_MAL\_146\_maldives | 2017-2018 | Maldives | 123456 | Maldives |
| JW\_MAL\_145\_maldives\_coi | 2017-2018 | Maldives | 123456 | Maldives |
| JW\_APAN\_119\_auspantala | 2016 | Australia: Queensland | 123456 | Australia |
| JW\_APAN\_116\_auspantala | 2016 | Australia: Queensland | 123456 | Australia |
| JW\_PAN\_139b | 2005 | USA: Hawaii | 123456 | USA |
| JW\_PAN\_143 | 2017 | USA: Tennessee | 123456 | USA |
| JW\_PAN\_144\_pantala | 2017 | USA: Tennessee | 123456 | USA |
| JW\_PAN\_142\_pantala | 2017 | USA: Tennessee | 123456 | USA |
| JW\_PAN\_141\_pantala | 2017 | USA: Tennessee | 123456 | USA |
| JW\_PAN\_140\_pantala | 2017 | USA: Tennessee | 123456 | USA |
| JW\_PAN\_139a\_pantala | 2005 | USA: Hawaii | 123456 | USA |
| JW\_PAN\_138\_pantala | 2005 | USA: Hawaii | 123456 | USA |
| JW\_PAN\_137\_pantala | 2005 | USA: Hawaii | 123456 | USA |
| JW\_PAN\_136\_pantala | 2004 | USA: Texas | 123456 | USA |

Table S2: Locality of samples used for isotope analysis.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ID | region | location | latitude | longitude | elevation | date | collector |
| 1 | India | Madana Palle, Chittoor, Andhra Pradesh | 13.5662 | 78.4990 | 0 | 2013 | M.K. Kohli |
| 2 | China | Tian Mu Mountain, Zhe Jiang Province | 30.4919 | 119.6150 | 1506 | 2008 | A.R. Rowat |
| 3 | China | Tian Mu Mountain, Zhe Jiang Province | 30.4919 | 119.6150 | 1506 | 2008 | A.R. Rowat |
| 4 | Japan | Saitama pref. | 35.8896 | 139.6520 | 12 | 2013 | H. Jinguji |
| 5 | Japan | Myagi pref. | 38.5587 | 140.8500 | 208 | 2013 | H. Jinguji |
| 6 | Australia | Queensland | -18.9000 | 145.7700 | 0 | 2017 | J.L. Ware |
| 7 | Australia | Queensland | -18.9000 | 145.7700 | 0 | 2017 | J.L. Ware |
| 8 | Australia | Queensland | -18.9000 | 145.7700 | 0 | 2017 | J.L. Ware |
| 9 | Australia | Queensland | -18.9000 | 145.7010 | 0 | 2017 | J.L. Ware |
| 10 | Senegal | 24 km North of Kidira | 14.6433 | -12.3363 | 23 | 2005 | J.C. Huff |
| 11 | Senegal | 24 km North of Kidira | 14.6433 | -12.3363 | 23 | 2005 | J.C. Huff |
| 12 | Senegal | 20 km west of Koungheul, near Mbaye Mbaye | 13.9726 | -15.0079 | 55 | 2005 | J.C. Huff |
| 13 | Guinea-Bissau | 40 km south Bambadinca along Rio Corubal | 11.6830 | -14.7977 | 14 | 2005 | J.C. Huff |
| 14 | Indian Ocean | hot tub on cruise ship | 18.0294 | 64.1041 | 0 | 2008 | Christine Johnson |
| 18 | Guyana | CEIBA biological station | 6.4833 | -58.2167 | 0 | 2012 | I. Biazzo |
| 19 | Guyana | CEIBA biological station | 6.4833 | -58.2167 | 0 | 2012 | I. Biazzo |
| 20 | USA | Hawaii, Oahu, Waimea Bay Beach Park | 21.6403 | -158.0630 | 5 | 2005 | W.R. Kuhn |
| 21 | USA | Hawaii, Oahu, Waimea Bay Beach Park | 21.6403 | -158.0630 | 5 | 2005 | W.R. Kuhn |
| 22 | USA | Hawaii, Oahu, Waimea Bay Beach Park | 21.6403 | -158.0630 | 5 | 2005 | W.R. Kuhn |
| 23 | USA | Hawaii, Oahu, Waimea Bay Beach Park | 21.6403 | -158.0630 | 5 | 2005 | W.R. Kuhn |
| 24 | Peru | Rio Tapiche | -7.4490 | -73.9403 | 295 | 1923 | H. Bassler |
| 25 | Peru | Dept Huanuco | -9.8933 | -76.3200 | ? | 1981 | J.C. Pallister |
| 26 | Peru | Dept Huanuco | -9.8933 | -76.3200 | ? | 1981 | J.C. Pallister |
| 27 | Brazil | Prov. Bahía, Feira de Santana | -12.1960 | -38.9414 | 250 | 1981 | R.B. Roberts |
| 28 | Costa Rica | Prov. Puntarenas, Penn. de Osa | 8.6143 | -83.5411 | 304 | 1970 | M.L. May |
| 29 | USA | Tennessee, Knoxville, World’s Fair Park | 35.9600 | -83.9240 | 260 | 2017 | W.R. Kuhn |
| 30 | USA | Florida, Gadsden County, pond at Hwy 269 | 30.4642 | -84.5953 | 43 | 1969 | M.L. May |
| 31 | USA | Texas, Travis County, Brackenridge Field Lab | 30.3356 | -97.9112 | 175 | 2004 | W.R. Kuhn |
| 32 | USA | Deptford, NJ | 39.8683 | -75.1877 | 4 | 2016 | C. P Hulick |

Table S3: A compilation of observations about migration and dispersal events in *Pantala flavescens*. We distinguish three types: TOM = transoceanic migration, TM = terrestrial migrations (including those along coasts), LDD = long distance dispersal events to formerly uninhabited area (in case of European LDD observations we list only the most recent and northern ones, which recapitulate the European records).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Type** | **Location & Coordinates** | **Distance mainland(s)** | **Month** | **Observation** | **Author** |
| TOM | Indian Ocean: Maldives  3.1764°N, 73.5096°E | ≥ 600 km S India | October | seasonal appearance on Maldives; reconstruction of migration routes from India to Africa via Indian Ocean islands and back | [1] |
| TOM (?) | Indian Ocean: Diego Garcia Is.  7.2722 S, 72.3703°E | 1800 km to India | February, March | occurrence on remote islands | [29] |
| TOM | Indian Ocean: ship off the coast of Australia, no exact coordinates | 466 km to Keeling Is,  1448 km to Australia | April | arrival of large numbers at a ship at night coinciding with onset of heavy rainfall | [46] |
| TOM | Indian Ocean: on ship near Sumatra, no coordinates | no information |  | before ship was hit by a typhoon | [47] |
| TOM | Indian Ocean: Cocos-Keeling Is.  12.1784°S, 96.8207°E | 1100 km to Java | not stated | appeared often after N winds | Wood-Jones (1910) in [47] |
| TOM | Indian Ocean: ship routes Singapore–Thursday Is & Java–Keeling Is. | no information | not stated | several observations on Indian Ocean during ship passages often without associated winds | Wood-Jones (1910) in [47] |
| TOM | Pacific Ocean: weather ship  29°N, 135°E | 450 km SE Japan  1800 km to Marianas | June - October | usual swarms (20-30 individuals) occurred continuously after W,NW or SW winds | [4] |
| TOM | Pacific Ocean: weather ship  29°N, 135°E | 450 km SE Japan  1800 km to Marianas | June - August | several observations; usually 1-5 individuals occurred after SE,SW or NW winds in June, W, WSW, E winds in July and ESE, SW winds in August; large swarm blackened the sky in early July in the eye of a typhoon | [5] |
| TOM | Pacific Ocean: weather ship  29°N, 135°E | 450 km to Japan  1800 km to Marianas | September - October | usually small groups (1-5 individuals) occurred after N, NNW or WNW winds such as autumn rain front | [6] |
| TOM | Pacific Ocean: weather ship  29°N, 135°E | 450 km SE Japan  1800 km to Marianas | July - October | swarms occurred from middle July to late August. 215 individuals captured night time on September 17. | [7] |
| TOM | Pacific Ocean: weather ship  29°N, 135°E | 450 km to Japan  1800 km to Marianas | June - July | continuous arrival of ca 20 individuals after S or SW winds; there were so many mature individuals that reproduction occurred on the sea | [48] |
| TOM | Pacific Ocean, East China Sea: navigation training ship  25°26-32°40.8’ N, 125°02’-128°59.4’E | 100 km to Japan | June - July | continuous arrival of small numbers at a ship on the rain front SW wind. | [49] |
| TOM | Pacific Ocean, Philippine Sea  22°06’N, 138°26’E | 1200 km to Japan  1700 km to Luzon | October | arrival after typhoon originating NE of Luzon | [50] |
| TOM | Pacific Ocean: Minami-Iowjima Is; 24°13.7’N, 141°27.7’E | 1300 km to Japan,  1320 km to Guam | June | record of first landing survey in a desert island for 10 days | [51] |
| TOM | Pacific Ocean: Ngulu Atoll  8.4547°N, 137.4834°E | 320 km to Palau  1250 km to Philippines | August | W wind assisted dispersal into Atoll | [28] |
| TOM | Pacific Ocean: Willis Island  16.7425°S, 151.5508°E | 450 km to Australia | March | records of arrivals related to wind systems across Coral Sea | [31] |
| TM | Africa: Entebbe, Uganda  0.061°N, 32.4638°E | - | October - December | large numbers of predominantly *P. flavescens* arrived in Entebbe, which in October had experienced the heaviest and most prolonged "short" rains since records began | [52] |
| TM | Africa: Vom, Nigeria  9.7437°N, 8.8118°E | - | November | swarm stayed for 4 days, mainly *Tramea basilaris* and less *P. flavescens*; noted swarms of *Pantala* appear when the weather has suddenly become hot and thundery | [53] |
| TM | Africa: Lagos, Nigeria  6.5153°N, 3.3729°E | - | November | a large swarm of dragonflies, (...), was observed passing over the Lagos area in approximately a NNW direction | [54] |
| TM | Africa: Zimbabwe  20.1285°S, 28.6023°E | - | November | large flight passing in ESE direction in front of a heavy storm and in the wake of kites | Irwin & Biscoe in [55] |
| TM | Africa: Zimbabwe  16.9557°S, 27.9718°E | - | December | large migration at Kariba Lake | Kenmuir (1975) in [55] |
| TM | Africa: Namibia, Swakop River  22.3792°S, 15.7489°E | - | March | directional flight into Namib desert by large aggregation, passing by lasting several hours with rain front from SW | [56] |
| TM | Africa: Namibia, near Etosha NP  19.3236°S, 15.2224°E | - | November | large aggregations of individuals after recent rainfalls observed over a stretch of ca. 40 km east | [57], Suhling (unpubl.) |
| TM | Africa: Natal, Republic of South Africa | - | October - January | groups of up to 400 individuals covered the whole area between Port Edward and Durban, 26000 km2, origin unclear, not locally developed; after untypically high precipitation for about a year | [58] |
| TM | Asia: north central Asian countries | - | Seasonality | spring generation represented by immigrant specimens; late summer generation probably migrates in a southerly direction; no hibernation at 36-37°N | [33] |
| TM | Asia: Russian Far East and Transbaikalika | - | June - September | several records; phenological observations: no overwintering at the northern limits; only present in summer; arrival in May with monsoons | [3] |
| TM | Asia: Nepal, several sites near Namche Basar  27.803°N, 86.708°E | - | May | no swarm observations, more than 1000 observed individuals flew down the southern slopes of the Himalaya | [34] |
| TM | Asia: India | - | - | various statements/information about migration in India | [59] |
| TM | Asia: South India  11.4218°N, 76.8617°E | - | October | swarm of 5 km, estimate > 1 Mio. Individuals; related to large butterfly migration | [60] |
| TM | Asia: Hindukush, Afghanistan  38.3607°N, 72.6347°E | - | August | migration across alpine region, 6000 m in elevation; identification of *P. flavescens* not secure | [61] |
| TM | Asia: Honshu, Japan  35.9945°N, 139.0611°E | - | seasonality 1993-1994 | large swarm formed with individuals flying irregularly around, though, whole of them move to a certain direction | [27] |
| TM | Asia: Japan  34°-36°N, 136°-140°E | - | July - October | eggs laid by migratory females, swarms | [62] |
| TM | Asia: Japan  33.8391°N, 132.7655°E | - | August | swarms about five hundred individuals over paddy fields | [63] |
| TM | Asia: Japan  35.92°N, 139.48°E | - | August-September | enormous large migration individuals estimated at least 2400000 observed Aug 25 and Sep 5 during typhoon | [65] |
| TM | Asia: China, Beihuang Island in the Bohai Gulf  38.3897°N, 120.9124°E | - | varying over the study years | across Bohai Sea; seasonality of migration; searchlight trapping 1 April-13 October over 14 years | [2,26] |
| TM | America: New Jersey  38.9208°N, 74.9128°W | - | July | associated with weather front | Dowdell (pers. comm.) in [66] |
| TM | America: Florida  29.7500° N, 85.4000° W | - | September to November | migration along peninsula, pushed on peninsula by prevailing winds from land | [67] |
| TM | North America: Florida  29.0736°N, 80.9100°W | - | July | groups following swarms of midges; “the sky was literally alive with dragonflies”; aggregations seen over vast area up to 30 miles inland | [68] |
| TM | America: Panama,  9.1659°N, 79.8361°W | - | October | observation of flight orientation to counteract crosswind drift; swarm over Lake Gatun | [69] |
| TM | America: Santa Catarina, Brazil  26.75°S, 48.66°W | - | February | migration, over sand dunes 3-10 m above sea level; “endless band“ of some 500 meters width in the mornings of 7 consecutive days; estimated half a million individuals | [44] |
| TM | Western Palearctic, Caucasus, Russian Federation  44°54'03-24” N, 37°34'47''-35'58'' E |  | July 2016 & 2917 | Several individuals flew over the crest of the hill at Natukhaevkaya village; with *Anax ephippiger*, although not in great numbers. | [39,49] |
| LDD | Atlantic Ocean: Azores  37.7403°N, 25.6619°W | 2100 km to Cape Verde  2500 km to Senegal | November | arrival of single individual; first record for the island | [21] |
| LDD | Atlantic Ocean: Trindade Island 20.505°S, 29.3275°W | 1200 km to Brazil | unknown | only information is that the species is found there [should be LDD because there are no breeding habitats] | [70] |
| LDD | Indian Ocean: New Amsterdam Is  37.8316°S, 77.5517°E | 5000 km to India,  3500 km to Australia  3200 km to Madagascar | February | two individuals on remote subantarctic island where no Odonata occur | [71] |
| LDD | Pacific Ocean: New Zealand  35°S, 173.5’E | > 2500 km to Fiji  2000 km to Australia | May | after anticyclone 3000 km wide had arrived from near Fiji | [72] |
| LDD | Pacific Ocean: New Zealand  41°S, 172°E | 2000 km to Australia | April | coinciding with wind trajectories from E Australia | [72] |
| LDD | Pacific Ocean: Kermandec Islands;  29.267°S, 177.9167°E | 2800 km to Australia  1300 km to Fiji | May-June | single record | JC Edwards in [73] |
| LDD | Asia: Kamchatka  53.3025°N, 157.9723°E | - | unknown | 1 female in 19th century, may have arrived with typhoons, another records later | [23] |
| LDD | Europe: Poland  51.3668°N, 22.5001°E  54.5531°N, 17.7324°E | > 2000 km to nearest reproduction sites | June, August | 2 records of single individuals far from normal range; overview of other records from Europe, mostly single individuals; suggest migratory route via eastern Europe | [41] |
| LDD | Europe: Germany  51.6125°N, 14.1814°E | > 2000 km to nearest reproduction sites | July | records of single individuals far from normal range; breeding record | [42] |
| LDD | Europe: Lithuania  55.3413°N, 21.1917°E | > 2000 km to nearest reproduction sites | May | record of single individual in bird trap, far from normal range | [74] |

**References (table S3)**

1. Anderson RC 2009 Do dragonflies migrate across the western Indian Ocean? J. Trop. Ecol. 25, 347-358.

2. Cao LZ, Fu XW, Hu CX & Wu KM 2018 Seasonal migration of *Pantala flavescens* across the Bohai Strait in Northern China. *Environm. Entomol*. **47**, 264-270.

3. Borisov SN & Malikova EI 2019 Distribution and migration strategy of *Pantala flavescens* (Fabricius, 1798) (Odonata, Libellulidae) near the northern limit of its range in Transbaikalia and in the Far East of Russia. *Euroasian Entomol. J.* **18**, 155–162.

4. Asahina S & Turuoka Y 1967 Records of the insects visiting a weather ship at the ocean weather station “Tango” on the Pacific. *Kontyû* **35**: 353-360 [in Japanese]

5. Asahina S & Turuoka Y 1968 Records of the insects visiting a weather ship located at the Ocean Weather Station “Tango” on the Pacific, II. *Kontyû* **36**: 190-202. [in Japanese]

6. Asahina S & Turuoka Y 1969 Records of the insects visiting a weather ship at the ocean weather station “Tango” on the Pacific, Ⅲ. *Kontyû* **37**: 290-304 [in Japanese]

7. Asahina S & Turuoka Y 1970 Records of the insects visiting a weather ship at the ocean weather station “Tango” on the Pacific, V. Insects captured during 1968. *Kontyû* **38**: 318-330 [in Japanese]

8. Chapman JW, Reynolds DR & Wilson K 2015 Long‐range seasonal migration in insects: mechanisms, evolutionary drivers and ecological consequences. *Ecology Letters* **18**, 287-302,<https://doi.org/10.1111/ele.12407>

9. Asahina S 1972 Indian paddy field Odonata taken by Miss I. Hattori. *Mushi* **46**, 115-127.

10. Corbet PS, Longfield C & Moore NW 1960. Dragonflies (New Naturalist 41). London: Collins, pp. xii+ 260.

11. Laister G, Lehmann G & Martens A 2014 Exotic Odonata in Europe. *Odonatologica* **43**, 125-135.

12. Englund RE 1999 The impacts of introduced poeciliid fish and Odonata on the endemic *Megalagrion* (Odonata) damselflies of Oahu Island, Hawaii. *J. Insect Conserv* **3**, 225-243.

13. Lambret P & Boudot JP 2013 *Hemianax ephippiger* (Burmeister, 1839)(Odonata, Anisoptera: Aeshnidae): présentation générale. *Martinia Hors-série, Hemianax ephippiger*, 13-28.

14. Meurgey F & Poiron C 2012 An updated checklist of Lesser Antillean Odonata. *Int. J. Odonatol* **15**, 305-316.

15. Weidner H 1969 Beobachtungen wandernder Feldheuschrecken auf hoher See. *Anz. Schadlingsk Pflanzenoch*. 43, 118–121.

16. Lovejoy NR, Mullen SP, Sword GA, Chapman RF & Harrison RG 2006). Ancient trans-Atlantic flight explains locust biogeography: molecular phylogenetics of *Schistocerca*. *Proc. R. Soc. London. B: Biol.* **273**, 767-774.

17. Song H 2004 On the origin of the desert locust *Schistocerca gregaria* (Forskål)(Orthoptera: Acrididae: Cyrtacanthacridinae). *Proc. R. Soc. London. B: Biol. Sc.* 271, 1641-1648.

18. Cordero Rivera A, Carballa ML, Utzeri C & Vieira V 2005 Parthenogenetic *Ischnura hastata* (Say), widespread in the Azores (Zygoptera: Coenagrionidae). *Odonatologica* **34**, 1-9.

19. Pellow K 1999 Common green darner *Anax junius* (Drury) in Cornwall and Isles of Scilly–the first British and European records*. J. Br. Dragonfly Soc*. **15**, 21-22.

20. Kalkman VJ & Prentice S 2015: *Anax junius* (Drury, 1773). In Boudot JP & Kalkman VJ (Eds.). Atlas of the European dragonflies and damselflies. KNNV publishing, the Netherlands,

21. Vieira V, & Cordero-Rivera A 2015 First record of *Pantala flavescens* from the Azores (Odonata: Libellulidae). *Odonatologica* **44**, 1-9.

22. Soustelle C, Moisset F & LeReec le Bricquir M-L 2019 Première mention documentée de *Pantala flavescens* en France métropolitaine (Odonata: Libellulidae). *Martinia* **34**, 61-67.

23. Dumont HJ, Haritonov AY, Kosterin OE, Malikova EI & Popova O 2005 A review of the Odonata of Kamchatka Peninsula, Russia. *Odonatologica* **34**, 131-153.

24. Sugimura M, Ishida S, Kojima K, Ishida K & Aoki T (ed.) 1999 Dragonflies of the Japanese Archipelago in Color. Publishing association of Hokkaido University, Hokkaido, Japan.

25. Paulson DR 2018 *Anax junius*. The IUCN Red List of Threatened Species 2018. e.T165081A65831504

26. Feng HQ, Wu KM, Ni YX, Cheng DF & Guo YY 2006 Nocturnal migration of dragonflies over the Bohai Sea in northern China. *Ecol. Entomol.* **31**, 511-520.

26. Schmidt E 1938 Check-list of Odonata of Oceania. *Ann. Entomol. Soc. Am*. **31**, 322-344.

27. Arai Y 1995 Some biological observations of *Pantala flavescens* in Saitama Prefecture. *Digest Japan. Odonatol. Short Comm.* **3**, 1-2.

28. Buden DW 2010 *Pantala flavescens* (Insecta: Odonata) rides west winds into Ngulu atoll, Micronesia: Evidence of seasonality and wind-assisted dispersal. *Pac. Sci.* **64**, 141-143.

29. Barnett LK & Emms C 1997 Odonata observations on the Chagos Archipelago, British Indian Ocean Territory: a review and update. *Notul. odonatol.* **4**, 153-164.

30. Hawking JH & Ingram BA 1994 Rate of larval development of *Pantala flavescens* (Fabricius) at its southern limit of range in Australia (Anisoptera: Libellulidae). Odonatologica **23**, 63-68.

31. Farrow RA 1984 Detection of transoceanic migration of insects to a remote island in the Coral Sea, Willis Island. *Austral. J. Ecol.* **9**,253-272.

32. Hobson KA, Anderson RC, Soto DX & Wassenaar LI 2012b. Isotopic evidence that dragonflies (*Pantala flavescens*) migrating through the Maldives come from the northern Indian subcontinent. *PLoS One* **7**, e52594.

33. Borisov SN 2012 Migrant dragonflies in Middle Asia. 3. *Pantala flavescens* (Fabricius, 1798) (Odonata, Libellulidae). *Euroasian Entomol. J.* **11**, 37-41 [in Russian]

34. Brockhaus T 2003 *Pantala flavescens* (Fabricius) in Khumbu Himal, Nepal (Anisoptera: Libellulidae). *Notulae odonatol*. **6**, 2-3.

35. Kipping J, Dijkstra K-DB, Clausnitzer V, Suhling F & Schütte K 2009 Odonata database of Africa (ODA). *Agrion* **13**, 20-23.

36. Durand E & Rigaux J 2015 Further additions to the knowledge of the odonate fauna of Armenia, with first record of *Pantala flavescens* (Odonata: Libellulidae). *Notulae odonatologicae* **8**, 157-201.

38. Seehausen M, Schröter A, Mumladze L & Grebe B 2016 Additional Odonata records from Georgia, southern Caucasus eco-region, with the first record of Ischnura fountaineae (Odonata: Coenagrionidae). *Notulae odonatologicae* **8**, 247-318.

39. Kosterin OE & Borisov SN 2018 New record and migration strategy of *Anax ephippiger* (Burmeister, 1839) (Odonata, Aeshnidae) in the territory of the Russian Federation. *Eurasian Entomol. J.* **17**, 73-79.

40. Kosterin OE & Solovyev VI 2017 Odonata found in mid-summer 2015 and 2016 at the north-westernmost Black Sea Coast of the Caucasus, with the first record of *Cordulegaster picta* Selys, 1854 in Russian Federation. *International Dragonfly Fund-Report* **107**, 1-43.

41. Buczyński P, Buczyńska E & Michalczuk W 2019 From southern Balkans to western Russia: do first Polish records of *Pantala flavescen*s (Fabricius, 1798) (Odonata: Libellulidae) indicate a migration route? *J. Entomol. Res. Soc.* **21**, 11-16.

42. Günther, A. (2019): Successful breeding by *Pantala flavescens* in Germany (Odonata: Libellulidae). *Odonatologica* 48: 203-210.

43. May ML 2013 A critical overview of progress in studies of migration of dragonflies (Odonata: Anisoptera), with emphasis on North America. *J. Insect Conserv.* **17**, 1-15.

44. Reichholf J 1973 A migration of *Pantala flavescens* (Fabricius, 1798) along the shore of Santa Catarina, Brazil (Anisoptera: Libellulidae). *Odonatologica* **2**, 121-124.

45. Renner S, Sahlén G & Périco E 2016 Testing dragonflies as species richness indicators in a fragmented subtropical Atlantic forest environment. *Neotropical Entomology* **45**, 231–239.

46. McLachlan R 1896 Oceanic migration of a nearly cosmopolitan dragon-fly (*Pantala flavescens*, F.). *Entomol. Monthly Mag.* **7**, 254.

47. von Frauenfeld G 1867 Das Insektenleben zur See. *Verhandl. Zool.-bot. Ges. Wien* **17**, 425-464.

48. Hashimoto Y & Asahina S 1969 Records of the insects visited a weather ship located at the ocean weather station “Tango” on the Pacific IV. Observations on dragonflies. *Kontyû* **37,** 305-319. [in Japanese]

49. Hayashi K, Suzuki H, Makino Y & Asahina S 1979 Notes on the transoceanic insects-captured on East China sea in 1976, 1977 and 1978. *Trop. Med.* **21**: 1-10 [in Japanese]

50. Nohira A 1960 *Pantala flavescens* hovering above the Pacific. *Tombo* **3**, 30-31.

51. Sato M 1983 Insect fauna on Minami-Iowjima Island. Conservation Reports of the Minami-Iwojima Wilderness Area. Japan Environment Agency (ed.), Tokyo, Japan: 303-327 [in Japanese]

52. Corbet PS 1984 Orientation and reproductive condition of migrating dragonflies (Anisoptera). *Odonatologica* **13**, 81-88.

53. Gambles RM 1951 A dragonfly migration at Vom. *J. Nigerian Field Soc.* **16**, 135-138.

54. Smith KG 1951 A dragonfly migration at Lagos. *J. Nigerian Field Soc.* **16**, 138-139.

55. Pinhey E 1979a Examples of Anisopteran swarms. *Arnoldia* **8**, 1-2

56. Suhling F, Martens A & Marais E 2009 How to enter a desert – patterns of Odonata colonisation of arid Namibia. *Int. J. Odonatol.* **12**, 287-308.

57. Suhling F, Martens A, Suhling I 2017 Long-distance dispersal in Odonata: examples from arid Namibia. *Austral Ecol.* **42**, 544-552.

58. Samways MJ & Caldwell P 1989 Flight behaviour and mass feeding swarms of *Pantala flavescens* (Fabricius) (Odonata, Anisoptera, Libellulidae). *J. entomol. Soc southern Africa* **52**, 326-327.

59. Corbet PS (Ed.) 1988 Current topics in dragonfly biology, 3. A discussion focusing on the seasonal ecology of *Pantala flavescens* in the Indian subcontinent. *Soc. int. odonal. rapid Comm.* *(Suppl.)* **8**, viii+24 pp

60. Larsen TB 1987 A migration of *Pantala flavescens* (Fabr.) in South India (Anisoptera: Libellulidae). *Notul. Odonatol.* **2**, 154-154.

61. Wojtusiak J 1974 A dragonfly migration in the high Hindu Kush (Afghanistan), with a note on high altitude records of *Aeshna juncea mongolica* Bartenev, and *Pantala flavescens* (Fabricius)(Anisoptera: Aeshnidae, Libellulidae). *Odonatologica* **3**, 137-142.

62. Ichikawa Y & Watanabe M 2014 Changes in the number of eggs loaded in *Pantala flavescens* females with age from mass flights (Odonata: Libellulidae). *Zoolog. Sci.* **31**, 721–724.

63. Kuwada K 1972 On a mass appearance and the swarm of *Pantala flavescens* observed in Matsuyama. *Tombo* **15**, 10-12 [in Japanese].

65. Wakana I 1959 On the swarm and migratory flight of *Pantala flavescens*, an observation in Kawagoe area. *Tombo* **1**, 26-30 [in Japanese].

66. Russell RW, May ML, Soltesz KL & Fitzpatrick JW 1998 Massive swarm migrations of dragonflies (Odonata) in eastern North America. *Am. Midland Natural.* **140**, 325-342.

67. Sprandel GL 2001 Fall dragonfly (Odonata) and butterfly (Lepidoptera) migration at St. Joseph Peninsula, Gulf County, Florida. *Florida Entomol.* **84**, 234-238.

68. Wright M 1944 Notes on dragonflies in the vicinity of New Smyrna Beach, Florida. *Florida Entomol*. **27**, 35-39.

69. Srygley RB 2003 Wind drift compensation in migrating dragonflies Pantala (Odonata: Libellulidae). *J. Insect Behav.* **16**, 218–232.

70. Alves RJ, Costa LA, Soares A, Silva NG & Pinto ÂP 2019 Open ocean nocturnal insect migration in the Brazilian South Atlantic with comments on flight endurance. *PeerJ* **7**, e7583.

71. Devaud M & Lebouvier M 2019 First record of *Pantala flavescens* (Anisoptera: Libellulidae) from the remote Amsterdam Island, southern Indian Ocean. *Polar Biol.* **42**, 1041-1046.

72. Corbet PS 1979 *Pantala flavescens* (Fabricius) in New Zealand (Anisoptera: Libellulidae). *Odonatologica* **8**, 115–121.

73. Rowe RJ 1980 Records of the dragonfly *Pantala flavescens* in New Zealand, with notes on *Tramea transmarina*, a possible immigrant (Odonata: Libellulidae). *New Zealand Entomol.* **7**, 139-141.

74. Jusys V, Eigridas V & Gliwa B 2019 First records of *Pantala flavescens* and *Anax ephippiger* (Odonata, Libellulidae) in Lithuania. *Lietuvos Entomologu Draugijos Darbai* **3**, 5-7.

Table S4: Dataset composition for molecular analyses presented here.

|  |  |
| --- | --- |
| Dataset | Number of samples of *Pantala flavescens* |
|  |  |
| Dataset | 653 |
| “Reduced” | 248 |
| “Reduced, Alvial samples not included” | 241 |

Supplementary Text S1: Hypotheses regarding *Pantala flavescens* migratory routes

**Possible migration routes of *Pantala flavescens*: hypotheses and evidences**

There are likely various migration routes of *P. flavescens* in many parts of the globe; information from the literature is compiled in table S3. Some regular transoceanic and within-continent migration routes are already published [1–3]. For reconstruction of additional migration routes we make use of available observations of swarms, particularly seen at sea. Also published cases of long-distance dispersal (LDD) of individuals of *P. flavescens* are compiled in Table S3. Additionally, arrivals of other migratory insects exotic to certain regions in the range of *P. flavescens* are used as indirect evidence that certain dispersal routes would be possible. Exotic species are easily recognized when newly appearing in an area, whereas the less conspicuous individuals of *P. flavescens* arriving e.g., with the same winds in areas already colonized by the species will likely not be noted. The migration routes presented below are based on the best evidence – but, they may not be the only ones that connect between or across continents.

**Long-distance migrations and costs of migration**

As mentioned in the discussion observations on long-distance dispersal and transoceanic migration (TOM) events (Table S3) gives ample evidence that individuals of *P. flavescens* are able to cross distances of several thousand kilometers. This includes records on isolated islands as well as records in southeast and north-central Europe. Swarms moving over the Indian Ocean are regular events [1] as are swarms over the Pacific Ocean / Philippine Sea [4–7]. We assume that most such records are caused by wind-supported translocation, which has often been directly observed, particularly connected to storms (Table S3).

Migration is typically assumed to impose costs, e.g. in terms of lower survival [8]. Concerning mortality, one may expect that the majority of *P. flavescens* individuals may die during the migration particularly on long distance migrations over the open ocean. However, some few migrating over continents would be enough for gene-exchange. Particularly in rice producing regions in Asia there may be a massive (over)production of *P. flavescens* since the species can ably reproduce in flooded rice paddies [9].

**Other possible means of transportation**

There is also an option that adult dragonfly individuals could be translocated by transportation such as ships or that larvae or eggs were imported with aquarium plants. Of *P. flavescens* few adults were recorded arriving in the UK with ships [10]. In Europe 41 exotic species are known to have been imported mostly as eggs or larvae with plants of which, however, none has been able to establish yet [11]; *P. flavescens* was rather rare among those. On the other hand, in Hawaii at least seven introduced species are established [12].

**New World - Old World exchange**

There are three possible routes: A-C.

***Route A.*** Across Atlantic Ocean from Africa to the Caribbean and South America.

There are records of other African Odonata and African Orthoptera on the open Atlantic and in the Caribbean and northern parts of South America. Transport would be supported by trade winds; Hurricanes developing in the Gulf of Guinea may provide extra support.

* Recent records of two other African migratory odonates (*Anax ephippiger*, *Tramea basilaris*) in northern South America and the Caribbean [13-14].
* Records of *Schistocerca gregaria* on the Atlantic Ocean [15] and particularly a swarm arrival of *S. gregaria* from West Africa at West Indies in 1988; supporting the Old-World Origin hypothesis of *Schistocerca* [16], but there is also a New-World Origin hypothesis [17].

In opposition to these observations, our Migrate-N analysis shows higher likelihood for the New to Old World direction for *P. flavescens*.

***Route B****.* Across the Atlantic Ocean from North America to Western Palearctic.

Records of American species in western Europe and on the Azores imply that translocation over the northern Atlantic is possible. Transport with westerlies and remnants of hurricanes touching western Europe is possible.

* Occurrence of the American *Ischnura hastata* on the Azores, halfway over the Atlantic Ocean [18].
* Records of the American migratory *Anax junius* in the UK (Cornwall, Scilly Islands) and France (Bretagne) [19–20]).
* A recently recorded *P. flavescens* on the Azores [21] may originate from N America. The authors regard America as more unlikely than Africa, but western winds at the time of record would also support origin in America.

A counter argument would be that *P. flavescens* was not yet recorded in continental western Europe, with the exception of one single record in southern France [22].

***Route C*.** Across Pacific Ocean from the Americas to Pacific Islands and East Asia.

There are records of *A. junius* in Asia (Kamchatka [23]; Iwo Jima, Japan [24]). Transport would be possible with trade winds within or on the edge of the ITCZ. Extra support by seasonal typhoons/cyclones forming in the trade wind belt may then move individuals far outside the ITCZ belt. Individuals of *A. junius* may also have arrived from Hawaii, which shortens the distance; whether the species is native or introduced to Hawaii is not known [25]. This migration route would comprise very long distances, 5,000-10,000 km; Kamchatka records of *A. junius* are very far north. Dragonfly fauna composition on most tropical Pacific islands implies colonization from Asia, i.e. against trade winds [26]. This route seems least probable.

**East Asia**

There is a comparatively big number of published observations of the species from this area. *P. flavescens* movements in China and Far East Russia is well supported by long-term observations [2,3,26]. There are also many reports of swarms in Japan [e.g. 27], over the Pacific Ocean / Philippine Sea [4-7] or arriving at islands [28]. The many observations from this area demonstrate that *P. flavescens* reaches oceanic islands and also regularly enters the temperate zone; single individuals may end up as far north as Kamchatka. Several records from the open ocean between Indonesia and Keeling Island imply that there may be also movements from E Asia deeper into the Indian Ocean. Also, more remote islands in the Indian Ocean Basin are colonised by the species (e.g. Chagos Archipelago [29]). This may have happened from India as well as from Indonesia, the latter supported by trade winds.

**Australia and adjacent islands**

At 37°S in Victoria, Australia all *P. flavescens* reproducing were immigrants as the ponds were drained in winter [30]. The authors did not speculate on the origin of these immigrants except stating that regular southward flights within Australia occurred. There is also a report of wind supported TOM via the Coral Sea [31].

**India to E Africa**

A route from India via Indian Ocean islands (Maldives, Seychelles) is well reconstructed based on several years of observations and isotope data [1,32]. Observations on seasonality of arrivals on Maldives, Seychelles and other islands in the Indian Ocean suggest that the dragonflies fly with north-easterly tail winds, within and behind the ITCZ. It is proposed that this massive movement of dragonflies is part of an annual migration across the western Indian Ocean from India to East Africa [1]. There are also hints for a return route from E Africa to India by a later generation [1]. This circular migration route is driven by the changing winds during the monsoons. Anderson [1] hypothesizes that there may be also a direct continuation deeper into Africa; this has yet to be confirmed.

**Central Asia**

According to Borisov [33] the first spring-time generation in Central Asia is represented by immigrant specimens from the southern part of the range. Large numbers of specimens are recorded from rice fields. After emergence, adult dragonflies can accumulate locally, but in late summer or early autumn the second generation of dragonflies probably migrate in a southerly direction. Directional flights were recorded at the beginning of August in East Pamir. This autumn movement connects directly to the southern movement with the monsoon winds over the Indian Ocean. One may speculate that these movements are connected to the migrations between India and Africa. Observations of directional southwards flights in the Himalayas June imply that offspring of generations developing in centrals Asia may cross the mountains to start their reproductive period in India [34], which again would connect the Indian-African route with central Asia. Whether there is a relation to monsoons for this needs to be better explored.

**Africa**

*Pantala flavescens* is breeding particularly in the savanna belt reaching from the Sahel via eastern Africa into southern Africa. Migratory swarms have been observed in West Africa, East Africa and Southern Africa (table S3). The observations are usually associated with the rain fronts that are moved over the continent with the shift of the ITCZ. This is particularly distinct in the summer rainfall areas of southern Africa, where the species is almost completely absent between June and September, and commonly found with onset of the rainy season (based on records in Odonata Database of Africa; [35]); there is a need for more observations on seasonality in the rest of Africa. There may be migration routes within western Africa and between eastern and southern Africa. There is a lack of observations that may point on connections between western and eastern/southern Africa.

**Western Palearctic**

There are not yet any established migration routes since only single individuals have been recorded, no larger swarms. However, there may be developing routes. Most records are in the eastern Mediterranean area and up north in the eastern parts of Central Europe but also in the Caucasus (36–40), which would suggest a connection to the Near East or Northeast Africa. There are also records from the Maghreb, southern France and Italy which may imply an additional influx on a more western route from Africa; for details see [41, 42] and references therein.

**North America**

This is not very well investigated yet [43]. According to May [43] adults commonly appear no earlier than late June. Particularly along the Atlantic Coast, they may be entrained in the outer winds of hurricanes and transported well northward. Inland they perhaps move northward carried in summer by the prevailing southwesterly air flow, from populations in northern Mexico and the southernmost United States and/or are brought into this flow by Atlantic trade winds from northern South America or the Caribbean.

**South America**

Intracontinental flights in South America are even less studied than in North America. an enormous swarm (going on several days) was observed off the coast of Santa Catalina in southern Brazil [44], but apart from this observation there are mostly just a set of single records of the species reported from all countries on the continent, except from the very south. Renner et al. [45] reported findings from October, January, April and May, indicating the species being active all year with the exception of winter in Rio Grand do Sul in southernmost Brazil. The species is often arriving with northern winds after rainy periods (Renner, pers. comm.), indicating a conformity to what is observed on other continents.