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DRAGONFLIES IN THE AUSTRALIAN ENVIRONMENT: TAXONOMY, BIOLOGY AND CONSERVATION

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The Australian dragonfly fauna includes slightly more than 100 species of Zygoptera and almost 200 of Anisoptera; there are two endemic families and one subfamily, and a high degree of endemism at generic and specific levels. Gondwana elements make up at least 15% and perhaps as much as 40% of the fauna, whereas 40% are of northern origin, with a lower degree of endemism. Most of the southern species breed in permanent flowing water, mainly along the eastern seaboard, with some in the north, north-west and south-west. The northern dragonflies penetrate southern Australia to a variable degree, principally along the east coast. Adult dragonflies occur throughout the arid inland; most are opportunistic wanderers. None has a drought-resistant larva, although drought-resistant and terrestrial larvae occur elsewhere in Australia. The conservation of Australia Odonata involves problems arising from habitat destruction or the alienation of fresh waters for human consumption or agriculture. Pollution does not threaten any Australian species of dragonfly, although it may affect local dragonfly faunas; adults and larvae of appropriately chosen species can serve to monitor water quality.

INTRODUCTION

The taxonomy of the Australian dragonflies is well established. Fabricius described the first known species, from material that Banks and Solander collected during their enforced stay at the Endeavour River in 1770, during Cook's voyage along the eastern Australian coast. European odonatists described a wealth of Australian dragonflies during the 19th century and early in the 20th century the emphasis swung to Australia itself, when R.J. Tillyard arrived in Sydney. Tillyard's work was primarily taxonomic and morphological and, by the time that it was completed, the Australian fauna was substantially documented. Subsequent taxonomic work has consisted principally of filling gaps in regional coverage and extending the knowledge of established taxa.

By comparison, biological studies have been meagre. Indeed, we still lack even the basic documentation of life histories for most of the Australian Odonata. This is at least partly due to the fact that since Tillyard's early days in Australia, there has been no long-term full-time odonatist there. However, the work of research students, particularly from the University of New England, of professional entomologists who were part-time odonatists, and of amateur entomologists has provided a considerable body of information on the life styles of our dragonflies, sufficient to give us some insight into the biology of several major components of the fauna and, more recently, into potential problems in their conservation.

In this paper I will look briefly at some of these perspectives: many of them were discussed in greater detail in a recent review on the ecology and biogeography of Australian Odonata (WATSON, 1981).

THE AUSTRALIAN DRAGONFLY FAUNA

Approximately 300 species of Odonata are known from Australia, slightly more than 100 species of Zygoptera and almost 200 Anisoptera. The larger groups of Zygoptera include the protoneurids (including the isostictines), coenagrionids, megapodagrionids and lestids, and among the Anisoptera, the gomphids, aeshnids (particularly brachytronines), synthemistids, corduliids (particularly gomphomacromiines) and libellulids (WATSON, 1981).

Some groups that are small numerically are of considerable systematic or zoogeographic interest. Thus there are the isostictine protoneurids, an Australo-Papuan group (13 species in perhaps 6 genera, all endemic, compared with approximately 25 species in 3 genera from New Guinea and adjacent islands and New Caledonia); the Lestoideidae, an endemic family of obscure affinities, including only the two species of *Lestoidea;* the chlorolestids, 8 species in 3 genera, including the monotypic genus *Chorismagrion* which, like *Hemiphlebia mirabilis* Selys, the only member of the endemic family Hemiphlebiidae, has the basal side of the discoidal cell open in the forewing; 5 species of the amphipterygid genus *Diphlebia* (STEWART, 1980), a genus apparently not closely related to the other amphipterygid genera, *Amphipteryx* and *Rimanella* (Americas), *Pentaphlebia* (Africa) and *Devadatta* (Asia), in all of which the laminae sub-anales are modified into tracheal gill tufts (cf. WATSON, 1981); the four species of *Petalura*, almost half the surviving species of petalurids; and the two monotypic genera of neopetaliine aeshnids, *Austropetalia* and *Archipetalia.*

Several families are not represented in the Australian fauna, including some that are very widely distributed elsewhere – the Platystictidae, Platycnemididae, Cordulegastridae and, in all probability, the Chlorocyphidae and Calopterygidae, one species of each having been recorded in the early literature but not collected since.

As the earlier paragraph suggests, the level of endemism is high. Of approximately 100 genera, 47 are endemic. The level of endemism is low in only two of the families with substantial representation, the coenagrionids (2 of 13 genera, and 53% of species) and the libellulids (2 of 26 genera, and 27% of species) (WATSON, 1981).

ZOOGEOGRAPHY

It is useful to comment at this stage on the apparent Gondwana affinities of the Australian fauna (cf. O'FARRELL & WATSON, 1974; WATSON, 1981). The chlorolestids, petalurids, neopetaliine aeshnids, and gomphines (including those Australian genera that FRASER (1953, 1959, 1960) placed in his "Epigomphinae") appear to represent southern continental relicts, and constitute approximately 15% of the Australian fauna. Other southern groups may also be interpreted in this way. *Aeshna brevistyla* Rambur is among them, as are the Gomphomacromiinae (sens. lat.) and the corduliine *Pentathemis*; and it is difficult to interpret the rich Australian brachytronine fauna except as a southern relict, although no brachytronines are known from other southern continents. These four comprise a further 20% of the Australian fauna.

Even this may not be the limit. The Gomphomacromiinae (sens. lat.) is complex, and includes two groups. The first comprises *Gomphomacromia* from South America and two Australian genera, *Archaeophya* and the genus to which a terrestrial larva from north Queensland belongs, probably *Pseudocordulia* (WATSON, 1982). Larvae in this group are synthemistine in appearance and lack setae on the crenations of the labial palps, but their wing buds are parallel (THEISCHINGER & WATSON, 1983). The remaining Australian genera (*Apocordulia, Austrocordulia, Austrophya, Hesperocordulia, Lathrocordulia* and *Micromidia*), and at least *Syncordulia* and *Oxygastra* among the extralimital genera, have typical corduliid larvae (THEISCHINGER & WATSON, 1983). The possibility arises that the synthemistids are an Australasian offshoot of an old southern corduliid stock, to which the two groups of Gomphomacromiinae are also closely cognate (THEISCHINGER & WATSON, 1983). If this were so, one would have to regard *Synthemis* and its allies as southern relicts, increasing the percentage of southerners to as much as 40%.

We can contrast these southern elements with families that have, it appears, entered Australia more recently, from the north. Predominant amongst these northerners are the coenagrionids and libellulids, totalling more than 80 species, but the lestids, anactine and gynacanthagine aeshnids, *Ictinogomphus* and, possibly, some of the corduliines are significant components.

DISTRIBUTION AND BIOLOGY

Australia is, essentially, a warm to hot, dry continent with a narrow, relatively well-watered coastal margin. The montane eastern seaboard shows a gradient from predominantly summer rainfall in the north to predominance of anticyclonic, winter rains in the south. The south-west of Western Australia is an area of winter rainfall, whereas the continent's northern coasts receive heavy rains in summer; both are areas of seasonal drought. The arid and semi-arid region of the inland amounts to perhaps two-thirds of Australia's land surface and, apart from the major rivers that drain through it from catchments in the mountains near its eastern margin, there is very little permanent water there.

It is something of a paradox that so many of the Australian Odonata breed only in permanent streams and rapidly-flowing rivers, perhaps 40% of both the Zygoptera and Anisoptera for which data are available (WATSON, 1981). Most of the stream-dwellers belong to southern genera, and their distributions follow that of the cooler permanent streams – mainly along the south- and central eastern seaboard, but extending into the montane and rain-forest streams of north-eastern Queensland, and with a substantial outlier in the south-west of Western Australia and a few northern and north-western species (WATSON, 1981). Some of the stream-dwellers, however, have northern affinities (the protoneurid *Nososticta*, the coenagrionid *Pseudagrion*, and the libellulids *Tetrathemis* and *Nannophlebia*) and their distributions are the converse of those found in southern genera – the north-west and north, extending southwards along the eastern seaboard into New South Wales.

Adult Odonata are not uncommon in the arid Australian inland.

WATSON (1962, 1963, 1981) has described aspects of their biology, and little needs to be said about it here. It is, however, appropriate to make two points.

First, these dry-country dragonflies are taxonomically diverse. The common species include coenagrionids, lestids, an aeshnid, a corduliid, and libellulids. All are very widely distributed, and occur in coastal as well as arid regions. Perhaps the most remarkable is the corduliine *Hemicordulia tau* Selys, an extremely common species which can have a very short larval life, and commonly breeds in temporary waters, although it is equally at home in rivers and montane lakes (WATSON, 1962; FARAGHER, 1980).

Second, at least the Anisoptera appear to be opportunists, and we have no evidence to suggest that they have drought-resistant immature stages. This raises a fascinating, and current, topic: the drought-resistance and terrestrial habits of some Australian odonate larvae.

DROUGHT-RESISTANT AND TERRESTRIAL LARVAE

Several Australian Odonata have larvae that, although aquatic, can survive for a while if free water is withdrawn; they then become inactive (TILLYARD, 1910; WATSON, 1967, 1981). Perhaps the most extreme cases are those of *Synthemis eustalacta* (Burmeister) and the gomphomacromiine *Austrocordulia refracta* Tillyard, which TILLYARD (1910) maintained under dry conditions for up to ten weeks. However, it seems likely that larvae of other Australian Odonata have an equal capacity to withstand desiccation; these include species of the brachytronine aeshnid *Telephlebia* and the megapodagrionids *Argiolestes* and *Podopteryx*. TILLYARD (1916) showed that *Telephlebia* larvae spend long periods out of water, and WATSON & THEISCHINGER (1980) reported them from damp litter near streams and from dry stream beds. Larvae of species in the *Argiolestes pusillus* complex (WATSON, 1977), like those of *Synthemis leachi* Selys, live in swamps that dry out for several months during the summer (WATSON, 1967, 1981). *Podopteryx selysi* (Förster) breeds in water-filled tree holes in northern Australian (and, presumably, New Guinean) rain forests but, during the dry winter, the water evaporates, leaving the cavities substantially dry (WATSON & DYCE, 1978). Perhaps *Argiolestes* and *Podopteryx* lay drought-resistant eggs; we do not know.

Paradoxically, all these dragonflies are restricted to the well--watered parts of Australia; none extends to the inland. Further-more, *Synthemis* and *Austrocordulia*, and perhaps *Telephlebia*, appear to be old, southern genera.

These cases of drought-resistance involve larvae that become inactive as their habitat dries out. Two remarkable instances have now come to light of anisopteran larvae that are active in terrestrial habitats for at least part of their lives.

The first example is somewhat equivocal, a last-instar larva of *Antipodophlebia asthenes* (Tillyard), a brachytronine aeshnid closely allied to *Telephlebia*, that was found on the underside of a log some 50 m from water (WATSON & THEISCHINGER, 1980). It was a pharate adult; perhaps it had wandered far from water in preparation for its emergence. Alternatively, *Antipodophlebia* may have elaborated, into a terrestrial life style, the semi-aquatic habits of its ally.

The second example is quite unequivocal, a gomphomacromiine corduliid larva, probably a species of *Pseudocordulia*, which appears to spend its entire life in the leaf litter of rain forest (WATSON, 1982). A well-grown larva, perhaps in its 3rd - 4th last larval stage, was maintained in the laboratory for six months, in a petri dish lined with damp filter paper; it fed on a wide range of terrestrial invertebrates, and moulted successfully out of water. Further larvae, some tiny, were recovered from litter samples gathered in other north Queensland rain forests. Like *Megalagrion oahuense* (Blackburn) from Hawaii and the enigmatic megapodagrionid from New Caledonia, the corduliid larva is truly terrestrial.

Again, however, these dragonflies are known only from areas with high rainfall, in habitats where the relative humidity will always be high (WATSON & THEISCHINGER, 1980; WATSON, 1982). They demonstrate the adaptability of larval respiratory mechanisms (cf. CORBET, 1962). They also raise interesting problems over the capacity of the eye to function in media with different refractive indices. Unfortunately, our knowledge of these terrestrial larvae, and of the drought-resistant species, doesn't help us to understand the absence of terrestrialism in the dragonflies of the Australian inland.

CONSERVATION

A theme that pervades this paper is Australia's dryness and, in the context of dragonfly conservation, it is again a major factor. Australia has rich mineral resources, many in arid areas, and their exploitation is, inevitably, accompanied by the exploitation of whatever fresh water resources the region offers. At least some, and perhaps many, of the substantial, isolated fresh waters in Australia support unusual or relict faunas (WATSON, 1969, 1973, 1981; THEISCHINGER & WATSON, 1979). As KEY (1978) has pointed out, Australian insect species "are endangered to the extent that their habitats are endangered .... Especially important for insects are certain restricted aquatic habitats, especially in arid regions and where damming or other water supply projects .... threaten their existence or character." WATSON & ARTHINGTON (1978), KEY (1978), WATSON (1981) and ARTHINGTON & WATSON (1982) have discussed instances of this kind, where dragonfly faunas have appeared to be threatened by development. It is useful to comment here on one of these instances, that of dune lakes in eastern Australia and on another that has recently come to light, the serious problem that faces *Hemiphlebia mirabilis.*

Along the coasts of southern Queensland and northern New South Wales are massive dune systems, some on the mainland and others forming a row of islands, from Fraser Island in the north to the Stradbroke Islands in the south (WATSON & ARTHINGTON, 1978; ARTHINGTON & WATSON, 1982). These dune masses contain large bodies of fresh water, particularly lakes and perched swamps; but they also contain valuable minerals, and are subject to extensive mining. The dune lakes and swamps support a dragonfly fauna that differs from that found at lakes away from the dunes; it includes two species known only from the dunes, *Austrolestes minjerriba* Watson and *Orthetrum boumiera* Watson & Arthington, two that are otherwise known only from tropical areas 1000 km and more to the north, *Austroagrion exclamationis* Campion and *Trapezostigma eurybia* (Selys), and one southern species, *Petalura gigantea* Leach, the known range of which reaches its northern limit on Fraser Island. Although mining has already degraded many of the dune fresh waters, national parks have now been established that will protect some of them, although more are needed in the southern dune masses.

By way of contrast, the conservation status of *Hemiphlebia mirabilis* seems to be perilous. As mentioned earlier, *Hemiphlebia* is an isolated genus; FRASER (1955) has commented that it will always be an enigma. Originally described, apparently in error, from north Queensland in 1868, it was rediscovered some 40 years later on flood-plain lagoons of the Goulburn River at Alexandra in Victoria. It was still abundant there during the early 1950's (FRASER, 1955; R. Dobson, pers. comm.), but DONNELLY (1974) had difficulty in finding it. More recently, A. Neboiss (pers. comm.) and I have visited the Alexandra lagoons, and found them much altered, with no sign of *Hemiphlebia*. The only other localities from which *Hemiphlebia* was known, lagoons in the middle course of the Yarra River, have been so degraded that *Hemiphlebia* appears to have died out there (A. Neboiss, pers. comm.). Two factors seem to have been important in the degradation of these habitats – the suppression of seasonal flooding (and, hence, the recharging of the lagoons) brought about by damming the upper courses of the rivers for water supply and irrigation, and the conversion of the flood plains for agriculture.

Fortunately, pollution has not yet threatened the survival of any species of dragonfly in Australia. There has, however, been some concern over the effects of uranium mining (WATSON, 1973), and this, together with the increasing awareness of the effects that contamination has had on fresh waters in urban or mining areas, has led to the study of dragonflies as potential monitors of water quality. Emphasis has centred on the possibilities that an untoward change in water quality might result in a detectable change in the local dragonfly fauna (WATSON, 1973), and that the adults of stream-dwelling species, which often tend to remain close to their emergence sites (CORBET, 1962; WATSON, 1981), might provide a ready means for recognising faunal disturbance.

In the case of uranium mining, the local circumstances proved to be inappropriate for the study (cf. WATSON & ABBEY, 1980); almost all of the dragonflies found downstream of the mine sites were species that disperse widely as adults. However, an investigation into the effects of contamination of Bulimba Creek, a stream in metropolitan Brisbane, provided a further opportunity (WATSON, ARTHINGTON & CONRICK, 1982). The contaminant was effluent from a sewage treatment works, and its effects were studied over a period of two years at five reasonably uniform riffle sites, spaced at intervals of 1-2 km downstream of the sewage outfall. Two uncontaminated sites, one upstream of the plant and the other on a tributary of Bulimba Creek served as controls.

In summary, the study showed that the dragonfly fauna diminished dramatically immediately downstream of the outfall; that adults of the obligatory stream-dwelling species (of *Nososticta, Argiocnemis, Pseudagrion, Argiolestes, Austroepigomphus, Choristhemis, Nannophlebia*) all but disappeared at the outfall, but reappeared progressively farther downstream, except for *Pseudagrion ignifer* Tillyard and *Nannophlebia;* that the number of species collected as larvae differed between sites, in a pattern similar to but more extreme than that shown by the adults of the stream-dwelling species; and that the distribution of both adult and larval dragonflies could be related to the concentrations of some potential toxicants, particularly chlorine (WATSON, ARTHINGTON & CONRICK, 1982). In other words, the adults of some stream-dwelling dragonflies have the potential to serve as monitors of water quality, the sensitivity to toxicants varying from species to species. Appropriately chosen species should, therefore, be able to provide a sensitive, low-cost evaluation of water quality in a wide range of streams.

PROSPECTS

Where, then, are the main challenges in studies of Australian Odonata? They are not in systematics or taxonomy of the adults, or in morphology; they are in biology, and the conservation issues that depend on it. There is, however, a major impediment. Time and again, we find ourselves unable to identify larval material that has been gathered in faunal or ecological studies, or in studies of water quality. This is our most pressing need: the correlation of larval and adult stages. It means, in effect, that there still has to be a bit of taxonomist in every student of Australian dragonflies.

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