Systematics and Biological Control Potential of *Toxorhynchites* (Diptera: Culicidae)

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ABSTRACT. The literature on the systematics, biology, and biological control potential of *Toxorhynchites* is reviewed preliminary to a biosystematic study of the world *Toxorhynchites*.

In preparation for a biosystematic study of the genus *Toxorhynchites* of the world, the author has reviewed the literature on all aspects of the taxonomy, biology, and biological control potential of *Toxorhynchites*. A summary of this review is presented here in hopes of stimulating more interest in the collection and rearing of all species of *Toxorhynchites*. One of the major difficulties in attempting a taxonomic study of *Toxorhynchites* is the lack of adequate material, especially link-bred or individually reared specimens. Entomologists interested in contributing specimens to this study on a loan or exchange basis are requested to contact the author.

The only systematic treatments of *Toxorhynchites* on a world-wide scale have been those of Theobald (1901) and Edwards (1932). Both authors included *Toxorhynchites* (as *Megarhinus)* in their treatises of the Culicidae. Giles (1900, 1902) also reviewed the genus (as *Megarhina*) in his handbooks of the family. Theobald (1901) reviewed 17 *Megarhinus* and 1 *Toxorhynchites* and included 12 *Megarhinus* in his key to species. Edwards (1932) placed the then 52 valid species in 3 groups based on differences in the form of the female maxillary palpus. His Group A *(Megarhinus)* included 20 species chiefly from the Neotropical Region, Group B *(Ankylorhynchus)* contained 2 Brazilian species, and Group C *(Toxorhynchites)* included 30 Old World species.

The species of *Toxorhynchites* have never been thoroughly revised from the world standpoint, although regional faunal studies have contributed to our knowledge of this fascinating group. The more important regional faunal works which treated several *Toxorhynchites* species have been those of Barraud (1934), covering the fauna of India; Belkin (1962), for the South Pacific; Hopkins (1952), for the Ethiopian Region; Howard, Dyar & Knab (1917), for the Central and North America area; Dyar (1928), for the entire New World; Lane (1953), for the Neotropical Region; and Belkin, Heinemann & Page (1970), for the Jamaica area.

The New World *Toxorhynchites* have been revised recently, but still need considerable clarification. Vargas (1953 a, b) treated the *Toxorhynchites* (as *Megarhinus)* of North America and provided a key to species. Lima, Guitton & Ferreira (1962) revised *Ankylorhynchus* and *Lynchiella,* which they treated as genera, and they also provided a key to species.

Toxorhynchites (Toxorhychites) amboinensis (Doleschall) was redescribed and its synonyms clarified (Steffan, 1968a). All 3 species of *Toxorhynchites* considered to be established in Hawaii were redescribed, illustrated, and keys provided for females, males, pupae and 4th-instar larvae (Steffan, 1968b). Also, the possible displacement of *T. brevipalpis* Theobald by *T. amboinensis* on Oahu, Hawaii, was reported (Steffan, 1970). Considerable data on the life history of *T. amboinensis* has been gathered by Steffan (unpublished), and a species file, incorporating Stone's literature citations, has been started.

Even though these studies and the many others treating 1 or 2 species of *Toxorhynchites* have added to our knowledge of the species involved, a large gap still remains with regards to our understanding of the interspecific relationships. Belkin (1970) mentions that species of *Toxorhynchites* are amazingly similar throughout their nearly world-wide distribution and are very difficult to identify at the species level.

According to Stone, Knight & Starcke (1959) and Stone (1961, 1963, 1967, and 1970), there are 66 valid species group names in *Toxorhynchites* distributed in the following 3 subgenera: 4 in *Ankylorhynchus*, 15 in *Lynchiella* and 47 in *Toxorhynchites*. There are 2 nomina dubia. Stone & Delfinado (1973) list 29 valid species group names in the subgenus *Toxorhynchites* from the Oriental Region. Only 53% of the 66 taxa are known in all stages and the eggs of only 5 species have been described.

Identification of even the more common species is difficult. Some species, introduced into new areas for biological control purposes, were misidentified. The species introduced into Hawaii as *T. splendens* Wiedemann was found to be *T. amboinensis*. Subsequent introductions of the misidentified *T. amboinensis* from Hawaii to other Pacific areas perpetuated this error. A sound revisionary study is essential, especially considering the potential use of these species as biological control agents against vector or pest mosquitoes.

The recent report of the ad hoc advisory panel of the Board on Science and Technology for International Development, National Academy of Sciences (1973) selected *Toxorhynchites* as one of the alternative control methods worthy of further investigation. As stressed in this report, the biology of most *Toxorhynchites* species is unknown and only a few species have been colonized. Very few of the approximately 60 species of *Toxorhynchites* have been studied in depth and little is known of the natural behavior of even some of the more common species. Considerable biological information exists but is scattered throughout the literature. An essential starting point is a comprehensive review of all published biological information on these species, augmented by available but unpublished collection records.

Pathogens, parasites and some predators, especially *Toxorhynchites*, offer a real potential for natural control of medically important insects; however, a prerequisite for successful application of a biological control agent is basic knowledge of the ecology and life history of the pathogens, parasites or predators and their insect hosts or prey (Jenkins, 1960).

Likewise, the possibility of utilizing integrated control measures against medically important arthropods is remote unless sound data are available on the ecology of the beneficial species and their significance in the biotic potential of the pest species (Schloof, 1962).

The potential value of the predaceous mosquitoes of the genus *Toxorhynchites* as biological control agents of vector mosquitoes was apparently first mentioned by Colledge (1911) in his paper on *Toxorhynchites speciosus*. Buxton & Hopkins (1927) also stressed their use as potential biological control agents.

Apparently the first attempt at an introduction of a *Toxorhynchites* species for control of a vector species was by Pemberton in 1929 in Hawaii (Swezey, 1930; Pemberton, 1931). The species, *T. inornatus* from New Britain, was briefly established but was thought to have died out. Hardy (1967) reported a female specimen collected on the windward side of Oahu identified by Stone as *T. inornatus*. Additional collections should be made from this area to confirm this record since females are difficult to identify.

Other introductions into Hawaii included *T. brevipalpis* from Africa in 1950 (Bonnet & Hu, 1951), *T. theobaldi* (Dyar & Knab) (introduced as *T. hypoptes* Knab) from Panama in 1953, and *T. amboinensis* (introduced as *T. splendens* (Wiedemann)) from Manila in 1953. Only *T. amboinensis* and *T. brevipalpis* were released and established. The laboratory colony of *T. theobaldi* was discontinued as it was difficult to rear (Hu, 1955). The latest status report on *Toxorhynchites* in Hawaii was given by Nakagawa (1963), in which he presented data on the numbers of *T. amboinensis* (as *T. splendens*) and *T. brevipalpis* released on the five major Hawaiian Islands between 1950 and 1957. He also reported on a cursory survey in an area where *Toxorhynchites* was well established and concluded that this predator was not effective in keeping the populations of *Aedes albopictus* below an effective sanitary threshold. Earlier reports on the status of *Toxorhynchites* in Hawaii were given by Bonnet & Hu (1951), Hu (1955) and Nakagawa & Hirst (1959). The taxonomy of the introduced Hawaiian *Toxorhynchites* was treated by Hardy (1960) and Steffan (1968b). Belkin (Hardy, 1964) correctly identified the species introduced as *T. splendens* as *T. amboinensis* but questioned whether it was the true *T. amboinensis*. Steffan (1968a, 1968b) confirmed this identification after obtaining specimens of *T. amboinensis* from the type locality. Steffan (1970) noted that preliminary surveys on Oahu indicated that *T. brevipalpis* may have been displaced by *T. amboinensis*. In view of the fact that *T. brevipalpis* is currently considered one of the most promising species in terms of biocontrol potential, the interaction between *T. amboinensis* and *T. brevipalpis* should be more thoroughly studied.

Additional introductions of *Toxorhynchites* have been made in American Samoa (*T. amboinensis*, as *T. splendens*, and *T. brevipalpis*, Peterson, 1965), Fiji (*T. inornatus* and *T. splendens*, Paine, 1934; Lever, 1938, 1941) and Tahiti (*T. brevipalpis*, Bonnet & Chapman, 1956). Apparently *Toxorhynchites* have become established in American Samoa and Fiji.

Other studies on *Toxorhynchites* have been done by Newkirk (1947) on *T. splendens* in New Guinea, Breland (1949) on *T. rutilus septentrionalis* (Dyar & Knab) in the U. S., Muspratt (1951) on *T. brevipalpis* in Africa, Corbet (1963) on *T. brevipalpis conradti* Grünberg in Uganda, Corbet & Griffits (1963) on *T. brevipalpis conradti* and *T. kaimosi* (Someren) in Uganda. Numerous other references are listed in Horsfall (1955), Jenkins (1964), and Sollers-Riedel (1973). Hemmerlein & Crans (1968) reviewed the biology of *T. rutilus septentrionalis*.

Trpis (1973) studied the population fluctuations of *T. brevipalpis* and *Aedes aegypti* in East Africa and suggested that vector control might be achieved by released predators immediately prior to increase of the vector population. Muspratt (1951) also recommended that releases during suitable times of the year should be considered. He suggested that other *Toxorhynchites* species be investigated as possible candidates for biological control. Recent laboratory studies, including those of Trpis (1972) on the effects of temperature on development and predatory behavior of *T. brevipalpis*, indicate a renewed interest in *Toxorhynchites*.

Considerable preliminary work has been done for this project by the author. Much of the literature on the use of *Toxorhynchites* in biological control has been obtained. Also a species file on every *Toxorhynchites* has been started. *T. amboinensis* was successfully reared in our laboratory for four generations before the colony was terminated. Preliminary studies on development under laboratory conditions was carried out to the extent that more sophisticated studies in the laboratory can be quickly initiated. The colonies were maintained in cages measuring 122 x 61 x 61 cm. Based on our laboratory studies, one striking difference between *T. amboinensis* and *T. brevipalpis* was the apparent absence in the former of "killing" behavior during the late 4th-instar, while this behavior is characteristic of *T. brevipalpis*. The significance of this peculiar behavior or lack of it needs to be studied more thoroughly, especially since *T. amboinensis* has apparently displaced *T. brevipalpis* on Oahu. The presence of an apparently large percentage of abnormal embryos in our culture was discovered by Mattingly (1973) and is worthy of further study.

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