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THE ANISOPTERA OF THE SAVANNAH RIVER PLANT, SOUTH CAROLINA, UNITED STATES: THIRTY YEARS LATER

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In 1955, W.H. CROSS (*J. Elisha Mitchell scient. Soc.* 71: 9-17) surveyed the Anisoptera of a 778 km^2 site (Savannah River Plant, SRP) on the upper Coastal Plain of South Carolina, U.S.A. However, since his study, the streams and swamps of the SRP have undergone dramatic changes associated directly with the discharge of thermal effluent into three of the stream systems and construction of a 1206 ha reservoir system on another. — The anisopteran spp. composition is discussed in terms of habitats sampled: (1) unimpacted blackwater streams, (2) post-thermal streams, (3) thermal streams, (4) thermally-altered delta-swamp, (5) post-thermal delta-swamp, (6) ponds and Carolina Bays, (7) Par Pond Reservoir system, and (8) the Savannah River. — Overall, there was no significant difference between the total number of anisopteran spp. collected by Cross (58) and during this study (63), despite the dramatic changes of aquatic habitats of the SRP. This was not surprising when considering the following: (1) the majority (75%) of the spp. collected during both studies were common ubiquitous limnophilic forms; (2) many of these were adapted for the fluctuating and unpredictable temperature and water levels occurring in the lentic habitats of the SRP; and (3) the colonization of newly-created habitats was enhanced by the long flight periods of many spp., and by the asynchronous multivoltinism of some. However, we could not find 6 spp. reported by Cross, but did collect 11 spp. not reported by him.

INTRODUCTION

In 1955, W.H. CROSS published a study of the "Anisopteran Odonata of the

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Savannah River Plant, South Carolina". He had collected dragonflies from September, 1951 to August, 1954, sampling "all of the available habitats" of this area as a part of an ecological baseline study. Cross characterized all five major stream systems occurring on the site as "clear water, sandy-bottomed type". There were no large lakes, only about a dozen artificial ponds, and several Carolina Bays. The large 3020 ha floodplain forest along the southwestern border of the Savannah River was a dense, closed canopy of bald cypress *(Taxodium distichum)* and tupelo gum *(Nyssa aquatica).*

However, since Cross' study, the streams and swamps of the Savannah River Plant (SRP) have undergone dramatic changes associated directly with the discharge of thermal effluent into three of the stream systems and construction of a reservoir on another.

A part of a comprehensive study (November, 1983 to October, 1985) of the autotrophic and macroinvertebrate response to, and recovery from, thermal stress in the streams and swamps of the SRP (KONDRATIEFF & KONDRATIEFF, 1984, 1985), a survey of adult and larval Odonata was included.

The purpose of this paper is to compare the species of Anisoptera found at present with those in Cross' study of over 30 years ago, before the many varied perturbations of the streams and swamps of the SRP occurred.

There have been several other investigations which included Anisoptera from the wetlands of the SRP. BENKE & BENKE (1975), BENKE (1978), COTHRAN & THORP (1982), and THORP & DIGGINS (1982) studied selected species from an old farm pond and the cooling reservoir, Par Pond, respectively. ROBACK & WESTFALL (1967) included specimens of Anisoptera taken by the numerous Academy of Natural Sciences of Philadelphia macroinvertebrates surveys (see MATTHEWS, 1982). TENNESSEN (1980) listed species collected during an intensive survey of the aquatic insects of Upper Three Runs Creek. PATRICK et al. (1967) listed several anisopteran species from the Savannah River, near the vicinity of the SRP. WHITE et al. (1980) included all of the above records in their compilation of anisopteran records of South Carolina. HUGGINS & BRIGHAM (1982) provide an excellent overview of the biology and ecology of the Anisoptera found in South Carolina.

In this paper we follow the anisopteran classification system of WESTFALL (1984). This is especially true in regard to the elevation of previous subgenera to genera of the *Gomphus* complex (NEEDHAM & WESTFALL, 1955). Many of the specimens collected by Cross are still in the University of Georgia Entomology Collection, Athens, Georgia. Voucher specimens from the present study have been deposited in the United States National Museum of Natural History and in the Frank L. Carle collection. About 600 adults and 300 larvae were collected during this study. Identifications of larvae were confirmed by reared or associated adults.

DESCRIPTION OF STUDY AREA

The Savannah Plant (SRP) (Fig. 1) occupies about 778 km² on the upper Coastal Plain in Aiken, Barnwell, and Allendale counties, South Carolina, U.S.A. The SRP is bordered for 27 km on the southwest by the Savannah River and its extensive floodplain swamps. Two subregions of the Coastal Plain are represented on the SRP: the elevated Aiken Plateau (above 82 m) and the Pleistocene Coastal Terrace (below 82 m) (LANGLEY & MARTER, 1973). Average annual temperature is between 17-18° C and mean monthly rainfall is 12.5 cm.

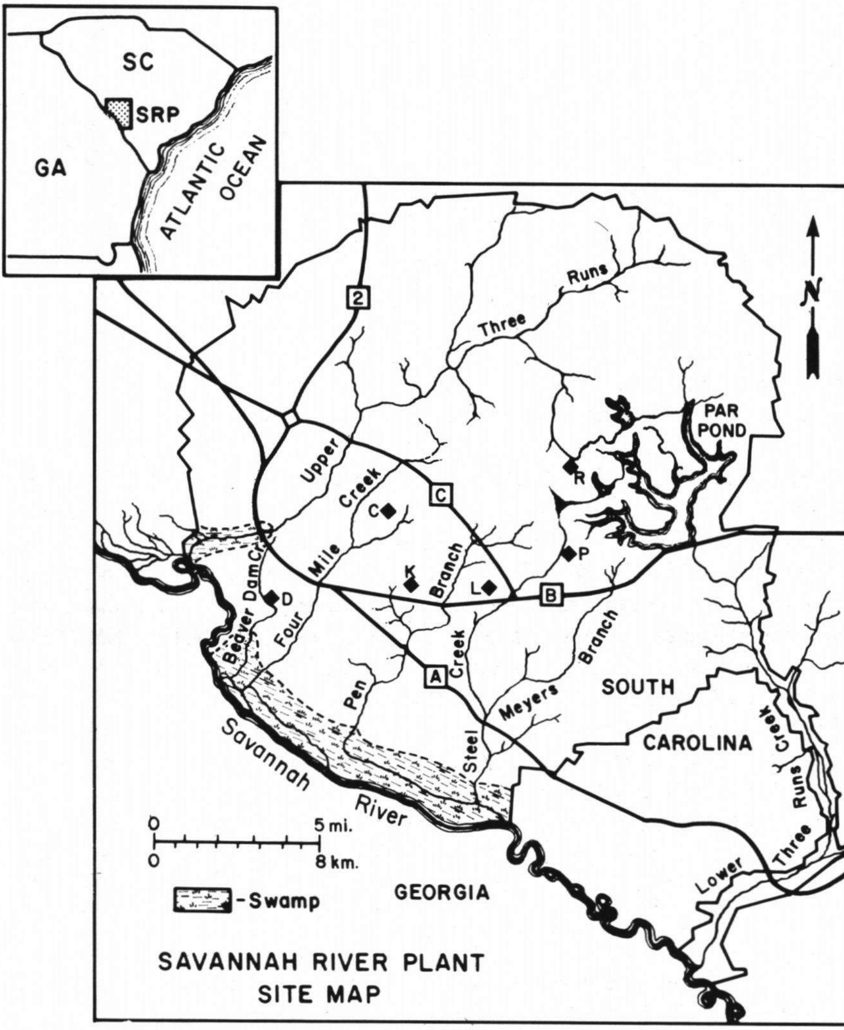

Fig. 1. Savannah River Plant, South Carolina, USA. Reactor areas are denoted by C, K, L, P and R.

Five main stream systems drain the SRP (Fig. 1). Upper Three Runs Creek (watershed $\geqslant$ 526 km^2) is a relatively unperturbed blackwater stream located in the northwestern portion of the SRP (for a more detailed description, see MORSE et al., 1980, 1983). The Beaver Dam Creek — Four-Mile Creek system (combined watershed ≥ 59 km²) receives thermal effluent from two different sources: Beaver Dam Creek from a coal-fired generator and Four-Mile Creek from a nuclear reactor. The Pen Branch system (watershed 91 km²) is also thermally perturbed, as it receives secondary cooling water from a nuclear reactor. The Steel Creek — Meyer's Branch system (combined watershed 91 km²) consists of a post-thermal stream (Steel Creek) and its tributary (Meyer's Branch), which has never received heated water. The southeasternmost stream on the SRP is Lower Three Runs Creek (watershed 490 km²), the upper reaches of which are impounded to form a 12 km² cooling water reservoir (Par Pond) for a nuclear reactor.

Four-Mile and Beaver Dam Creeks, Pen Branch, and Steel Creek flow into a contiguous 3020 ha river floodplain swamp (Savannah River Swamp Systems, SRSS) which drains into the Savannah River. The SRSS is separated from the main flow of the Savannah River by a natural levee along the river bank. Throughout most of the year, water levels are maintained in the swamp by flow from Beaver Dam, Four-Mile, Pen Branch, and Steel Creeks. Flow through the SRSS is generally shallow sheet flow with well-defined channels only where the streams enter the upper side of the swamp or exit through natural breaks in the levee. Usually during winter (January to April), the Savannah River floods (river discharge ≥ 440 m³/s) and overtops the levee, thus reversing flow in several of the creeks and substantially altering many physiochemical features of the SRSS.

RESULTS AND DISCUSSION

GENERAL CHANGES

The major aquatic perturbations which have occurred on the SRP since Cross' 1951-1954 survey of dragonflies, are the result of the discharge of thermal effluent from the reactors and a coal-fired generating plant into three of the five stream systems, and of the construction (1957-1961) of the 1206 ha Par Pond Reservoir system (Fig. 1). This has created a variety of thermally-affected aquatic regions on the SRP (LANGLEY & MARTER, 1973). The most dramatic effects due to thermal releases into the SRP streams was a total elimination of 7%, and slight to moderate reduction of an additional 55%, of the tree canopy of the SRSS (SHARITZ et al., 1974a). Water temperatures as high as 25° C above ambient often occur in portions of the SRSS (KONDRATIEFF & KONDRATIEFF, 1984, 1985). Two of the reactors were placed on standby in 1964 and 1968, respectively, and are presently not operating (1985). The termination of these reactors' operations has allowed subsequent biotic recovery in the lotic and lentic post-thermal habitats created in the former receiving stream systems, especially the Steel Creek system (SMITH et al., 1981; KONDRATIEFF & KONDRATIEFF, 1984, 1985).

The anisopteran species composition will be discussed in terms of the predominant habitats sampled. These habitats included: (1) unimpacted blackwater streams, (2) post-thermal streams, (3) thermal streams, (4) thermally altered delta-swamps, (5) post-thermal delta-swamp, (6) ponds and Carolina Bays, (7) Par Pond Reservoir system, and (8) the Savannah River (Tab. I).

CROSS (1955) collected a total of 58 anisopteran species (erroneously cited in

Table I

List of soecies collected bv habitat types, Savannah River Plant. South Carolina

	Primarily lotic				Primarily lentic			
Species	Unimpacted blackwater stream	Post-thermal stream	Thermal streams	Savannah River	Thermally altered delta-swamp	Post-thermal delta-swamp	Ponds and Carolina Bays	Par Pond System
Cordulegaster bilineata	+							
C. maculata	+							
Aphylla williamsoni					+	+		+
Dromogomphus armatus	+	+				+		
D. spinosus					+	+		+
Arigomphus pallidus					+	+		
Gomphurus dilatatus		+				+		
Gomphus diminutus	+							
G. exilis		+			+	+	+	+
G. lividus	+	+			+	+	+	+
Hylogomphus parvidens	+							
Stylurus ivae	+	+						
S. plagiatus	+			+	+			
Hagenius brevistylus	+	+		+	+	+		
Ophiogomphus incurvatus	+							
Progomphus obscurus	+	+						
Anax junius							+	+
A. longipes							+	+
Basiaeschna janata	+					+		
Boyeria vinosa	+	+		+		+		
Coryphaeschna ingens								+
Epiaeschna heros		+				+		+
Gomphaeschna furcillata						+		
Nasiaeschna pentacantha						+		
Didymops transversa	+	+						
Macromia georgina		+		+				
M. taeniolata		+			+	+		
Epicordulia regina		+		+	+	+		+
Helocordulia selysii	+							
Neurocordulia alabamensis	+	+				+		
N. molesta		+		+				
Somatochlora georgiana	+							
S. linearis	+							
Tetragoneuria cynosura					+	+	+	+
T. semiaquea							+	+
T. spinosa						+		
Brachymesia gravida								+
Celithemis amanda							+	+
C. elisa							+	+
C. eponina							+	+
C. fasciata							+	+
C. ornata							+	+
Erythemis simplicicollis	+	+	+	+	+	+	+	+
Erythrodiplax minuscula							+	
Ladona deplanata					+	+	+	+
Libellula auripennis							+	
L. axilena							+	+
L. flavida							+	+
L. incesta	+	+	+	+	+	+	+	+
L. luctuosa							+	+
L. needhami						+	+	+
L. semifasciata							+	+
L. vibrans				+	+	+	+	+
Pachydiplax longipennis		+	+		+	+	+	+
Pantala flavescens			+		+	+	+	+
P. hymenaea					+	+	+	+
Perithemis tenera					+	+	+	+
Plathemis lydia					+	+	+	+
Sympetrum ambiguum	+	+						
S. vicinum	+	+						
Tramea carolina					+	+	+	+
T. lacerata							+	

Cross as 48) from September 1951 to August 1954. In this study 63 species were collected, including 11 species not reported by Cross. Six species were reported by Cross which were not collected during this study (Table II). WHITE et al. (1980) listed 105 species of Anisoptera as occurring in South Carolina, therefore about 60% of these species may be collected on the SRP.

ANISOPTERA OF UNIMPACTED BLACKWATER STREAMS

Pristine blackwater streams with shifting sand substrate were once characteristic of the Coastal Plain of the southeastern United States. These streams often have high diversity of aquatic insects (MORSE et al., 1983; KONDRATIEFF & KONDRATIEFF, 1985). Unfortunately, many of these streams have been destroyed by industrial, domestic, or agricultural practices.

A group of apparently sensitive rheophilic anisopteran species occurred only in the unperturbed headwater reaches of Four-Mile Creek, Pen Branch, Lower Three Runs Creek, throughout the Upper Three Runs Creek drainage (including Mill Creek and Tinker Creek), and Meyers Branch of the SRP (Fig. 1). Upper Three Runs Creek has apparently changed little since CROSS' (1955) study. Meyers Branch, a tributary of Steel Creek, also supports a rich fauna similar to Upper Three Runs Creek (KONDRATIEFF & KONDRATIEFF, 1984, 1985). The species (Tab. II) found in these creeks included: *Helocordulia selysii, Neurocordulia alabamensis, Gomphus diminutus, Hylogomphus parvidens, Ophiogomphus incurvatus, Stylurus ivae, Cordulegaster maculata,* and *C. bilineata.* Of these species, Cross previously collected *Hylogomphus parvidens* (as *Gomphus parvidens*), *Stylurus ivae, Helocordulia selysii,* and *Neurocordulia alabamensis* (as *Neurocordulia* sp.). Many of these species are restricted to the southeastern United States (NEEDHAM & WESTFALL, 1955) and *G. diminutus* and *O. incurvatus* are considered at "risk in the U.S. and Canada" by BICK (1983).

Several more facultative and geographically widespread species such as *Boyeria vinosa, Basiaeschna janata, Progomphus obscurus,* and *Hagenius brevistylus* were also common in the unimpacted streams.

ANISOPTERA OF POST-THERMAL STREAMS

Thermal discharge was halted in early 1968 into Steel Creek and this stream has been in a state of recovery and succession for the last 16-17 years (SMITH et al., 1981; KONDRATIEFF & KONDRATIEFF, 1985). The stream is characterized by channels of shifting sand substrate with very few snags, log jams or instream hydrophytes, and an open canopy. In most reaches only *Boyeria vinosa* was found, often reaching densities of 5 larvae/m^2 of substrate. Other species such as *Dromogomphus armatus, Stylurus ivae, Macromia taeniolata,* and *Neurocordulia alabamensis* occurred in very low numbers, primarily in the lower

Table II

Comparison of Anisoptera collected by CROSS (1955) and this study from the Savannah River Plant, South Carolina

Species	CROSS (1955)	This study	Species	CROSS (1955)	This study
Tachopteryx thoreyi (Hagen)	+	+	*S. linearis* (Hagen)	+	+
Cordulegaster bilineata (Carle)[1]		+	*Tetragoneuria cynosura* (Say)	+	+
C. maculata Selys		+	*T. semiaquea* Burmeister	+	+
Aphylla williamsoni (Gloyd)		+	*T. spinosa* (Hagen)	+	+
Dromogomphus armatus Selys[2]	+	+	*T. williamsoni* Muttkowski[5]	+	
D. spinosus Selys	+	+	*Brachymesia gravida* (Calvert)		+
Erpetogomphus designatus Hagen	+		*Celithemis amanda* (Hagen)	+	+
Arigomphus pallidus (Rambur)		+	*C. elisa* (Hagen)	+	+
Gomphurus dilatatus (Rambur)		+	*C. eponina* (Drury)	+	+
Gomphus diminutus Needham		+	*C. fasciata* Kirby	+	+
G. exilis Selys	+	+	*C. ornata* Rambur	+	+
G. lividus Selys	+	+	*C. verna* Pritchard	+	
Hagenius brevistylus Selys	+	+	*Erythemis simplicicollis* (Say)	+	+
Hylogomphus parvidens (Currie)	+	+	*Erythrodiplax minuscula* (Rambur)	+	+
Ophiogomphus incurvatus Carle		+	*Ladona deplanata* (Rambur)	+	+
Progomphus obscurus (Rambur)	+	+	*Libellula auripennis* Burmeister	+	+
Stylurus ivae (Williamson)	+	+	*L. axilena* Westwood	+	+
S. laurae (Williamson)	+		*L. flavida* Rambur	+	+
S. plagiatus Selys	+	+	*L. incesta* Hagen	+	+
Anax junius (Drury)	+	+	*L. luctuosa* Burmeister	+	+
A. longipes Hagen	+	+	*L. needhami* Westfall		+
Basiaeschna janata (Say)	+	+	*L. pulchella* Drury	+	
Boyeria vinosa (Say)	+	+	*L. semifasciata* Burmeister	+	+
Coryphaeschna ingens (Rambur)		+	*L. vibrans* F.	+	+
Epiaeschna heros (F.)	+	+	*Nannothemis bella* (Uhler)	+	
Gomphaeschna furcillata (Say)[3]	+	+	*Pachydiplax longipennis* (Burmeister)	+	+
Nasiaeschna pentacantha (Rambur)	+	+	*Pantala flavescens* (F.)	+	+
Didymops transversa (Say)		+	*P. hymenaea* (Say)	+	+
Macromia georgina (Selys)	+	+	*Perithemis tenera* (Say)	+	+
M. taeniolata Rambur	+	+	*Plathemis lydia* (Drury)	+	+
Epicordulia regina (Hagen)	+	+	*Sympetrum ambiguum* (Rambur)	+	+
Helocordulia selysii (Hagen)	+	+	*S. vicinum* (Hagen)	+	+
Neurocordulia alabamensis (Hodges)[4]	+	+	*Tramea carolina* (L.)	+	+
N. molesta (Walsh)	+	+	*T. lacerata* Hagen	+	+
Somatochlora georgiana Walker	+	+	Total number of species	58	63

[1] This species was previously confused with *C. diastatops* (Selys) (CARLE, 1983). Cross (as *C. diastatops*) reported it as occurring near the SRP in Georgia.
[2] WESTFALL & TENNESSEN (1979) corrected Cross' misidentification (as *D. spoliatus* (Hagen)).
[3] Actually *G. furcillata*; Cross listed his specimens as *G. antilope* (Hagen).
[4] Cross listed his specimens as *Neurocordulia* sp., *N. alabamensis* was described in NEEDHAM & WESTFALL (1955).
[5] Considered by some authorities as a synonym of *T. costalis* (Selys) (CARLE, 1982; HUGGINS & BRIGHAM, 1982).

reaches near the deltaic fan zone of Steel Creek delta-swamp. *Gomphus diminutus, Hylogomphus parvidens, Ophiogomphus incurvatus,* and *Helocordulia selysii,* which occurred in the unimpacted streams were not collected from Steel Creek and apparently have not been able to recolonize this stream.

Lower Three Runs, below Par Pond (Fig. 1) has much more woody substrate, instream hydrophytes (i.e. *Sparganium americanum*), and canopy cover. *Gomphurus dilatatus, Hagenius brevistylus, Stylurus ivae,* and *Macromia georgina* were common.

The surrounding swamps and backwater areas of both Steel Creek and Lower Three Runs were abundantly inhabited by *Gomphus exilis, G. lividus, Erythemis simplicicollis, Libellula incesta, L. vibrans, Pachydiplax longipennis,* and *Sympetrum ambiguum.*

ANISOPTERA OF THERMAL STREAMS

Reactor effluent water is currently released into two of the SRP stream systems (Four-Mile Creek and Pen Branch) (Fig. 1). Water temperatures often exceed 70° C near point of discharge and remain as high as 45-50° C before entering the SRSS. Additionally, the increased discharge causes scouring of the substrate (with few instream retention devices remaining) and changes the exposure of stream bottom and surrounding wetlands. No Odonata are found in the instream regions during reactor operations. The larvae of a few euthermal species (GARTEN & GENTRY, 1976; GENTRY et al., 1975) such as *Erythemis simplicicollis*, *Libellula incesta*, and *Pachydiplax longipennis* are able to survive in cooler backwater areas and surrounding wetlands.

The periodic shutdown for maintenance of the reactors which discharge into Four-Mile Creek and Pen Branch results in various periods of releases of ambient water and reduced flows. This cycling occurs 10 to 12 times per year in Pen Branch and about four times per year in four-Mile Creek. Larvae are able to survive these severe temperature extremes and unpredictable fluctuating water levels by burying themselves in mud (MARTIN & GENTRY, 1974). Anisopteran species also rapidly colonized the pools of Four-Mile Creek and Pen Branch during longer periods of ambient water temperatures, especially during the warmer months. Colonization occurs by oviposition or by larvae moving in from nearby refugia. These species include the limnophilic species *Erythemis simplicicollis*, *Libellula incesta*, and especially *Pantala flavescens*. These species apparently can complete their life cycle in three to four weeks (personal observation).

ANISOPTERA OF THERMALLY ALTERED DELTA-SWAMPS

Four-Mile Creek and Pen Branch receive about 11.4 m^3/s of thermal effluent continuously during reactor operations. As streams enter the SRSS, they form deltas where almost all of the canopy vegetation has been killed and the herbaceous flora significantly altered (SHARITZ et al., 1974a) (Fig. 1). Thick mats of euthermal blue-green algae (including *Oscillatoria* and *Phormidium*) cover the bottom of shallow areas (2-35 cm). In the braided stream channels of the deltaic fans, where water temperatures can often exceed 25° C above ambient (i.e. January, 30-35° C average; July, 40-45° C average), surprisingly several species of Anisoptera inhabited these zones. These were *Libellula incesta*, *Erythemis simplicicollis*, and *Pachydiplax longipennis*.

At the peripheral zones along the forested uplands and scrub-shrub and backwater wetlands areas where water temperatures are on the average, 15-20° C cooler, *Agrigomphus pallidus*, *Gomphus exilis*, *G. lividus*, *Epicordulia regina*, *Ladona deplanata*, and *Tetragoneuria cynosura* were abundant.

Pen Branch flows through a 9.5 km closed canopy zone in the SRSS to join Steel Creek (Fig. 1). Much of this area is only 1-5° C above ambient, and supports an anisopteran fauna similar to the Steel Creek delta-swamp.

The mildly elevated temperatures of Beaver Dam delta-swamp (temperatures are approximately 20-25° C year round) did not preclude as many species as did the severely thermal Four-Mile and Pen Branch delta-swamps. Other perturbations to Beaver Dam Creek, such as pH shifts and high levels of coal ash effluent from the power plant, have however, affected the number of species present. In the channel zones, larvae of *Macromia taeniolata* and *Epicordulia regina* may be found on the submerged wood or among hydrophytes (*Alternanthera philoxeroides, Polygonum* spp. and *Myriophyllum brasiliense*). In the depositional areas, larvae of *Aphylla williamsoni, Dromogomphus spinosus, Stylurus plagiatus,* and *Nasiaeschna pentacantha* were present. None of the above species were abundant in terms of number of specimens collected.

ANISOPTERA OF POST-THERMAL DELTA-SWAMPS

The release of thermal effluent into Steel Creek was terminated in early 1968. A large sedimentary delta and treekill zone was formed at the mouth of Steel Creek in the SRSS (Fig. 1). This area of considerable variation in water regimes vegetated rapidly into a scrub-shrub wetland over the years [*Salix nigra*-*-Cephalanthus occidentalis* dominated community] (SHARITZ et al., 1974b), but the re-establishment of the original swamp forest vegetation (primarily *Taxodium distichum* and *Nyssa aquatica*) has not occurred (SHERROD et al., 1980).

The canopy-reduced deepwater areas (0.5-2.0 m) where the main flow of Steel Creek courses among scattered live bald cypress (Fig. 1) has become highly productive in terms of aquatic vegetation and aquatic macroinvertebrates (SMITH et al., 1981; KONDRATIEFF & KONDRATIEFF, 1984, 1985; THORP et al., 1985). This zone is characterized by extensive colonies of submerged and emergent hydrophytes *Ceratophyllum demersum, Hydrocotyle ranunculoides, Leersia* spp., *Myriophyllum brasiliense, Polygonum* spp., *Sagittaria* spp., and *Sparganium americanum*). The Steel Creek delta-swamp supports the richest Odonata fauna presently found on the SRP. Forty-one species of dragonflies and damselflies were collected (KONDRATIEFF & KONDRATIEFF, 1985). This diversity is the result of the combination of lentic-lotic depositional zones, lentic-lotic vascular hydrophyte zones, and varied lentic-lotic littoral zones. The deep channels meandering throughout the swamp with year-round flows of ambient water also support many rheophilic species (i.e., *Boyeria vinosa, Neurocordulia* spp., and *Stylurus ivae*).

Many species of Anisoptera were exceptionally abundant: *Epiaeschna heros, Gomphus exilis, G. lividus, Gomphurus dilatatus, Dromogomphus armatus,* *Hagenius brevistylus, Macromia taeniolata, Epicordulia regina, Tetragoneura cynosura, Perithemis tenera, Ladona deplanata, Libellula incesta,* and *Erythemis simplicicollis.* Several uncommon species such as *Nasiaeschna pentacantha, Aphylla williamsoni,* and *Tetragoneuria spinosa* were also frequently collected.

The more limnophilic libellulid species, *Ladona deplanata, Libellula incesta,* and *Erythemis simplicicollis,* were very abundant in the lentic habitats of the shallower deltaic fan zones of the Steel Creek delta-swamp. Most of the gomphines, such as *Gomphurus dilatatus, Dromogomphus armatus,* and *Hagenius brevistylus* were generally restricted to the canopy-reduced-deepwater channel zones where numerous standing dead or live trees occurred. Larval exuviae of these species were commonly found on trees and stumps from late spring to early summer.

ANISOPTERA OF PONDS AND CAROLINA BAYS

The species composition of dragonflies occurring in the abandoned farm ponds (2.5 to 7.5 ha in size) and Carolina Bays probably have not changed since CROSS' (1955) study. Several of the ponds and perhaps some of the Carolina Bays have undergone some ecological succession, with some of the previous open water areas becoming marsh or smaller wet weather pools. The unique Carolina Bays, with their highly fluctuating water levels, are discussed by DUKES (1984). These ponds and Bays support a typical southeastern limnophilic libellulid-corduliid fauna, including *Celithemis elisa, C. fasciata, C. ornata, Erythrodiplax minuscula, Erythemis simplicicollis, Ladona deplanata, Libellula axilena, L. incesta, L. vibrans, Pachydiplax longipennis, Perithemis tenera, Plathemis lydia, Tramea carolina, Tetragoneuria cynosura,* and *T. semiaquea.* The widespread aeshnid, *Anax junius,* was also common in certain ponds. This species flew throughout the year and, as CROSS (1955) postulated, it may in fact overwinter as an adult in this area of South Carolina. These ponds and Bays often become nearly dry during the summer. After wet weather, several anisopteran species rapidly recolonized these habitats. These species were *Erythemis simplicicollis, Libellula incesta,* and *Pantala flavescens.*

ANISOPTERA OF PAR POND SYSTEM

The Par Pond reservoir system (including Pond B and Pond C) includes about 1206 ha (Fig. 1). The various reservoirs were impounded between 1957 and 1961, and are part of a closed-loop cooling system for one of the operating nuclear reactors. A detailed discussion of the Par Pond system can be found in WILDE & TILLY (1985). The temperature of the reactor effluent entering Par Pond is coincident with reactor operation and ranges from ambient to above 40 °C. However, there is apparently no significant thermal impact on the overall macroinvertebrate community of Par Pond (KONDRATIEFF et al., 1985). The reservoir system has a typical complement of aquatic species, including Odonata, found in other southeastern U.S. cooling reservoirs (KONDRATIEFF et al., 1985). The dominant Anisoptera in the Par Pond system were common ubiquitous limnophilic species: *Celithemis fasciata, Erythemis simplicicollis, Ladona deplanata, Libellula incesta, Pachydiplax longipennis, Perithemis tenera,* and *Tetragoneuria cynosura.* Several uncommonly collected species such as *Aphylla williamsoni, Anax longipes, Coryphaeschna ingens,* and *Brachymesia gravida* also occurred in Par Pond and Pond B. *A. williamsoni, C. ingens,* and *B. gravida* were not reported by CROSS (1955).

COTHRAN & THORP (1982) studied the patterns of emergence of several of the above libellulid and corduliid species along a thermal gradient in Par Pond. They detected some variation in emergence and distribution of these species.

THE ANISOPTERA OF THE SAVANNAH RIVER

The Savannah River and its flora and fauna in the vicinity of the SRP has been well documented by PATRICK et al. (1966). They listed at least fifteen species of Anisoptera from the River. Some of these, however, are not typical riverine species. CROSS (1955) did not emphasize the river in his study and actually recorded only *Erpetogomphus designatus.* The following species were collected as larvae with associated adults during this survey: *Boyeria vinosa, Hagenius brevistylus, Stylurus plagiatus, Macromia georgina, Neurocordulia molesta,* and *Epicordulia regina. Erpetogomphus designatus* and *Gomphurus vastus* (which was collected nearby by Cross were both listed by PATRICK et al. (1966), but were not collected during this study. Apparently these two species have not been reported from this area since the early 1950's (WHITE et al., 1980) and may no longer occur in this stretch of the River. The regulation of river levels (often 3-5 m change/week) by the large upstream reservoirs (Clarkshill, Hartwell, and Russell) and past dredging may have eliminated habitats for these species.

The Savannah River floods the SRSS and other areas of the contiguous riverine flood plain primarily from January to April. High water levels may remain as late as June, and flood events occur unpredictably during other times of the year. For example the SRSS was inundated during late July and August 1984. The extents of water levels are determined by the upstream dams. Therefore, many delta-swamp species such as *Erythemis simplicicollis, Libellula incesta,* and *L. vibrans* become abundant along the river throughout the summer. Larvae of these species usually do not occur in the river except in some of the shallow oxbow lakes and backwater areas.

CONCLUSIONS

Overall, there was no significant difference between the total number of anisopteran species collected by Cross (58) and during this study (63), despite the dramatic changes of the aquatic habitats of the SRP. This was not surprising when considering the following: (1) the majority (75%) of the species collected during both studies were common ubiquitous limnophilic forms (Tab. II); (2) many of these species are ideally adapted for the fluctuating and unpredictable temperature and water level regimes occurring in the lentic habitats of the SRP; and, (3) the invasion and colonization of constantly newly-created habitats are enhanced by the long flight periods of many species (see CROSS 1955), and by the asynchronous multivoltinism of some species.

The quantity of lentic habitat on the SRP was substantially increased by the construction of Par Pond and the discharge of thermal effluent via three stream systems into the SRSS. The latter increased water levels of the streams and their surrounding wetlands and receiving deltas. Ubiquitous limnophilic species, especially *Gomphus exilis, Libellula incesta, Erythemis simplicicollis,* and *Pachydiplax longipennis* became the dominant Anisoptera of all sampled lentic habitats of the SRP (Tab. I). These species were already abundant during Cross' survey, and are able to tolerate remarkable changes in water temperatures and water levels because of physiological and behavioral adaptations (MARTIN & GENTRY, 1974). GARTEN & GENTRY (1976) suggested that some of these species are preadapted to these conditions because of their long evolutionary history in shallow ponds, which are naturally subject to extremes in temperature and water levels.

All obligate rheophilic species were eliminated by the thermal discharges into the streams. Even after 16-17 years of recovery of the post-thermal stream, species having low vagility or narrow environmental tolerances (WRIGHT, 1943) were not collected and apparently have not recolonized. These species include *Gomphus diminutus, Hylogomphus parvidens, Ophiogomphus incurvatus,* and *Helocordulia selysii.*

The majority of the 11 species collected during this study and not reported by Cross were rheophilic forms (Tabs I, II). One of the most conspicuous species not collected by Cross was the large southeastern Coastal Plain gomphine, *Gomphurus dilatatus.* This species was exceptionally abundant (scores of adults flying from April to August) in the post-thermal Steel Creek delta-swamp of the SRSS. This species, which apparently prefers pools or backwater areas of rivers (CARLE, 1982) may have occurred in portions of the Savannah River or in open channels of the SRSS during Cross' time.

Of the 6 species reported by Cross and not collected during this survey, the only one surprisingly absent was the gomphid, *Stylurus laurae.* This species has been previously collected from both the Upper Three Runs and Lower Three Runs drainages.

Two species, *Anax junius* and *Erythemis simplicicollis*, could be collected as adults throughout the year. *Anax junius* presumably could overwinter as adults (CROSS, 1955). The warmer winter temperatures of thermal delta--swamps allowed *E. simplicicollis* to have continuous generations with sporadic emergences. Only during the longer (20-30 days) reactor shut-down periods in winter (water temperature < 10° C) could teneral adults and exuviae of this species not be collected.

POSTSCRIPT

A nuclear reactor using Steel Creek was re-started in late 1985. In order to ameliorate the effects of discharging reactor effluent (> 70° C) into Steel Creek, the stream was impounded to form a 405 ha, once-through cooling lake in the fall of 1985. It is anticipated that 50 percent of the lake surface area will reach 32° C during portions of the summer. Reactor shutdown periods are planned during mid-summer to meet a mid-lake temperature limit of 32° C. Projected water temperatures at the Steel Creek delta-swamp is expected to be (within 1-10° C) above ambient (GLADDEN et al., 1985).

Several brief generalizations can be made concerning the effects on the Anisoptera. The more obligate rheophilic species present in Steel Creek such as *Boyeria vinosa, Progomphus obscurus,* and *Neurocordulia* spp. will be eliminated by the impoundment, and limnophilic species (libellulids and corduliids) will colonize the environmentally suitable areas of the lake (*Libellula incesta, Erythemis simplicicollis, Tetragoneuria cynosura* and *Gomphus exilis*). It is anticipated that several species, especially the presently common gomphids (*Dromogomphus armatus* and *Gomphurus dilatatus*) and *Macromia taeniolata, Epicordulia regina,* and *Tetragoneuria spinosa* may be eliminated in many areas of the Steel Creek delta-swamp. In summary, euthermal limnophilic species such as *Libellula incesta* and *Erythemis simplicicollis* will probably become even more abundant throughout the delta-swamp.

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