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Abundance, Diversity and Seasonality of Adult Trichoptera in and Around Hydroelectric Generating Stations Along the Winnipeg River

BY

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ABSTRACT

Hydroelectric generating stations along the Winnipeg River are subject to emergence of large numbers of caddisflies which cause work-related allergies. The purpose of this study was to determine peaks in seasonal and nightly flight activity of the most abundant caddisfly species in and around the generating stations and to recommend management practices to alleviate the problems caused by caddisflies. Modified New Jersey light traps were used to capture caddisflies during the 1997 and 1998 field seasons at hydroelectric generating stations at Great Falls and Seven Sisters. The estimated total number of caddisflies caught over the two-year period was 526,607; 275,806 in 1997 and 250,801 in 1998. The caddisflies belonged to 14 families, 35 genera and at least 76 taxa. The caddisfly flight season, from first capture to last, differed by only one week in the two years. In 1997, caddisflies were collected from 1 June to 16 October, and in 1998 from 26 May to 8 October. Peak flight activity occurred one week earlier at Great Falls than at Seven Sisters. In 1997, approximately 75% of caddisflies were captured during the five-week period from the last week of June to the end of July. The peak flight activity in 1998 occurred from mid-June to mid-July (four weeks), when approximately 80% of the yearly total of caddisflies were captured. Peaks in nightly flight activity were seen between 2300 and 0100, when approximately 62% of the nightly total were captured.

Large numbers of caddisflies were captured inside the generating stations. To determine the caddisfly mode of entry, four nights were spent in the stations. Through personal observations and the use of emergence traps, it was established that caddisflies enter the buildings through various openings (i.e., broken windows, under doors) and by emergence from the gate openings inside the gate rooms. Insect particulates, including identifiable caddisfly parts, which were blown into the generating stations through the air-cooling system, were also collected in fine nylon filters attached to the turbine caps in the powerhouses.

Changes in management practices are required to decrease the exposure of Manitoba Hydro employees to caddisfly particulate. These must include maintaining and improving sanitation practices and increased vigilance to remove or exclude caddisflies from the generating stations.

CHAPTER I

GENERAL INTRODUCTION

The Winnipeg River system runs north and west from near Lake Superior to Lake Winnipeg over 765 km (Manitoba Hydro 2001). The drainage basin of the river is made up of 150,000 km^2, covering northwestern Ontario, northern Minnesota and eastern Manitoba (Manitoba Hydro 2001). The Winnipeg River itself is 260 km long and is within 100 km of the City of Winnipeg in eastern Manitoba.

The Winnipeg River is an ideal place for hydroelectric power generation due to its fast flowing nature and the geology of the region. The long-term average flow of the Winnipeg River is 850 cubic metres per second (m^3/s) (Manitoba Hydro 2001). Key geographic features of the river are that bedrock is present close to the surface and that a series of deep basins are present, which form natural reservoirs. Six hydroelectric generating stations are located on the Winnipeg River, having the capacity to produce 560 megawatts (MW) of energy (Manitoba Hydro 2001). The two stations of interest in this study are at Great Falls and Seven Sisters.

The Great Falls Hydroelectric Generation Station is located approximately 130 km northeast of the City of Winnipeg. It is the oldest dam on the Winnipeg River, with its construction completed in 1928. The generating station at Great Falls has the capacity to produce 132 MW with an average annual production of 750 million kW·h. The dam measures 516 m across the river with a reservoir, or forebay, of 10 km^2. Great Falls has a total spilling capacity of 4,390 m^3/s (Manitoba Hydro 2001).

The Seven Sisters Hydroelectric Generating Station is located 90 km northeast of City of Winnipeg. Construction was completed 1952. Seven Sisters is the largest electricity producer on the Winnipeg River, with a capacity of 150 MW and an average annual production of 990 million kW·h (Manitoba Hydro 2001). The forebay created Lake Natalie, which is 24 km long and 0.8 km to 2.4 km wide, with a discharge capacity of 1,030 m^3/s (Manitoba Hydro 2001).

The same geological features that make the Winnipeg River suitable for hydroelectric power generation also create ideal conditions for the production of aquatic invertebrates, including caddisflies. Trichoptera, or caddisflies, are small to moderately sized, moth-like insects, which are usually dull in appearance and covered with fine hairs or setae. Trichoptera is one of the largest aquatic insect orders with 9,000 to 10,000 species worldwide, occurring in both freshwater and saline environments (Wiggins 1996a). Female Trichoptera lay 300 to 1000 eggs in or near the water. The eggs hatch into larvae that develop within the water. The pupa cuts its way out of the cocoon, swims to the surface, crawls out and attaches to dry substrate. The adult emerges, mates and the life cycle begins again (Ross 1944).

Trichoptera fall into three suborders, the larvae of which represent varying lifestyles and feeding techniques (Wiggins 1996a). The suborder Spicipalpia is made up of families whose larvae make closed cocoons. Annulipalpia larvae are fixed-retreat makers that use silk nets to capture food from the flowing water, and the Integripalpia is made up of portable-case makers (Wiggins 1996a).

Under ideal conditions, caddisflies may emerge in large numbers, causing both nuisance and occupational health problems. During a series of studies performed on St. Helen's Island, Montréal, Corbet *et al.* (1966) caught millions of Trichoptera emerging from the St. Lawrence River. For example, in 1964, 3,307,668 and in 1965, 2,660,390 caddisflies were collected. The mass emergence and accumulation of caddisflies around Manitoba Hydro dams are caused by several factors: the fast flowing water provides a nutritional source and ideal hydrological conditions, the physical structures of the dams provide a stable larval habitat, and lights located around the stations attract adults (Kraut *et al.* 1994). During the summer, a student was hired at the Seven Sisters generating station whose primary function is to clean up dead caddisflies. Enormous numbers of Trichoptera litter all areas of the stations throughout the summer season.

The first reported case of an allergy to caddisflies was described by Parlato (1929) on the shores of Lake Erie. Several people in that area developed extreme respiratory allergies each year around the time when mass emergence of Trichoptera occurred from the nearby lake. To date, the specific caddisfly allergen has not been identified.

I became involved in this project in 1997 to look at the caddisfly problem facing Manitoba Hydro. The hydroelectric generating stations along the Winnipeg River are subjected to nuisance and maintenance problems associated with large numbers of adult Trichoptera entering the facilities. Another problem has been that some employees have developed allergies to caddisflies. These problems were first addressed by Kraut *et al.* (1994) at Pointe du Bois, a Winnipeg Hydro facility also on the Winnipeg River. Insect debris is easily made air-borne when the desiccated bodies are disturbed; Kraut *et al.* (1994) believed this could lead to allergy problems. Kraut (1996) demonstrated that employees of the generating stations on the Winnipeg River had developed allergies to caddisflies, with employees working on the floor having a higher incidence than office staff. Hébert & Côté (1994) described similar results in Quebec at the Shipshaw hydroelectric generating station. In both of these studies, employees developed hypersensitivity after repeated exposure to large numbers of caddisflies over a prolonged period of time. Atopic individuals exhibit watery eyes, runny nose, sinus congestion, cough, wheeze and shortness of breath (Kraut *et al.* 1994). Atopic individuals are people who suffer from the type of allergic mechanism that appears to be hereditary in nature and is characterized by immediate wheal reaction to skin tests with the allergen (Sherman 1968). At least two Manitoba Hydro employees were relocated because of the adverse effects caddisfly allergies had on their ability to perform their regular duties (Kraut 1996).

The objectives of this research involve collection of basic biological information and practical application of this information to help solve the problems facing Manitoba Hydro and its employees. The objectives of this study are:

i.) to establish seasonal and nightly peaks in Trichoptera flight activity to determine the times of greatest accumulation of debris,

ii.) to determine the species of adult caddisflies attracted to and entering the generating stations,

iii.) to determine the mode of entry of adult caddisflies and caddisfly particulates into the generating stations, and

iv.) to prepare recommendations to minimize the impact of caddisflies on Manitoba Hydro employees.

CHAPTER II

REVIEW OF PERTINENT LITERATURE

Introduction

The importance of insects in terrestrial and aquatic food chains is well established (Borror *et al.* 1989). In aquatic habitats, insects are known to play an important role in energy transfer and are significant in the nutrition of fish, waterfowl and other aquatic vertebrates (Wiggins 1979). However, the nuisance, economic and allergy problems associated with masses of emerging aquatic insects have not been subject to as thorough an examination.

To understand fully the reasons for mass emergences that lead to nuisance and allergy problems, the life history of three of the most diverse groups of aquatic insects, Chironomidae (midges), Ephemeroptera (mayflies) and Trichoptera (caddisflies) will be discussed. Each of these groups has representatives that have been implicated as causative agents in nuisance and allergy problems. Adults insects in these groups may emerge synchronously and subsequently form dense mating swarms.

There are several hypotheses to explain the biological or evolutionary reasons that would promote synchronous emergence of aquatic insects. There are three main hypotheses that attempt to explain the mass emergence and swarming demonstrated by chironomids, mayflies and caddisflies: 1) to increase chances of finding a mate (Corbet 1964); 2) to increase chances of avoiding predation (Sweeney & Vannote 1982); 3) to avoid interspecific competition (Resh & Solem 1978).

Synchronous emergences of adult aquatic insects cause a number of nuisance, economic and allergy problems around the world. Nuisance and economic problems associated with the flight activity of the short-lived adults are felt primarily among people who live or work near lakes and rivers. It has been recognized for most of the 20th century that insects and other arthropods can be responsible for respiratory allergic reactions (Mathews 1989). Inhalant insect allergies have been documented in association with occupational and recreational exposures. Caddisflies, mayflies and midges have all been implicated as causative agents in insect allergies (Bellas 1990).

The objectives of this chapter are: to examine the life history of mass emerging, non-biting aquatic insects, which are responsible for nuisance, economic and allergy problems, to explore some of the possible reasons for mass emergence, to look at the nuisance problems and the economic issues related to them, and to introduce and define the immunological problems caused by mass-emerging insects.

Life History

Most groups of aquatic insects spend only a portion of their life cycle in the water. The juvenile stages are spent in the water and adults are aerial, which is conducive to mating and dispersal (Williams 1979).

Diapause is an important characteristic among mass-emerging aquatic insects. This allows cohorts to catch up to one another developmentally and to synchronize adult emergence after "dissimilar periods of larval development" (Wiggins 1996b). Diapause suspends development until conditions become favourable and may occur in all stages of development, depending on the species (Wiggins 1996a).

i. Chironomidae

The Chironomidae, commonly known as midges, are represented in Canada by 480 species distributed transcontinentally, including Arctic areas (McAlpine *et al.*, 1979). Worldwide there are approximately 20,000 species of chironomids, with more than 2000 species in the Nearctic Region (Coffman & Ferrington 1996). Midge larvae are able to survive a wider range of environmental conditions than any other group of aquatic insects. Different species within the Chironomidae are able to thrive in a complete range of gradients of "temperature, pH, salinity, oxygen concentration, current velocity, depth, productivity, altitude and latitude" (Coffman & Ferrington 1996:635). Larval chironomids are found in moist to wet habitats under a wide range of environmental conditions. Some species are capable of surviving in the oxygen-poor sediments at the bottom of lakes, riffles of large rivers, reservoirs and even saline water bodies (Foote 1991). Midge larvae feed on a great diversity of organic materials, but most are detritivores (Foote 1991). Chironomids exhibit an extremely high diversity, with the number of species in most aquatic ecosystems representing at least 50% of total macroinvertebrate species diversity (Coffman & Ferrington 1996).

Midges are holometabolous, with four distinct life stages: egg, larva, pupa and adult. There are four larval instars which last from two weeks to several years, depending on the species and the environmental conditions (Coffman & Ferrington 1996). In northern latitudes, chironomids are usually either univoltine or bivoltine (McAlpine *et al.* 1979).

Adult midges are small, delicate flies that are commonly found swarming at dusk near bodies of water. The swarms are made up almost exclusively of males. Females enter the swarm to initiate mating (Foote 1991). Mating swarms can take place aerially, on the water surface or on the ground (Coffman & Ferrington 1996). Completion of mating is conducted on the ground. Adult midges generally do not feed, although some species may feed on nectar (Foote 1991). In most species, female chironomids oviposit in gelatinous masses on vegetation near water or on the water surface itself (Coffman & Ferrington 1996).

Midges play an important role in aquatic and terrestrial habitats. Larval chironomids are important in the decomposition and recycling of nutrients and also provide a food source for other invertebrates and fish. Adult midges are included in the diets of spiders, birds and other invertebrates (McAlpine *et al.* 1979). Chironomids can be used as indicators of water quality. The species diversity present in polluted aquatic habitats can even indicate the type of pollution that is present (Ali 1980a).

ii. Ephemeroptera

The Ephemeroptera, or mayflies, are represented in Canada by 300 species in 15 families (Lehmkuhl 1979). Mayfly larvae are found in a wide variety of freshwater habitats. Most species are collectors or scrapers, feeding on detritus and algae (Edmunds & Waltz 1996). Some species of mayfly larvae can be used as indicators of water quality. Burrowing mayfly larvae in the genus *Hexagenia* have several characteristics that make them suitable indicators: they possess a relatively long life cycle, they are unable to swim long distances to escape toxic conditions, and their distribution may be reflective of the effect of combinations of pollutants (Anonymous 1970).

Mayflies have a unique hemimetabolous life cycle containing two winged forms. In most species, oviposition occurs at the water surface with the eggs laid singly or in one to two clusters. Eggs are often covered with an adhesive substance and have species-specific anchoring devices (Edmunds & Waltz 1996). In temperate regions, egg diapause is common. Egg development can begin directly or take up to a year, depending on the species (Edmunds & Waltz 1996). Mayfly larvae go through several moults. Larvae can be a substantial source of food for fish, with populations reaching levels up to 1,000/m^2 (Lehmkuhl 1979). From the mature larva, the subimago emerges. The subimago is the fully winged, sexually immature stage that lasts from a few minutes to a week, depending on the species. Adults, the sexually mature imago stage, are delicate insects that do not feed, and survive from a few hours to a few days (Lehmkuhl 1979). Mating swarms occur where females enter swarms of 'dancing' males to choose their mate (Anonymous 1970).

iii. Trichoptera

Trichoptera are represented in Canada by 22 families containing 546 species (Schmid 1998). Trichoptera is one of the most diverse aquatic insect orders with over 11,000 species occurring in 45 families worldwide (Wiggins 1998, Morse 2003). Caddisflies are found in a broad range of aquatic habitats where they "contribute to the transfer of energy and nutrients through the trophic levels of all freshwater systems" (Wiggins 1996b:3). Trichoptera larvae can also be used as indicators of perturbation; caddisfly species identification is a valuable aid in monitoring the health of freshwater systems (Resh & Unzicker 1975).

In temperate latitudes, the generalized trichopteran life cycle consists of egg, five larval instars, pupa, and adult phases, with one generation per year (Wiggins 1996b). Adult female Trichoptera lay 300 to 1000 eggs in or near the water. Females lay their eggs under water, in strings forming irregular masses that are surrounded by a thin matrix. The females of some families lay their eggs in gelatinous masses on vegetation overhanging the body of water. These egg masses are liquified by rain, allowing newly hatched larvae to fall to the water surface (Ross 1944). The eggs hatch into larvae that, depending on the family, may be free-living (cocoon-makers), fixed-retreat makers, or portable-case makers (Wiggins 1998). In most species, the larval stage can last for up to one year. The pupa cuts itself out of the cocoon, swims to the surface, crawls out and attaches to a dry object, where the adult emerges (Ross 1944). Adult caddisflies are generally short-lived, seldom surviving for more than one month. However, some species enter a reproductive diapause and may survive for several months (Wiggins 1996a).

Adult caddisflies of some species form dense mating swarms. *Hydropsyche orris* Ross swarms appear as “dense plumes of black smoke which undulate slowly in the breeze” (Fremling 1960:860). Males within the mating swarm move rapidly in an up and down, zig-zag pattern, with the females flying in straight lines (Fremling 1960). Once initiated in the air, mating occurs on land (Fremling 1960).

Synchronous Emergence

Corbet (1964) proposed that adult synchronization in short-lived, spatially dispersed insects is a valuable evolutionary adaptation because it increases the frequency of intraspecific encounters, thereby increasing the probability of finding a mate in groups such as caddisflies, mayflies and midges. The importance of intraspecific synchrony was supported by Resh and Solem (1978:41) who stated that “...the simultaneous emergence and swarming of males and females helps to insure the continuity of the population through the next generation." However, Sweeney & Vannote (1982) argued that Corbet's hypothesis was difficult to test because spatial dispersion is hard to ascertain. It was also observed that no decrease in mating success has been documented for early or late-emerging aquatic adults (Sweeney & Vannote 1982).

Sweeney & Vannote (1982) hypothesized that the predator satiation hypothesis more adequately explains synchronous emergences in aquatic insects. With a fixed length of time and number of predators, the superabundance of adult insects far exceeds the capacity of predators to consume them (Sweeney & Vannote 1982, Donaldson 1993). Sweeney & Vannote (1982) demonstrated that, as predicted by the predator satiation hypothesis, the percentage of the mayfly, *Dolanna americana* Edmunds and Traver, preyed upon by various predators was inversely related to the total number of prey specimens available, i.e. as the number of prey available increased, with a fixed number of predators, a greater proportion of the prey population survived. Similar results were given by Williams & Simon (1995) who showed that the synchronous emergence of another group of insects, the periodical cicadas in the genus *Magicicada,* coupled with a fixed predator population, led to predator satiation. Karban (1982), also working with periodical cicadas, demonstrated that greater reproductive success was achieved at higher adult densities. The results were believed to be a direct result of predator satiation, and it was concluded that the strategy of adults emerging synchronously is a selective advantage to individual cicadas (Karban 1982).

Synchrony may also be important interspecifically as a means of temporally separating food resources of larvae and mating swarms of adults in closely related species that occupy similar niches (Corbet 1964, Malas & Wallace 1977). Malas & Wallace (1977) studied the strategies for coexistence of three species of net-spinning caddisflies. They concluded that, along with variations in capture net mesh size and distinct microdistributional patterns, temporal variations in life cycles enabled the three species to coexist in a small watershed. Temporal separation of the adult mating swarms in closely related species with poor sexual recognition can decrease the incidence of abortive sexual interaction and interspecific crossing (Corbet 1964, Jackson & Resh 1992).

The environmental cues involved in adult synchronization are complex and are not fully understood. Some of the factors involved include: temperature, light intensity, wind velocity, relative humidity and lunar phases (Corbet 1964, Nimmo 1966).

The factors involved in the evolution of synchronous emergence are also unclear. It appears that there is no simple answer to explain synchronous emergence of adult aquatic insects. It is more likely that a myriad of factors are involved. The causes of mass emergence may be a single factor or a combination of several factors that apparently differ from species to species (Corbet 1964).

Nuisance Problems and Economic Issues

Nuisance and economic problems associated with the flight activity of short-lived aquatic adults are felt primarily among people who live or work near lakes and rivers (Ali 1980b). Generally, nuisance results from "unwelcome physical contact with the insects near lights during the first part of the evening" (Corbet 1966a).

In areas where adult aquatic insects reach extreme densities, several nuisance problems have been documented. Enjoying outdoor activity is nearly impossible where swarms of midges, caddisflies and mayflies fly into and land on peoples faces, into their food and drinks, flying or crawling into open shirt collars and under eyeglasses (Fremling 1960, Corbet *et al.* 1966, Anonymous 1970, Ali 1980a). During the day, these insects seek shelter from the heat in cool, shady places such as the walls of buildings, staining fresh paint, stucco and other wall finishings. On mornings after high-density flights, accumulations of dead and dying midges, mayflies and caddisflies cover automobiles and make roads and sidewalks slippery and hazardous. This necessitates frequent maintenance, including washing of homes and store fronts and removing the piles of decomposing insects, which create a foul smell similar to that of rotting fish (Langlois 1951, Fremling 1960, Corbet 1966a, Anonymous 1970, Ali 1980a).

At night, midges, mayflies and caddisflies are attracted to lights, causing several nuisance problems. Again, car headlights and windshields can be covered by mayflies and midges, creating hazardous driving conditions (Anonymous 1970, Lehmkuhl 1979, Ali 1980a). Some midge species are small enough to go through conventional window screens, leading to indoor nuisance problems such as ruining laundry, staining indoor walls and irritating the human inhabitants (Ali 1980a). Mayflies in the genus *Hexagenia* at one time emerged in such large numbers along the Mississippi River as to make navigation hazardous. The adult *Hexagenia* were attracted *en masse* to the powerful arc searchlights used by boats to spot unlit channel markers (Anonymous 1970).

Caddisfly nuisance problems can be so extreme as to affect large cities. Montréal, Québec, and Calgary, Alberta, are two examples of this. A three-year study was carried out to assess and control the nuisance caddisfly population of St. Helen's Island prior to the 1967 World Exhibition in Montréal (Corbet *et al.* 1966). During the World Exhibition Shadfly Project, almost six million caddisflies, also known by the common name shadfly, were collected over two seasons (Corbet *et al.* 1966). Adjacent to the Bow

River, residents of the Lynwood Ridge area of Calgary, Alberta, have also been faced with nuisance populations of caddisflies. Throughout the 1980s and 1990s, residents filed complaints with city aldermen and Central Parks Services. People with homes in the Lynwood Ridge area claimed that they were unable to do any yard work or pursue recreational activities during the evenings from June to September (Reichardt 1997).

Economic problems are also created by the synchronous emergence and dense swarms of aquatic adult insects. Plastic and paint industries in Florida reported large numbers of midges getting into and destroying their final products (Ali 1980a). In several communities located near bodies of water, it has been noted that their downtown areas become deserted during peak swarming activity (Anonymous 1970, Ali 1980a). Ali (1980a) reported the results of an economic impact study carried out by the Sanford Chamber of Commerce, Sanford, Seminole Co., Florida. He found that midges emerging from a nearby lake caused business losses of approximately three to four million dollars annually. The Holiday Inn in downtown Sanford, Florida spent approximately $50,000 annually on property maintenance and attempts to control the pest insects (Ali 1980a).

The swarming activity of adult midges around lights at night can induce nuisance problems and has been increasing over the past few decades (Resh & Grodhaus 1983). Ali (1980a) gave three reasons for the increased incidence of pest midge populations in the United States: 1) an increased number of man-made residential-recreational lakes, providing new midge habitats, 2) a deteriorating water quality, which is suitable for pest species, and 3) the increasing tendency of humans to move closer to bodies of water.

Impoundment of water and increasing enrichment due to pollution can lead to greater availability of food sources for larvae, thereby increasing the number of adults of some species of chironomids (McAlpine *et al.* 1979). Whereas populations of pest midge species seem to thrive in areas of increased water degradation, caddisfly and mayfly populations decrease. As Lake Erie became increasingly polluted, the swarming activity of mayflies and caddisflies in adjacent towns and cities significantly declined. Both of these groups of insects are sensitive to pollution and a dramatic change in population size has been noted (Fremling 1960, Anonymous 1970, Rosenberg & Resh 1996).

Immunology

Insects have long been known to cause allergic reactions in people. Allergic reactions to arthropods can take several forms. The three primary modes of entry for allergens into the human body are oral, inhalation and injection, each of which can result in an immune response in susceptible individuals (Kagen 1990). Oral allergens include all substances that cause a reaction when ingested; crustaceans are the best example of this (Kagen 1990). Injected allergens, usually venoms, are pricked directly into the body. Anaphylactic shock is the most severe form of injected allergen response resulting from the sting of some species of Hymenoptera. Inhalant arthropod allergens are inhaled in the form of insect debris, such as setae, scales, and frass (Kagen 1990). Inhalant insect allergens are the focus of this discussion.

To introduce this topic properly, several terms will be defined. An allergy is defined by Cayne (1988:24) as "an exaggerated and specific antigen-antibody reaction marked by sneezing, difficulty in breathing, swelling, itching rash and other symptoms...The allergens responsible are diverse and may include pollen, dust, animals, bacteria, drugs and food." An antigen has a complex chemical structure with molecular weights exceeding 10,000. Most antigens are proteins, but complex carbohydrates may also act as antigens (Sherman 1968). Allergens are made up of antigens and haptens, the latter of which have a low molecular weight and may become attached to a protein molecule forming a compound antigen (Sherman 1968).

The human immune system protects itself from foreign proteins through the use of antibodies. Antibody activity is carried out in the globulin portion of blood plasma (Sherman 1968). Each antibody is specific to the foreign macromolecule (antigen) for which it was formed to destroy (Stryer 1988).

Antibodies arise in an individual after an antigen has been introduced. Following an incubation period, these antibodies generally reach a peak concentration within one to two weeks. The antibody concentration then drops to almost zero within approximately one month of antigen introduction (Sherman 1968). Subsequent introductions of the same antigen into the body require a much shorter incubation period, with the antibody concentration reaching higher levels and lasting longer (Sherman 1968).

It has been recognized for most of the 20th century that insects and other arthropods can be responsible for allergic reactions (Mathews 1989). Eleven orders of insects have been implicated as having one or more species that can cause an immunological response: Ephemeroptera, Orthoptera, Blattaria, Hemiptera, Homoptera, Coleoptera, Siphonaptera, Diptera, Trichoptera, Lepidoptera and Hymenoptera (Urbach & Gottlieb 1941, Feinberg *et al.* 1956, Mathews 1989, Sigler *et al.* 1996).

Respiratory or inhalant allergy symptoms caused by insects are very similar to those caused by pollen and mould. These symptoms include asthma, allergic rhinitis and allergic conjunctivitis (Kagen 1990). Rhinitis is the inflammation of the mucous membrane of the nose resulting in sneezing and itchiness (Cayne 1988). Conjunctivitis is the inflammation of the mucous membrane lining the front of the eyeball and inner surface of the eyelid and causes watery, red and itchy eyes (Cayne 1988). Respiratory insect allergies are caused by the dissemination of antigenic portions of insects or their by-products into the atmosphere and subsequent inhalation by atopic individuals. Atopic individuals are people who suffer from the type of allergic mechanism that apparently results from hereditary influence and is characterized by immediate wheal reaction to skin tests with the antigen (Sherman 1968). The specific cause of this predisposition is unknown, but generally, when an individual suffers from an allergy to one substance, they are likely to react to other antigens (Warrington 1997).

Most of the work that has been done on inhalant insect allergies is related to occupational exposure. Allergies through occupational exposure have been demonstrated for several groups of insects that are reared for teaching, research and other purposes (Mathews 1989). Crickets, locusts, grasshoppers and cockroaches have all induced occupational insect allergies (Mathews 1989). Honey bee overwintering facilities have been implicated in occupational allergies due to moulds that accumulate on dead bees (Sigler *et al.* 1996). Several species of Coleoptera have also been associated with occupational inhalant allergy manifestations. For example, a museum curator developed incapacitating asthma from exposure to Dermestidae larvae, which are used to remove flesh from skeletons of zoological specimens (Sheldon & Johnston 1941). Other insect orders that are known to cause occupational inhalant allergies include Lepidoptera, Diptera and Hymenoptera (Mathews 1989). Recently, Trichoptera were added to the list when it was proven that caddisfly antigens were responsible for occupational allergies among employees of hydroelectric generating stations along the Winnipeg River in Manitoba (Kraut *et al.* 1994). Trichoptera-induced allergies will be discussed in more detail as a source of recreational inhalant insect allergies.

Early in the investigations into insect allergies, Urbach & Gottlieb (1941) reported that the three most important insect orders implicated in inducing respiratory immunoresponses are Ephemeroptera, Trichoptera and Lepidoptera. The causative allergens associated with these three orders are thought to be the cast subimago cuticle of Ephemeroptera, the setae of Trichoptera, and the scales of Lepidoptera (Urbach & Gottlieb 1941).

Many inhalant insect allergens are seasonal in nature, associated with times in the insect life cycle when adults are present in large numbers. Outdoor, airborne insect debris has been known to cause allergic reactions since Parlato published a series of papers (1929, 1930, 1932, 1934) proving that caddisflies were responsible for hay fever-like allergies in people living along the Niagara River in Fort Erie, Ontario, and Buffalo, New York. The exact nature of the allergen is unknown, although it is believed that wing setae and body particles are responsible (Parlato *et al.* 1934, Osgood 1956a, 1956b, Kraut *et al.* 1994). Mayflies, chironomids and aphids are also implicated as sources of aeroallergens and, like caddisflies, generally only cause allergic reactions seasonally when large numbers of the adult insects are present, allowing their debris to reach high concentrations (Figley 1929, Gaillard 1950, Feinberg *et al.* 1956, Mathews 1989).

The effects of inhalant insect allergies can be countered in several ways. The first option, which is not usually attainable, is to avoid the areas of high allergen concentration during the season of symptom occurrence (Kagen 1990). However, contact with the allergen can be minimized by keeping windows and doors closed and by adding filters to ventilation systems (Sherman 1968). Antihistamines may be effective as a second option. Antihistamines block the effect of the symptom-causing compounds, histamines, and are beneficial in some types of allergic reactions. These drugs are useful in the treatment of allergic rhinitis and acute urticaria (rash or hives) associated with seasonal hay fever-like reactions (Sherman 1968). Finally, immunotherapy can be effective in alleviating symptoms in some cases. Immunotherapy or desensitization therapy involves injecting allergic human individuals with an extract of the allergen (Kagen 1990). Many researchers have investigated the feasibility of controlling the pest insects as another option to alleviate both nuisance and allergy problems.

Control

Very few control techniques are available to alleviate the nuisance and economic problems caused by mayflies, caddisflies and midges. Historically, organochlorine and organophosphate insecticides were used to control the larval and adult stages of these insects. During the World Exhibition Shadfly Project at the site of Expo 67 DDD, as a larvicide, and DDT, as an adulticide, were applied successfully in a temporary abatement scheme to reduce the nuisance caddisfly population (Fredeen 1971, 1972). DDT was also used successfully as an adulticide in Fort Erie, Ontario, for 15 consecutive years to control the nuisance caddisfly population (Fredeen 1971). The banning of many organochlorine insecticides, such as DDT, and increased regulation of insecticides used in aquatic habitats has all but eliminated the use of chemical control for these pest insects.

Ali (1980a) proposed the use of biological control agents such as viruses, fungal pathogens, nematodes and predators for chironomids. In small habitats (<200 ha), a combination of cultural, biological and chemical control can be effective (Ali 1980a). In larger habitats, however, adequate control by these sources is not feasible due to the immense numbers of pest insects, the high cost of chemical control, chemical displacement and dilution problems (Ali 1980a).

Several cultural control techniques have been proposed that would deliver at least some control. Changing the colour and use of home and street lights in affected neighbourhoods would decrease the number of caddisflies attracted to the area. Use of red and yellow neon lights in shopping districts, which are less attractive than blue and green, could decrease pest species numbers in these areas (Fremling 1960). Homeowners could reduce the caddisfly nuisance factor by keeping outdoor lighting to a minimum, using yellow light bulbs outside and by keeping their curtains closed at night (Reichardt 1997). A proposed cultural control technique for midges in concrete-lined storm drains is the mechanical removal of accumulated substrate on the concrete, which is a suitable habitat for midge larval development. This technique reduced midge populations substantially for two weeks, but full recovery occurred within four weeks (Ali *et al.* 1976). An integrated approach, using a combination of the above recommendations, would likely result in the best control.

Discussion and Conclusions

The nuisance and immunological problems associated with mass-emerging aquatic insects are complex and involve several economic issues as well. As more people utilize aquatic habitats for recreational purposes, the incidence of nuisance and allergy problems is likely to become more widespread in North America.

The economic implications demonstrated are large and varied. Several cultural control techniques have been proposed that would deliver at least some control and ease the economic impact. Chemical control does not appear to be a feasible option, as few chemicals are registered for aquatic use, and also because there are problems with displacement and dilution. Further research into integrated methods of control could prove useful to decrease the nuisance pressure exerted by mass-emerging aquatic insects, although controlling these insects may have a detrimental effect on the aquatic ecosystems from which they emerge. Larvae of chironomids, mayflies and caddisflies are beneficial in that they are a source of food for freshwater fish and are important in the transfer of energy through aquatic ecosystems. Finding a suitable equilibrium between the level of human inconvenience and the health of aquatic habitats is difficult.

Immunotherapy or desensitization therapy, and the use of antihistamines seem to be the only viable solutions for people suffering from recreational and occupational inhalant insect allergies. Unfortunately, if these options are not available or do not work for an allergic individual, the only remaining alternative is to avoid those areas of high allergen concentration by either leaving the vicinity of the water source or by changing their occupation.

To decrease exposure and reduce allergic symptoms, an integrated approach should be utilized. In the case of caddisfly allergy problems, which are especially apparent in Manitoba Hydro hydroelectric generating stations along the Winnipeg River, it would be beneficial to reduce the quantity of aeroallergens. This could be accomplished by decreasing the concentration of caddisflies and caddisfly particulates within the stations. It is usually impossible to eliminate allergen concentrations completely. It would, therefore, be beneficial to elucidate, through further research, the exact nature of the protein antigens involved in respiratory insect allergies. If the exact nature of the antigen is known, the part of the insect that is responsible for the allergic symptoms could be verified. Knowing this might make sampling for the allergen and possibly excluding it through the use of biofilters a control option.

CHAPTER III

DIVERSITY, SEASONALITY AND PERIODICITY OF ADULT CADDISFLIES AT TWO MANITOBA HYDRO HYDROELECTRIC GENERATING STATIONS ON THE WINNIPEG RIVER, MANITOBA, CANADA.

ABSTRACT

Hydroelectric generating stations along the Winnipeg River are subject to emergence of large numbers of caddisflies which cause work-related allergies. The purpose of this study was to determine peaks in seasonal and nightly flight activity of the most abundant caddisfly species in and around the generating stations and to recommend management practices to alleviate the problems caused by caddisflies. Modified New Jersey light traps were used to capture caddisflies during the 1997 and 1998 field seasons at hydroelectric generating stations at Great Falls and Seven Sisters. The estimated total number of caddisflies caught over the two-year period was 526,607: 275,806 in 1997 and 250,801 in 1998. The caddisflies belonged to 14 families, 35 genera and at least 76 taxa. The entire caddisfly flight season, from first capture to last, differed by only one week in the two years. In 1997, caddisflies were collected from 1 June to 16 October, and in 1998 from 26 May to 8 October. Peak flight activity occurred one week earlier at Great Falls than at Seven Sisters. During 1997, approximately 75% of caddisflies were captured during the five-week period from the last week of June to the end of July. The peak flight activity in 1998 occurred from mid-June to mid-July (four weeks), when approximately 80% of the yearly total of caddisflies were captured. Peaks in nightly flight activity were seen between 2300 and 0100, when approximately 62% of the nightly total were captured.

Large numbers of caddisflies were captured inside the generating stations. To determine the mode of entry of the caddisflies, four nights were spent in the stations. Through personal observations and the use of emergence traps, it was established that caddisflies get into the buildings through various openings (e.g., broken windows, under doors) and by emergence from the gate openings inside the gate rooms. Insect particulates, including identifiable caddisfly parts, blown into the generating stations through the air-cooling system, were also collected in fine nylon filters attached to the turbine caps in the powerhouses.

Management practices are required to decrease the exposure of Manitoba Hydro employees to caddisfly particulate. These must include maintaining and improving sanitation practices and increased vigilance to remove or exclude caddisflies from the generating stations.

INTRODUCTION

Trichoptera larvae make an important contribution to the community of macrobenthos that processes organic matter in aquatic ecosystems (Anderson & Grafius 1975). The order Trichoptera is divided into three suborders. Caddisflies in the suborder Annulipalpia are collector-gatherers, i.e. larvae that build fixed retreats in lotic water (Frania & Wiggins 1997). The suborder Annulipalpia accounted for 90% of the caddisflies caught in my study.

Annulipalpia caddisflies can reach extraordinary densities when environmental factors are favourable for larval development. Conditions such as substrate availability, adequate food, and favourable hydrologic conditions influence the number and distribution of these caddisfly larvae (Parker & Voshell 1983). These conditions are readily available at hydroelectric generating stations along the Winnipeg River. During the open water period, adult caddisflies are abundant in and around the hydroelectric generating stations.

The abundance of adult caddisflies and caddisfly particulates has caused nuisance and allergy problems among Manitoba Hydro employees who work in areas with high numbers of caddisflies and their particulates (Kraut *et al.* 1994). These employees have experienced respiratory allergy symptoms after prolonged exposure to caddisfly allergens. The hydroelectric generating stations at Great Falls and Seven Sisters are air-cooled systems which require large volumes of air to be circulated around the turbine shafts. Air is drawn in through screens, onto which many insects get trapped, die and are desiccated. The insect particulates are then drawn in with the air and drawn into the stations through the turbine caps. Insect particulates are also produced when adult caddisflies die and are allowed to accumulate and decompose inside the stations.

The objectives of my study were: 1) to identify the patterns of seasonal and nightly abundance of the most dominant species of caddisflies in and around the Great Falls and Seven Sisters hydroelectric generating stations, 2) to identify the times of greatest caddisfly debris deposition, 3) to examine the modes of entry of both adult caddisflies and caddisfly particulates into the generating stations, and 4) to identify possible management techniques that might ease the problems associated with caddisfly allergy among Manitoba Hydro employees.

MATERIALS AND METHODS

Data on the seasonal and nightly patterns of Trichoptera flight activity were collected during the summers of 1997 and 1998 at two sites, Great Falls (50° 28' N, 96° 00' E) and Seven Sisters (50° 07' N 96° 01' E) Hydroelectric Generating Stations. Both Seven Sisters and Great Falls Generating Stations are air-cooled systems. In such systems, a large volume of air is drawn into the station to cool the spinning turbine shafts. Water is used to cool the turbine shafts in newer generating stations. At Great Falls and Seven Sisters, the air intakes are located over the tail race area and were covered with screens. The air is drawn directly into the rooms where the turbine shafts are spinning, and then forced into the powerhouse through the turbine caps (Figure 1).

i. Sampling Methods

Caddisflies were collected using modified New Jersey light traps equipped with 100W frosted incandescent light bulbs. Traps were placed at five locations at each site. Three traps were placed outside on the tailrace deck, spillway, and beside the tailrace water and were identified at each site as traps 1, 2, and 3, respectively. Two traps were placed inside at opposite ends of the gate room and were identified at each site as 4 and 5, respectively (Figure 2). Means from the three traps outdoors were calculated as were the means from two traps located indoors each station.

The traps were suspended with the light source at approximately 1.5 m above the surface. Inside the stations, traps were hung either from brackets or from pre-existing structures. Tripods were constructed for the remaining locations. Each tripod consisted of three 2.4 m lengths of 1.3 cm electro-metallic tubing (EMT) with holes drilled at 13 cm, 30.5 cm, 1.3 m and 2.4 m from the bottom (Figure 3). Heavy gauge wire was used to hold the lengths of EMT together through the top holes, the middle holes were strengthened with rope, and the bottom holes allowed attachment to concrete blocks. Concrete blocks were 20 cm x 20 cm x 8 cm with an 18 cm length of 1.5 cm diameter EMT placed in the centre of each block to act as a receptacle for tripod attachment. Holes were drilled in the receptacle 2.5 cm from each end, with the bottom hole holding a nail to secure the receptacle into the concrete. The top hole aligned with the hole drilled at the 13 cm point of the tripod legs, enabling a cotter pin to be placed through both.

Wide mouth Nalgene® bottles (1 L) were attached to the traps and filled with 500 mL of 70% ethanol for overnight samples and 250 mL of 70% ethanol for hourly samples. A drop of liquid detergent was added to break the surface tension of the ethanol.

The greatest number of caddisflies counted and identified in one sample was 809 (14.viii.97 GF4). Sub-sampling was required when trap catches exceeded approximately 0.25 L of caddisflies. Sub-sampling was required for 72 samples in 1997 and for 48 samples in 1998. Each sample requiring sub-sampling was placed in a 16.8 L bucket, which was filled with water to approximately 10.5 L. A glass rod was used to stir the sample until a vortex was created in the centre of the bucket. A small sieve (7 cm diameter, 3.5 cm deep, mesh size of 1 mm x 0.5 mm) was then used to collect a sub-sample. Five sub-samples were taken from various depths. The sub-samples and the whole sample were strained and then allowed to drain on paper towels for up to five minutes and then weighed. The average number of caddisflies and the masses of the sub-samples were used to estimate the total number of caddisflies in the weight of the entire sample.

The validity of the sub-sampling technique was tested by performing the sub-sampling as outlined above, estimating the total number of caddisflies in the sample (3.vii.97 SS4), then counting the number of caddisflies present in the entire sample. The estimated number of caddisflies was then compared to the actual number counted to give the per cent efficiency of the sub-sampling technique.

Adult caddisflies were preserved in 70% ethanol and identified to species with totals for each species calculated on a weekly basis. Caddisflies were identified using the following keys: Ross (1944), Yamamoto & Wiggins (1964), Blickle (1979), Schmid (1982, 1983, 1998), Hilsenhoff (1985), Nimmo (1971, 1986, 1987), Lago & Harris (1987), Ruiter (1995), Cooper & Morse (1998), and Wiggins (1998). Females in the family Hydropsychidae (*Hydropsyche* Pictet and *Cheumatopsyche* Wallengren) were identified to genus only and their numbers were pooled because identifying females not directly associated with males is not usually possible (Wiggins 1990).

Specimens of troublesome species were verified by Don Cobb of the Freshwater Institute and Dr. J. Morse of Clemson University. Voucher specimens were deposited in the J.B. Wallis Museum, Department of Entomology, University of Manitoba.

ii. Seasonal Flight Activity

Caddisflies were collected twice weekly during the summer of 1997 from 6 May to 24 October. Sampling took place once weekly in 1998 from 23 April to 15 October. Traps were operated on each collection date from approximately 20:00 to 8:00 the following morning. Sampling dates were chosen to correspond with favourable weather forecasts.

iii. Nocturnal Flight Periodicity

On four different occasions, samples of caddisflies were taken hourly. In 1997, this occurred at Great Falls on 10 July and at Seven Sisters on 24 July. In 1998, hourly samples were collected at Great Falls on 6 July and at Seven Sisters on 13 July. Sunset occurred at approximately 2130, with sunrise the following morning at approximately 0530 on all sample dates. Trap collections began at 2000 and were removed hourly from 2100 to 0600. Air temperature data were not collected.

Direct observations of adult flight activity were taken hourly on 6 July, 1998 at Great Falls to determine, in a qualitative fashion, the abundance or number of caddisflies that were active each hour. Observations were made at the beginning of each hour from

2100 to 0500, in the same location each hour, outside the generating station. The number of caddisflies flying around one of the lights on the generating station were estimated hourly, by the same person, to be low (fewer than 500 caddisflies), moderate (500 to 1000 caddisflies) or high (more than 1000 caddisflies).

iv. Avenues of Entry

The means of entry of caddisflies and caddisfly particulates into the generating stations were evaluated during 1997 and 1998. Trichoptera activity on the air intake screens was measured on 10 July, 1997 at Great Falls (screen surface area = 5.5 m^2) and on 17 July, 1997 at Seven Sisters (screen surface area = 2.8 m^2), by counting the number of caddisflies that were moving around on a 0.1 m^2 or 0.2 m^2 area during one-minute intervals. Three, one-minute observation intervals were made three times over the course of each night.

To determine if insect particulates were entering the plants through the air-cooling system, two fine nylon filters were attached to the open panels of the turbine caps inside the powerhouse. The nylon filters were in the form of a tube with one closed end, 60-cm long with a 10-cm opening. Filters were in place for approximately seven day, on three occasions during July and August, 1998. The contents of the filters were examined for insect particulates. No attempt was made to quantify the amount of particulates caught due to the large surface area of the nylon and the uneven distribution of the particulates.

In the gate room of each station, there were head gate openings, each with a surface area of approximately 6 m^2 of standing water. To determine if caddisflies were emerging from these openings inside the stations, samples were taken from the open water of the gate openings at Seven Sisters. An emergence trap was constructed using a 4-L plastic jar fitted with a plastic sieve fastened to the opening. Traps were suspended from a rope onto the surface of the standing water in the gate opening. Emergence traps were left in place for three- to five-day periods, 11 times in 1998, beginning on 16 June, 1998 and ending on 12 September, 1998. Samples of the debris floating on the surface of the water in the gate openings were also taken using an aquatic sampling net.

RESULTS

i. Sampling Methods

Of the caddisflies caught over the course of this study, the estimated number that were damaged was 416,943. The caddisflies whose genitalia were damaged or were not present represented 54% of the total number caught.

The efficiency of the sub-sampling technique was calculated by comparing the actual number of caddisflies caught (14,269) to the estimated number of caddisflies caught (16,155) in one sample. The efficiency of the sub-sampling technique was calculated to be 112%. Reported results are unadjusted for sub-sampling efficiency.

ii. Species Composition

Total estimated number of Trichoptera caught over the two years of the study was

526,607: 275,806 in 1997 and 250,801 in 1998. Of these, 54,698 (1997) and 38,769 (1998) from entire samples and sub-samples, were identified to species. These caddisflies belonged to 14 families, 35 genera and at least 76 taxa (Table 1).

iii. Seasonal Flight Activity

The entire caddisfly flight season, from first capture to last, differed by only one week in the two years. In 1997, caddisflies were collected from 1 June to 16 October, and in 1998 from 26 May to 8 October (Figure 4). During 1997, approximately 75% of caddisflies were captured during the five week period from the last week of June to the end of July. The 1998 peak in flight activity occurred from mid-June to mid-July (four weeks), when approximately 80% of the yearly total of caddisflies was captured. Peak flight activity began one week earlier at Great Falls than at Seven Sisters.

Caddisflies of the suborder Annulipalpia represented the most numerically abundant taxa caught over two years of sampling (Table 2). The families in this suborder caught during this study include: Philopotamidae, Hydropsychidae, Psychomyiidae, Polycentropodidae and Dipseudopsidae. The six most abundant taxa were: *Hydropsyche* females, *Cheumatopsyche* females, male *Hydropsyche simulans* Ross, *Neureclipsis valida* (Walker), male *Hydropsyche alternans* (Walker) and *Psychomyia flavida* (Hagen).

a. Outdoor Flight Activity

There were distinct peaks in the outdoor flight activity of the dominant taxa.

Mean numbers per trap from the three outdoor traps at each site were used to examine the outdoor flight activity pattern and seasonal peaks for each of the dominant species caught.

Female Hydropsychidae were identified to genera only because of the inadequacy of available keys and the level of difficulty and unreliability of species identification given the poor condition of many specimens in the traps. However, over the course of the study five species of *Hydropsyche* were captured (*H. alternans*, *H. simulans*, *H. bidens* Ross, *H. scalaris* Hagen and *H. slossonae* Banks). Female *Hydropsyche* were the most abundant caddisflies, making up 54% of the total catch over both years. Based on the proportion of males caught, most of the *Hydropsyche* females were likely *H. simulans* and *H. alternans*. In 1997, *Hydropsyche* females were caught outside in two peaks. The first peak was extended in duration from approximately 13 July to 10 August (mean ± SE: 7,437 ± 3,034.4 on 24 July) predominantly at Seven Sisters (Figure 5). The second peak occurred on 31 August (1,991 ± 694.2). In 1998, the number of *Hydropsyche* females caught was also greater at Seven Sisters. The peak in outdoor flight activity was more defined, lasting from approximately 23 June to 21 July (10,335 ± 4,573.0) (Figure 6).

Female *Cheumatopsyche* made up 11% of the total catch over the two years. Over the course of the study, three species of *Cheumatopsyche* were identified (*C. gracilis* (Banks), *C. speciosa* (Banks) and *C. campyla* Ross). There was no defined period of peak flight in the early summer of 1997, when female *Cheumatopsyche* reached their highest numbers (1,375 ± 531.2) (Figure 7). A secondary peak was seen later in the summer on 31 August at Seven Sisters (785 ± 407.4). In 1998, female *Cheumatopsyche* had an earlier peak, which lasted from 16 June to 21 July (1,564 ± 905.7), at Great Falls and Seven Sisters (Figure 8). Later in the season, another peak of outdoor flight activity was seen at Seven Sisters lasting from 5 August to 12 September (133 ± 56.4).

There was one large peak of outdoor flight activity in male *Hydropsyche simulans* (Ross) in 1997 and 1998, accounting for 10% of the total catch (Figures 9 and 10). In 1997, *H. simulans* was present in relatively small numbers from 26 June to 24 July (655 ± 621.5) at Seven Sisters (Figure 9). In 1998, male *H. simulans* was caught outdoors from approximately 9 June to 13 July (993 ± 801.2) (Figure 10).

Male and female *Neureclipsis valida* (Walker) accounted for 8% of the total catch of caddisflies over the two years of the study. Adult *N. valida* were caught in small numbers throughout the summer of 1997 (Figure 11), with one small peak on 7 July at Great Falls (250 ± 132.4). In 1998, one peak in outdoor flight activity of *N. valida* was seen, from 9 June to 13 July (824 ± 544.7) (Figure 12).

Male *Hydropsyche alternans* made up 5% of the total number of caddisflies caught in 1997 and 1998. In 1997, small numbers of *H. alternans* were caught throughout the summer at both Great Falls and Seven Sisters (Figure 13). The greatest number of *H. alternans* caught in 1997 was 194 ± 68.7 at Seven Sisters on 4 August. In 1998, male *H. alternans* flight activity probably began prior to traps being put out and ended on 9 June (490 ± 483.4), with the second peak occurring from 27 July to 15 September (131 ± 57.7) (Figure 14) .

Psychomyia flavida Hagen made up 2% of the total number of caddisflies caught.

In 1997, *P. flavida* was caught outdoors at Seven Sisters in two distinct peaks from 13 to 24 July (435 ± 350.6) and on 31 August (478 ± 373.7) (Figure 15). In 1998, *P. flavida* was caught in two peaks represented at both sites, although the numbers were greater at Seven Sisters. *Psychomyia flavida* was most abundant from 16 June to 13 July (462 ± 364.7) and from 27 July to 31 August (189 ± 177.5) (Figure 16).

b. Indoor Flight Activity

Large numbers of Trichoptera were also captured in traps placed inside the hydroelectric generating stations. The first adults and peaks of indoor activity for each species generally occurred earlier than outside.

Female *Hydropsyche* were caught in large numbers inside the generating stations. In 1997, one peak occurred from 19 June to 7 August (4,498 ± 3,826.0) (Figure 5). Female *Hydropsyche* were caught indoors in 1998 with one peak from 6 June to 27 July (6,435 ± 5,581.0) (Figure 6).

Female *Cheumatopsyche* were caught indoors from 19 June to 7 August in 1997 (1,020 ± 764.5) (Figure 7). In 1998, the peak indoor flight activity of *Cheumatopsyche* females occurred from 9 June to 20 July (223 ± 177.0) (Figure 8).

Hydropsyche simulans was caught in a distinct peak inside the Seven Sisters Hydroelectric Generating Station in 1997 and inside the Great Falls Hydroelectric Generating Station in 1998. In 1997, male *H. simulans* peaked from 23 June to 4 August (6,667 ± 5,620.0) (Figure 9). In 1998, male *H. simulans* were caught from 9 June to 20

July (740 ± 698.5) (Figure 10).

Neureclipsis valida was caught in greater numbers inside the generating stations than outside. In 1997, two peaks of *N. valida* flight activity indoors occurred from 23 June to 24 July (1,761 ± 1,602.5) and from 4 August to 17 September (433 ± 217.5) (Figure 11). In 1998, one peak was observed for *N. valida* from 9 June to 13 July (1,031 ± 935.0) (Figure 12).

Male *Hydropsyche alternans* were caught inside the generating stations in two peaks in 1997, from 15 June to 24 July (1,921 ± 1,488.5) and from 4 August to 31 August (117 ± 67.9) (Figure 13). In 1998, a similar trend was seen with *H. alternans* peaks occurring from 26 May to 6 July (130 ± 59.5) and from 20 July to 24 August (75 ± 11.0) (Figure 14).

Psychomyia flavida adults were caught in small numbers throughout the summer of 1997 (Figure 15). In 1998, the peak indoor catch of *P. flavida* was from 9 June to 6 July (98 ± 96.0) (Figure 16).

iv. Nocturnal Flight Periodicity

a. Outdoor Flight Activity

Female *Hydropsyche* were caught from 2200 until 0200 in 1997, with the greatest numbers caught at 2300 (4423 ± 1807.0) at Seven Sisters (Figure 17). In 1998, *Hydropsyche* females were active from 2200 until 0400 at both Seven Sisters and Great Falls. The peak flight activity occurred at Great Falls at 2400 (373 ± 233.0) (Figure 18).

Female *Cheumatopsyche* were caught from 2200 until 0500 in 1997, with the greatest numbers caught at 2300 (373 ± 146.0) at Seven Sisters (Figure 19). In 1998, *Cheumatopsyche* females were caught from 2300 until 0500, with the greatest numbers caught at 2400 (124 ± 85.0) at Great Falls (Figure 20).

Male *Hydropsyche simulans* were caught from 2200 until 0400 in 1997, with the greatest numbers caught at 2300 (224 ± 124.0) (Figure 21). In 1998, male *H. simulans* were caught outside from 2200 until 0500, reaching a peak at 2400 (99 ± 79.0) at Seven Sisters (Figure 22).

In 1997, *Neureclipsis valida* was caught in low numbers in the outside traps at Seven Sisters from 2300 until 0200 (19 ± 12.0) (Figure 23). In 1998, *N. valida* was caught from 2200 until 0500 at Great Falls, reaching a peak at 2400 (39 ± 13.0) (Figure 24).

In 1997, adult *Psychomyia flavida* were caught from 2300 until 0400 at Seven Sisters, with the greatest numbers caught at 2300 (319 ± 282.0) (Figure 25). In 1998, *P. flavida* adults were caught in extremely low numbers outside at both sites (not shown).

Adult *Oecetis inconspicua* (Walker) were not among the ten most abundant taxa caught in my study, but were caught in 1997 at Seven Sisters from 2200 until 0300, reaching a peak at 2300 (80 ± 40.0) (Figure 26). In 1998, *O. inconspicua* adults were caught in extremely low numbers outside at both sites (not shown).

Neureclipsis crepuscularis (Walker) were not among the ten most abundant taxa caught in my study, but were more abundant during hourly sampling. In 1997, adult *N. crepuscularis* were caught outside at Seven Sisters from 2200 until 0500, reaching a peak at 2300 (30 ± 15.0) (Figure 27). In 1998, *N. crepuscularis* were caught outside at Great Falls from 2300 until 0400, with a peak at 2400 (63 ± 57.0) (Figure 28).

Male *Cheumatopsyche gracilis* were caught from 2200 until 0400 in 1997 at Seven Sisters, with the greatest numbers caught at 2300 (26 ± 9.0) (Figure 29). In 1998, *C. gracilis* were caught outside at Great Falls from 2300 until 0500, reaching a peak at 2400 (39 ± 37.0) (Figure 30).

In 1997, male *Cheumatopsyche speciosa* were caught outside at Seven Sisters from 2200 until 0100, reaching a peak at 2300 (14 ± 10.0) (Figure 31). In 1998, *C. speciosa* were caught at Great Falls from 2300 until 0300, with a peak at 2400 (25 ± 24.0) (Figure 32).

Direct observations were taken hourly at Great Falls on 6 July, 1998 to determine in a qualitative fashion the abundance or number of caddisflies that were active. Observations were made at the beginning of each hour from 2100 to 0500, in the same location each hour, outside the generating station. Flight activity was ranked as low (under 500 caddisflies), moderate (500 to 1000 caddisflies) and high (more than 1000 caddisflies) flying outside the stations (Table 3).

b. Indoor Flight Activity

Hourly trap catches inside the Great Falls and Seven Sisters generating stations were consistently lower than those outside the stations and numbers caught were generally consistent from hour to hour throughout the night. The exceptions to this were *Neureclipsis valida* (Figure 23, 24), male *Cheumatopsyche gracilis* (Figure 29, 30) and male *Cheumatopsyche speciosa* (Figure 31, 32).

In 1997, *N. valida* was caught inside Great Falls throughout the night reaching a peak at 0300 and 0400 (51 ± 23.0) (Figure 23). In 1998, *N. valida* was also caught throughout the night at Great Falls, reaching a peak at 0200 (21 ± 13.0) (Figure 24).

Cheumatopsyche gracilis males were caught from 2200 until 0500 in 1997, reaching a peak at 0300 (23 ± 11.0) (Figure 29). Male *Cheumatopsyche speciosa* were caught throughout the night in 1997, reaching a peak at 0300 (10 ± 6.0) at Great Falls (Figure 31). For both species, fewer than five individuals were captured in any of the hourly samples taken indoors in 1998.

v. Avenues of Entry

a. Adults

The condition of the physical structure of the hydroelectric generating stations was observed throughout the study and on nights of hourly sampling. In 1997 and 1998, several windows were broken or left open for weeks at a time. On many occasions, doors leading to the powerhouse and the gate rooms were left open throughout the day and were not completely closed at night. During all the nights of hourly sampling, it was noted that most of the lights were left on in the gate room and powerhouse.

Caddisfly larvae were collected from driftwood that had been removed from the trash racks, and also from a scroll case, which had been drained for repairs. In both of these locations, extremely large numbers of larvae of Hydropsychidae (*Hydropsyche* and *Cheumatopsyche*) and Polycentropodidae (*Neureclipsis*) were found.

Large numbers of caddisflies were captured inside the generating stations. The standing water in the gate openings was observed for five minutes twice on 10 July 1997 between 0330 and 0400. No emergence of caddisflies was seen but cast skins of Odonata could be seen on the walls and on the winch wires. Pharate adults of the families Hydropsychidae, Polycentropodidae, Psychomyiidae and Leptoceridae, and adults of *Hydropsyche simulans, H. alternans, H. bidens, Cheumatopsyche gracilis, C. speciosa,* and *Neureclipsis valida* were collected in dip-net samples taken from the debris floating in the gate openings.

An emergence trap was put in place eleven times, for three- to five-day intervals, from 16 June, 1998 to 22 September, 1998. *Neureclipsis valida* and *Ceraclea* sp. adults were collected during the period from 20 July to 23 July, 1998. No other caddisflies were captured in the emergence trap. However, the cast larval skin of a Plecoptera was found on the outside of the emergence trap on 12 September, 1998.

b. Particulates

The mean numbers of caddisflies moving on or through a 10 cm^2 or 20 cm^2 area on the air intake screens of Seven Sisters and Great Falls Hydroelectric generating stations screen are given in Table 4. Results are given as mean number of caddisflies present over three, one-minute intervals of observation. The mean numbers of caddisflies moving over the screens was highly variable, ranging from 0 at Great Falls on 10 July, 1997 to 36 ± 14 at Seven Sisters on 18 July, 1997.

Fine nylon filters attached to the turbine caps in the powerhouses collected insect particulates being blown into the generating stations through the air-cooling system. The particulates contained identifiable caddisfly particulate and midges (Diptera: Chironomidae) (Figure 33). Although no attempt was made to quantify the volume of insect particulates being blown into the plants, clearly identifiable insect body parts were collected.

DISCUSSION

i. Sampling Methods

The large percentage of caddisflies that were damaged during sampling is likely due to the design of the modified New Jersey light traps. The traps are constructed with a motorized fan, which draws insects that are attracted to the light source down through a mesh funnel into the attached killing jar. New Jersey light traps were originally designed to catch smaller insects (e.g., mosquitoes), which would be less prone to damage (Reinert

1989). Corbet *et al.* (1966) and Nimmo (1966) examined seasonality of adult caddisfly and nocturnal flight activity in Montréal using Robinson traps, constructed of a cone and lamp set on plastic buckets. Neither of those authors reported large numbers of damaged caddisflies. In future studies on adult caddisflies, I would recommend the use of the modified New Jersey light traps for sample collection if the objectives of the study are similar to mine. However, if the study is being designed as a means of collecting caddisflies for taxonomic investigation I would suggest using Robinson traps.

The efficiency of the sub-sampling method used in my study was calculated to be 112%. Therefore, the estimated number of caddisflies caught based on sub-sampling was a 12% overestimate of the actual number caught. One possible reason for this overestimation is that the sub-sampled caddisflies were all identified to the lowest practical taxonomic level, whereas the actual numbers caught were not examined as closely. It is possible that some microcaddisflies in the family Hydroptilidae were overlooked when the actual numbers caught were counted, as they were often found within the folded wings of larger species. The sub-sampling technique used in my study appeared to be effective; however, I would recommend that more samples be sub-sampled in future studies to determine the effectiveness of the technique used (see Sebastien *et al.* 1988).

ii. Species Composition and Seasonality

The caddisfly community in the Winnipeg River near the dams is diverse, with at least 76 taxa identified. The most abundant group of taxa belongs to the suborder Annulipalpia, the fixed-retreat makers. Overall, the suborder Annulipalpia was represented by 5 families, 9 genera and 19 taxa. Of these, the family Hydropsychidae, represented by 11 taxa in 3 genera, accounted for 79% of the total estimated number of adult caddisflies caught over the course of my study. The suborder Spicipalpia was represented by 2 families, 8 genera and 17 taxa and the suborder Integripalpia was represented by 7 families, 18 genera and 45 species.

The species composition of caddisflies captured along the Winnipeg River was reflective of the diversity of aquatic habitats that can be found in the area. Caddisflies from each of the Trichoptera suborders were represented, including species that develop in a wide variety of lotic and lentic habitats. The only family present in Manitoba but not represented in my study was Rhyacophilidae (Flannagan & Flannagan 1982).

Flannagan (1977) studied the caddisfly species composition in the Roseau River, Manitoba, where caddisflies were caught with emergence traps. In that study, 10 families, 21 genera and 42 species were identified (Flannagan 1977). Flannagan (1977) caught a similar number of taxa in the suborder Spicipalpia (2 families, 7 genera, 17 taxa), fewer caddisflies in the suborder Annulipalpia (3 families, 5 genera, 12 taxa) and fewer Integripalpia (5 families, 9 genera, 13 taxa) than were caught in my study on the Winnipeg River. Although the Roseau River is a large river, the diversity of caddisflies in the suborder Annulipalpia was lower than that caught from the Winnipeg River. This may be due to the sampling methods employed, as Flannagan (1977) used emergence traps, set over four substrates (boulders, cobbles, gravel and sand), that were emptied every 2nd day over approximately 4.5 months. The use of emergence traps, rather than light traps, could have led to an underestimation of the Annulipalpia species diversity present in the Roseau River. The difference between the number of caddisfly taxa in the suborder Integripalpia is likely due to the wide variety of aquatic habitats that are present around the dams on the Winnipeg River, which would not be present in an unregulated river such as the Roseau River.

Cobb *et al.* (1984) examined the caddisfly diversity in two streams in the Duck Mountains of Manitoba, South Duck River and Cowan Creek. Emergence traps captured caddisflies from 10 families, 22 genera and 31 species (Cobb *et al.* 1984). In that study, many fewer caddisfly taxa belonging to the suborder Annulipalpia were caught (4 families, 5 genera, 12 taxa). The lower diversity in Annulipalpia caught is probably due to the use of emergence traps and the size of the river and creek examined.

Elsewhere in Canada, Corbet *et al.* (1966) studied the adult caddisfly fauna along the St. Lawrence River at St. Helen's Island in Montréal, Quebec. Corbet *et al.* (1966) used light traps (Robinson traps) to catch adult caddisflies on 114 nights in 1964 and 181 nights in 1965. The fauna caught by Corbet *et al.* (1966) was represented by Spicipalpia (3 families, 10 genera, 19 taxa), the suborder Annulipalpia (5 families, 9 genera, 28 taxa) and Integripalpia (7 families, 18 genera, 50 taxa). A higher diversity of each suborder of caddisflies was caught in Montréal than on the Winnipeg River. This is likely because the St. Lawrence River is a larger river than the Winnipeg River and the authors of that study sampled more intensively, with nightly rather than weekly sampling. Corbet *et al.* (1966) collected samples on 283 nights over two years, whereas I collected samples on 57 nights over two years.

On the Winnipeg River over the two years of my study, more caddisflies were captured at Seven Sisters than at Great Falls Generating Station, 353121 versus 190813, respectively. This was likely due to the nature of the aquatic conditions around each site. At Seven Sisters, the tail race area consisted of shallow water, forming a defined riffle area that aided development of Annulipalia larvae. There were also numerous trees surrounding the tail race area, providing resting areas for adult caddisflies. At Great Falls, the tail race area consisted of much deeper water and there were no trees close to the dam.

The overall seasonality of caddisfly flight activity on the Winnipeg River was similar to flight activity in other areas of Canada. Where there were differences between the seasonal flight activity for a given species in my study and that from other areas of Canada, the differences may be related to the intensive nature of the sampling done and the sampling technique used in my study. Many studies have been conducted on caddisfly seasonality by monitoring emergence patterns only (e.g., Flannagan & Lawler 1972, Resh *et al.* 1983, Cobb *et al.* 1984). Caddisfly emergence alone does not, in all cases, accurately reflect the times of adult caddisfly flight activity. Emergence traps only have the opportunity to capture caddisflies as they leave the water whereas light traps have the opportunity to capture caddisflies over the entire period of their adult lives.

Hydropsyche simulans is found throughout central North America and adults are on the wing from May to late August (Nimmo 1987). Adult *H. simulans* were caught in Indiana from early June to late September (Waltz & McCafferty 1983). In my study, male *H. simulans* were caught outside from 9 June to 1 October and inside from 9 June to 22 September.

Also in the family Hydropsychidae, male *Hydropsyche alternans* (*H. alternans* = *H. recurvata* Banks) were caught in large numbers. *Hydropsyche alternans* is common in northern North America and is widespread in Canada (Nimmo 1987). *Hydropsyche alternans* was listed by Freeden (1971) as one of the pest species at St. Helen's Island, Montréal. This species was on the wing from 8 May to 16 October, with peak activity in June and July (Nimmo 1987). On the Winnipeg River, male *H. alternans* were caught outside from 26 May to 1 October and inside from 26 May to 22 September. In Manitoba, this species has been collected from the Roseau River, the Red River and the Souris River (Flannagan 1977, Flannagan & Flannagan 1982, Sebastien *et al.* 1989).

Cheumatopsyche gracilis is found transcontinentally in North America from at least 12 May to 29 August (Nimmo 1987). *Cheumatopsyche gracilis* is univoltine in Manitoba and has been reported to have a female-biassed sex ratio of 1:4 (Flannagan 1977). On the Winnipeg River, adult males of this species were caught outside from 26 May to 12 September and inside from 26 May to 22 September. It was not possible to determine the sex ratio of *C. gracilis* captured on the Winnipeg River only males could be identified to species. In Manitoba, this species has been collected from the Roseau River and God's River (Flannagan 1977, Flannagan & Flannagan 1982).

Cheumatopsyche speciosa is found from Alberta to Labrador and south to Oklahoma and South Carolina and adults have been collected from 6 July to 29 August with a diffuse peak in late June and July (Nimmo 1987). On the Winnipeg River, adult male *C. speciosa* were caught outside from 26 May to 12 September and inside from 26 May to 4 September. This species was included in the list of pest species presented by Corbet *et al.* (1966) at St. Helen's Island in Montréal. The sex ratio of *C. speciosa* was found to be female biassed (Kovats *et al.* 1996). In Manitoba, this species has previously been collected from the God's River (Flannagan & Flannagan 1982).

Neureclipsis valida is primarily a northern species, found from central Saskatchewan to eastern Hudson Bay and the eastern townships of Quebec, only found in the United States from New York and Minnesota (Nimmo 1986). From available Canadian records, adults of this species are active from 29 May to 12 September (Nimmo 1986). On the Winnipeg River, adults were caught outside from 9 June to 1 October and inside from 6 June to 16 October. In Manitoba, adult *N. valida* caught at Heming Lake in emergence traps were all females (Flannagan & Lawler 1972). Flannagan & Flannagan (1972) reported that this species has also been collected from McCreary Island, Lake Winnipeg and the Roseau River.

Psychomyia flavida is Holarctic and is generally on the wing from the start of June to the end of September (Schmid 1983). On the Winnipeg River, adult *P. flavida* were caught outside from 26 May to 12 September and inside from 9 June to 21 August.

Female *P. flavida* are known to be parthenogenetic in some locations (Corbet 1966b), although there is no evidence of this in Manitoba. This species was univoltine with peak adult flight activity at the start of July at the Roseau River in Manitoba (Flannagan 1977). Flannagan (1977) also found that *P. flavida* was the numerically dominant species on boulders in the Roseau River. *Psychomyia flavida* is found in lotic waters, small streams and creeks and has also been reported from Churchill, Lake Winnipeg and the Souris River (Flannagan & Flannagan 1982, Sebastien *et al.* 1989).

Two families in the suborder Integripalpia (i.e., Brachycentridae and Leptoceridae) were also represented in the ten dominant taxa caught on the Winnipeg River. *Micrasema rusticum* (Brachycentridae) is found in eastern and central North America and is generally on the wing from the end of May to middle of August (Schmid 1983). In my study, adults were caught outside from 26 May to 31 August and inside from 26 May to 27 July. The last capture date, 31 August, was represented by only three individuals. *Micrasema rusticum* is univoltine with a male-biassed sex ratio of 4:1 (Flannagan 1977). Hilsenhoff (1985) found *M. rusticum* to be semivoltine in Wisconsin, with a single short emergence period and two distinct larval size classes. In Manitoba, this species has been collected from the Roseau River (Flannagan 1977, Flannagan & Flannagan 1982).

In the Leptoceridae, *Ceraclea diluta* is found throughout central and eastern North America (Morse 1975). Adult *C. diluta* were very rare in Montréal; only four individuals were caught from 2 June to 4 July (Nimmo 1966). On the Winnipeg River, *C. diluta* was on the wing outside from 16 June to 31 August and inside from 9 June to 31 August. In Manitoba, this species has been collected from Lake Winnipeg (Flannagan & Flannagan 1982).

Other families in the suborder Integripalpia represented the least commonly collected species in my study, especially the Limnephilidae and Phryganeidae. These families are made up of species whose larvae develop in lentic habitats in portable tube-cases. The Limnephilidae and Phryganeidae species caught in my study likely developed in lentic habitats which surround and in some cases were formed by the construction of the dams.

The numbers of adult caddisflies caught inside the hydroelectric generating stations were similar at each site. This was not unexpected as each site was seen to have many areas through which caddisflies could enter (i.e., broken windows, windows left open, large spaces under doors, doors left open). The high temperatures and humidity and lack of wind within the generating stations allowed adult caddisflies to remain active indoors regardless of the weather conditions outside.

iii. Nocturnal Flight Periodicity

Diel periodicity of caddisfly flight activity has not been studied on many occasions. In most studies, the times of emergence and oviposition have been the focus (e.g., Corbet 1966b, Wrubleski & Ross 1989). Nimmo (1966) is an exception to this. In his study he examined the effect of environmental conditions on the diel flight activity of caddisflies in Montréal, Quebec. Direct comparisons cannot be made between my study and the study conducted by Nimmo (1966) for several reasons; because UV light was used as an attractant in his study; due to the differences in environmental and microclimate conditions between a rooftop in Montréal and beside hydroelectric generating stations in eastern Manitoba; and because I chose to do my hourly sampling on nights where temperatures were favourable and when winds were light. However, the conclusion that temperature and wind are the primary factors in determining the timing of evening peaks in flight activity (Nimmo 1966) is applicable to my study.

In my study, the peak caddisfly nightly outdoor flight activity occurred from 2300 to 0100, during which time 62% of the total nightly number was caught. This discrete peak in caddisfly flight activity can be used in the development of management practices to decrease the number of adult caddisflies entering the generating stations.

Overall, the number of caddisflies caught inside the stations seemed to be consistent from hour to hour throughout the night. This makes sense since inside the gate rooms the temperature remains the same and there is little or no wind.

iv. Avenues of Entry

a. Adults

The nature of the working conditions at hydroelectric generating stations may lead employees to open doors during the night. Temperatures inside air-cooled hydroelectric generating stations can be extremely high, prompting employees to attempt to cool the powerhouses during the night. Opening doors and windows that have no screens can allow large numbers of caddisflies to enter the stations, where they can accumulate and cause nuisance and/or allergy problems.

The extremely low number of caddisflies, two adults, caught in the emergence trap may be due to the type of emergence trap used in my study. The emergence trap used was constructed of opaque white plastic. Flannagan & Lawler (1972) indicated that an important factor in emergence trapping is that emerging pupae may avoid a trap because of the shading effect caused by traps constructed of light-absorbing materials. The emergence trap used in my study likely led to an underestimation of the number of caddisflies emerging through the gate openings into the generating stations. The large numbers of pharate adult caddisflies found in the debris on the surface of the open water in the gate openings were an indication that emergence was likely taking place within the stations. Caddisfly emergence directly into hydroelectric generating stations has not been reported in any other study.

b. Particulates

The presence of caddisfly and other insect particulates in nylon filters that were attached to turbine caps within the powerhouse of Seven Sisters demonstrated that the air-cooling system is a means of entry for caddisfly particulates. Particulates and the presence of caddisflies within the generating stations act as a source of the caddisfly allergen since it is believed that caddisfly setae and body particles are responsible for inhalant allergic reactions in atopic individuals (Parlato *et al.* 1934, Osgood 1956a, 1956b, Kraut *et al.* 1994).

v. Management Implications

a. Impact on Employees

The presence of caddisfly particulates and adults within the generating stations has led to work-related allergies among Manitoba Hydro employees. Kraut *et al.* (1994) found that employees who work in areas with high exposure to caddisflies had more work-related allergic symptoms and were 5.3 times more likely to react to a commercial caddisfly antigen in skin prick tests. Manitoba Hydro staff employed as technicians were most commonly associated with positive skin prick tests to commercial caddisfly allergen (Kraut 1996). The design of these particular generating stations, as air-cooled systems, promotes the addition of caddisfly allergen into the stations.

Caddisflies emerge throughout most of the open-water season along the Winnipeg River. However, the peak flight activity occurs over a short, well-defined period from approximately the middle of June to the middle or end of July. Adult caddisflies and their particulates enter the stations by coming in from the outside, emerging into the gate rooms and being drawn in through the air-cooling system. To decrease employee exposure to caddisfly allergens, these points of entry must be managed.

b. Health and Safety Recommendations

To decrease the number of adult caddisflies entering the stations, screens and windows must be repaired, and windows or doors without screens must be kept closed during peak times of adult caddisfly activity. Unnecessary lights inside and outside the stations should be turned off before dusk. If this is not feasible, then lights should be dimmed during peak caddisfly nightly flight periods (i.e., from 2300 to 0100). Also, gate openings should be screened as a preventative measure to decrease the number of caddisflies emerging directly into the stations.

Employee exposure to the allergenic insect particulates can be reduced by continuing to vacuum up carcasses. However, at the time of my study, the Seven Sisters vacuum exhaust was located in an area that could increase employee exposure to insect particulate. The debris vacuumed up within the generating station was vented out to an area where the prevailing wind carried the debris toward the air intake screens and potentially back into the station. Therefore, the vacuum exhaust at Seven Sisters should be moved to a more suitable location. In the past, the insects that were stuck to the air intake screens were swept off, leading to a larger amount of insect particulates being drawn into the generating stations. Instead, insect debris should be vacuumed from the air intake screens on a daily or weekly basis during peak caddisfly flight activity. Vacuuming the screens is a viable option because the turbines are not always running at full power.

Employee exposure to aeroallergens could be further reduced in one of two ways.

First, the air intake screens could be raised to a higher location, such as on top of the station, with very little or no lighting around them. However, this would cause several problems associated with air flow to the turbine shaft, and would not completely eliminate the insect particulates entering the stations. Second, more complete control could be achieved by switching the generating stations from air-cooled to water-cooled systems. The feasibility of this option is unknown.

vi. Conclusions

The Winnipeg River is a large, fast-flowing river that runs north and west over 260 km (Manitoba Hydro 2001). The bedrock of the region is close to the surface and forms a series of deep natural reservoirs that have been utilized by Manitoba Hydro. The Winnipeg River is composed of many habitats that can be exploited by aquatic insects.

The development of hydroelectric power generating stations added three habitat types to the Winnipeg River. In the forebay areas, the dams create deep reservoirs that are good for the development of lentic species. The turbines create a very fast-flowing, lotic habitat with considerable artificial substrate, in the form of the cement scroll casing around the turbines and the debris that accumulates against the trash racks. There is also a fast-flowing riffle area below the dam itself in the tail race area. These additional habitats have been greatly exploited by Annulipalpia caddisfly larvae and have led to a diverse group of caddisfly adults (5 families, 9 genera and 19 taxa) present in very large numbers. This suborder of caddisflies represented the most abundant caddisflies caught in my study.

The abundance of adult caddisflies and their particulates have led to nuisance and allergy problems among the employees of Manitoba Hydro, who work and live close to the dams. Peak seasonal caddisfly flight activity takes place from approximately mid-June to the end of July, with peak nightly flight activity occurring from 2300 to 0100. These discrete flight periods should allow management practices to be put into place that would decrease the problems associated with caddisflies at the generating stations along the Winnipeg River or at least reduce the numbers of caddisflies entering the stations.

Table 1. Total numbers of Trichoptera, extrapolated from sub-sample abundance and unadjusted for sub-sampling efficiency, collected in light traps at Winnipeg River Generating Stations (Great Falls and Seven Sisters): 1997 and 1998.

Taxa	Great Falls		Seven Sisters	
	1997	1998	1997	1998
Glossosomatidae				
Protoptila maculata (Hagen)	0	0	2	0
Hydroptilidae				
Hydroptila females	578	363	1679	2071
H. albicornis Hagen	146	275	215	294
H. amoena Ross	38	6	41	35
H. angusta Ross	1	0	25	2
H. consimilis Morton	75	52	32	96
H. hamata Morton	26	9	58	27
H. virgata Ross	3	5	3	1
H. waubesiana Betten	1	4	26	36
Agraylea multipunctata Curtis	119	13	44	54
Ithytrichia clavata Morton	93	0	139	0
Leucotrichia cf. pictipes (Banks)	0	0	17	0
Ochrotrichia females	141	0	36	41
O. tarsalis Hagen	30	2	82	148
Oxyethira females	11	2	22	534
O. aeola Ross	14	3	51	203
Mayatrichia ayama Mosely	0	0	85	0
Philopotamidae				
Chimarra aterrima Hagen	28	106	3806	3133
Hydropsychidae				
Cheumatopsyche females	14392	9475	12333	8213
C. gracilis (Banks)	1495	1943	976	618
C. speciosa (Banks)	1588	757	1076	212
C. campyla Ross	4	0	0	0
Hydropsyche females	19386	26255	82420	89867
H. alternans (Walker)	12312	3916	4921	1514
H. bidens Ross	36	131	97	185
H. scalaris Hagen	0	0	2	0
H. simulans Ross	4092	8170	29162	5365
H. slossonae Banks	0	1	0	0
Potamyia flava (Hagen)	50	5	93	5

Continued

Taxa	Great Falls		Seven Sisters	
	1997	1998	1997	1998
Psychomyiidae				
Psychomyia flavida Hagen	196	1236	3400	4364
Polycentropodidae				
Neureclipsis crepuscularis (Walker)	1161	840	1340	736
N. valida (Walker)	15531	10315	3190	5480
Nyctiophylax sp.	1	0	0	0
Polycentropus cinereus (Hagen)	3	0	15	18
P. interruptus (Banks)	0	1	2	12
Dipseudopsidae				
Phylocentropus placidus (Banks)	44	15	6	40
Brachycentridae				
Micrasema rusticum (Hagen)	588	1262	4091	1313
M. wataga Ross	0	0	0	1
Lepidostomatidae				
Lepidostoma cf. togatum Hagen	222	1275	226	1398
Limnephilidae				
Anabolia bimaculata Walker	0	2	0	1
Glyphopsyche irrorata (Fabricius)	0	0	8	0
Limnephilus dispar McLachlan	0	0	2	1
L. hyalinus Hagen	1	0	0	0
L. indivisus Walker	1	0	0	0
L. minisculus (Banks)	0	0	3	0
L. moestus Banks	9	0	0	16
L. parvulus (Banks)	1	0	1	0
L. sackeni Banks	0	0	3	0
L. sericeus (Say)	0	11	1	0
Nemotaulius hostilis Hagen	0	0	1	0
Platycentropus radiatus (Say)	0	0	0	1
Pycnopsyche guttifer (Walker)	0	1	0	0
P. subfasciata (Say)	1	9	5	0

Continued

Taxa	Great Falls		Sėven Sisters	
	1997	1998	1997	1998
Phryganeidae				
Agrypnia deflata (Milne)	0	1	0	0
A. improba (Hagen)	0	0	2	0
Phryganea cinerea Walker	0	2	0	3
Banksiola crotchi Banks	0	6	0	14
Leptoceridae				
Ceraclea albosticta (Hagen)	4	0	27	0
C. ancylus (Vorhies)	57	386	187	480
C. annulicornis (Stephens)	1423	396	404	211
C. cancellata (Betten)	49	37	369	285
C. diluta (Hagen)	2235	3250	330	1022
C. erratica (Milne)	27	0	49	23
C. flava (Banks)	10	1	67	8
C. maculata (Banks)	12	13	56	57
C. mentiea (Walker)	95	18	439	22
C. tarsipunctata (Vorhies)	196	57	215	84
C. transversa Hagen	72	8	118	78
Nectopsyche spp.	420	116	253	96
Oecetis avara (Banks)	287	81	1092	784
O. cinerascens (Hagen)	54	3	41	0
O. immobilis (Hagen)	7	2	27	5
O. inconspicua (Walker)	327	375	1607	821
O. ochracea (Curtis)	20	0	15	0
Mystacides longicornis (Linnaeus)	2	1	0	0
Triaenodes baris/tarda	2	4	0	1
T. frontalis Banks	7	0	2	17
T. grisea Banks	0	0	0	2
Molannidae				
Molanna flavicornis Banks	34	25	299	179
M. uniophila Vorhies	2	0	15	0
Helicopsychidae				
Helicopsyche borealis Hagen	59	0	109	9

Table 2. Total estimated numbers of the 10 dominant caddisfly taxa caught at Great Falls and Seven Sisters Hydroelectric Generating Stations and the percentage of the total catch they represent.

Taxa	1997	1998	Grand total	% of total
Hydropsyche females	101,807	122,095	223,902	54
Cheumatopsyche females	26,725	19,564	46,289	11
Hydropsyche simulans males	25,084	15,576	40,660	10
Neureclipsis valida	18,722	16,212	34,938	8
Hydropsyche alternans males	17,241	5,431	22,672	5
Psychomyia flavida	3,597	5,626	9,223	2
Micrasema rusticum	4,679	2,575	7,254	2
Ceraclea diluta	2,566	4,529	7,095	2
Cheumatopsyche gracilis males	2,566	4,529	7,095	2
Cheumatopsyche speciosa males	2,640	1,319	3,959	1
Unknown (Unidentifiable)[1]			416,943	

[1] Unknown caddisflies were those in which genitalia had been damaged or were not present, but which were intact otherwise.

Table 3: Qualitative results of direct observation of caddisfly flight activity on four nights at Great Falls (GF) and Seven Sisters (SS), 1997 and 1998. Flight activity was ranked as low (under 500 caddisflies), moderate (500 to 1000 caddisflies) or high (more than 1000 caddisflies).

	1997		1998	
	10 July (GF)	24 July (SS)	6 July (GF)	13 July (SS)
2100	Low	Low	Low	Low
2200	Low	Low	Low	Low
2300	High	High	Moderate	Moderate
2400	High	High	High	Moderate
0100	Low	High	High	Moderate
0200	Low	Moderate	Moderate	Low
0300	Low	Moderate	Moderate	Low
0400	Low	Low	Low	Low
0500	Low	Low	Low	Low

Table 4: Mean number (± SE) of Trichoptera moving on or through a 0.1 m^2 or 0.2 m^2 area of air intake screens at Great Falls (10 and 11 July, 1997) and Seven Sisters (17 and 18 July, 1997) in three one-minute increments during each observation period.

Site	**Date**	**Time**	**Size of area**	**No. caddisflies**
Great Falls	10 July 1997	2125	0.2 m^2	0 ± 0
	11 July 1997	0040	0.2 m^2	0.7 ± 0.7
	11 July 1997	0525	0.2 m^2	1.7 ± 1.5
Seven Sisters	17 July 1997	2245	0.2 m^2	6.3 ± 1.9
	18 July 1997	0225	0.2 m^2	36.0 ± 14.0
			0.1 m^2	9.0 ± 4.0
	18 July 1997	0530	0.2 m^2	0.7 ± 0.7

Figure 1. Schematic diagram of cross-section through a generating station (Manitoba Hydro, 1996).

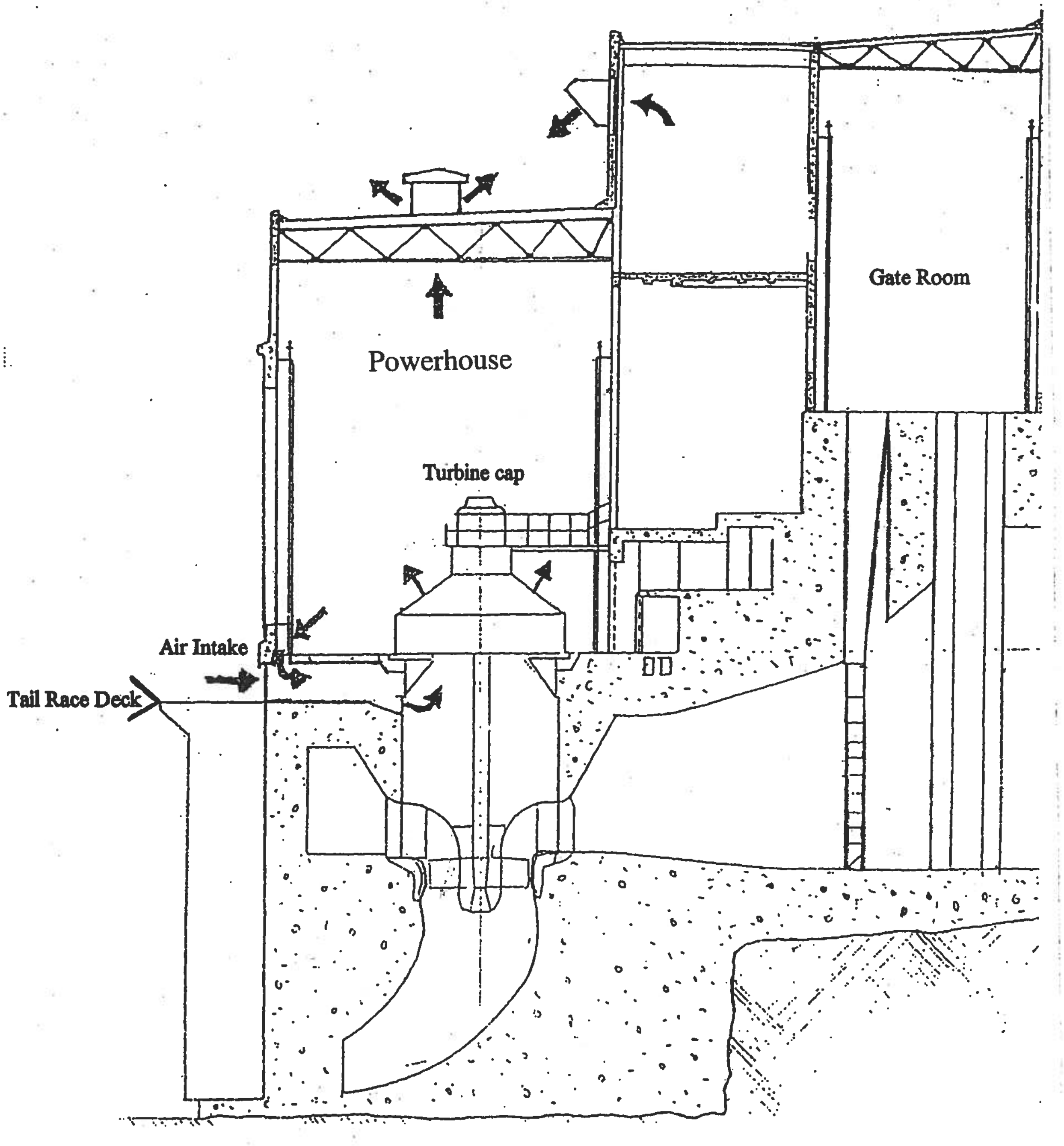

Gate Room
Powerhouse
Turbine cap
Air Intake
Tail Race Deck

Figure 2. Photograph of Seven Sisters Hydroelectric Generating Station with trapping locations indicated as 1 (Tailrace deck), 2 (Spillway), 3 (beside tailrace water) and 4 and 5 (inside Gate room).

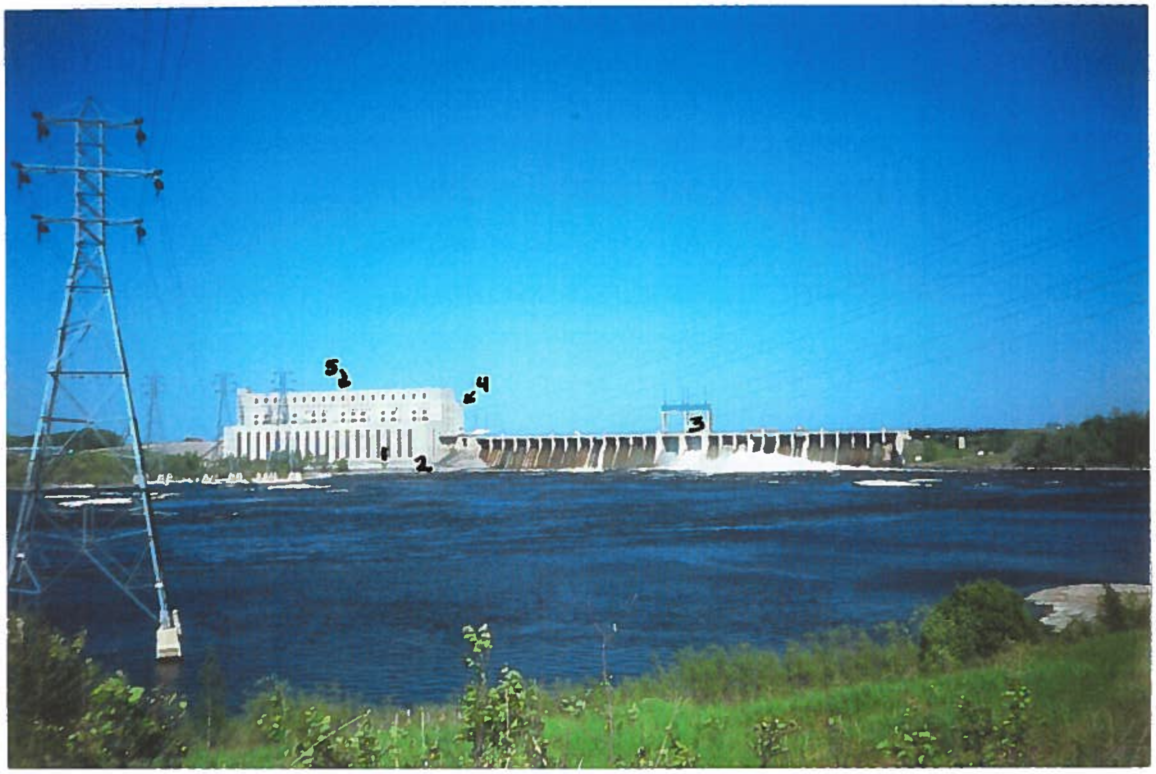

5
4
3
1
2

Figure 3. Tripod with modified New Jersey Light Trap, set up at Great Falls Generating Station.

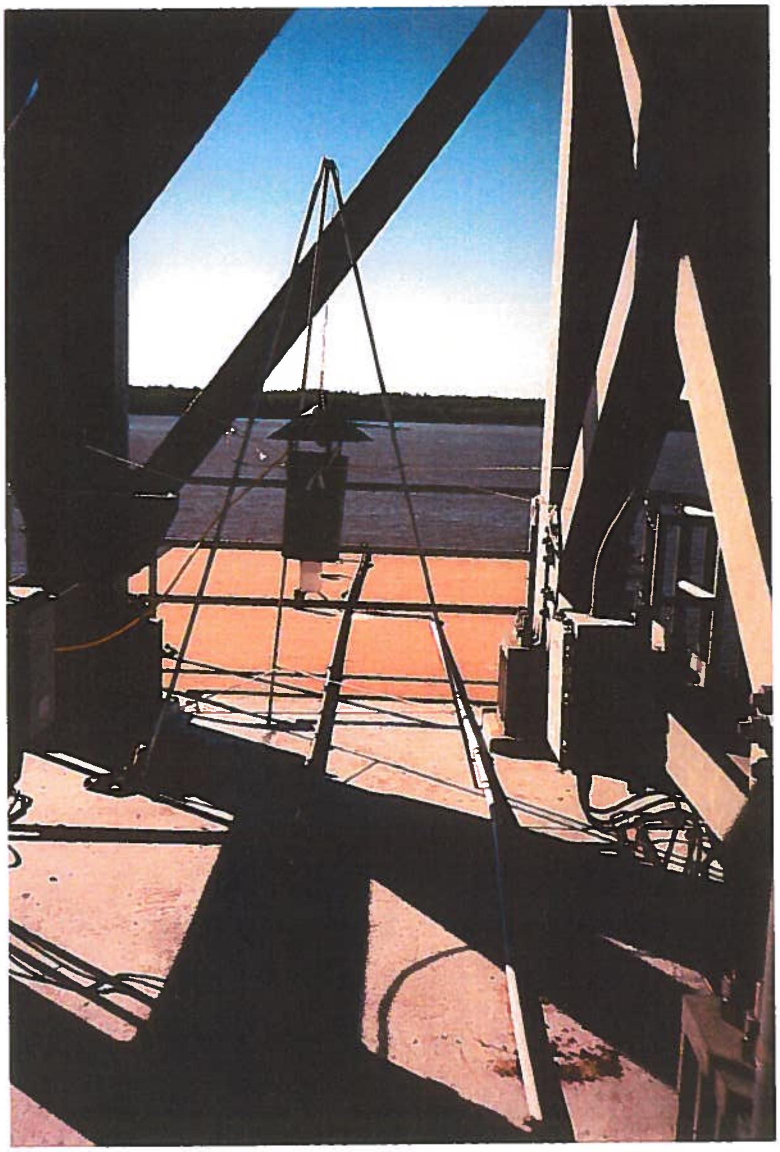


Figure 4. Estimated mean total number of caddisfly adults caught inside and outside of Great Falls and Seven Sisters Hydroelectric Generating Stations in 1997 and 1998.

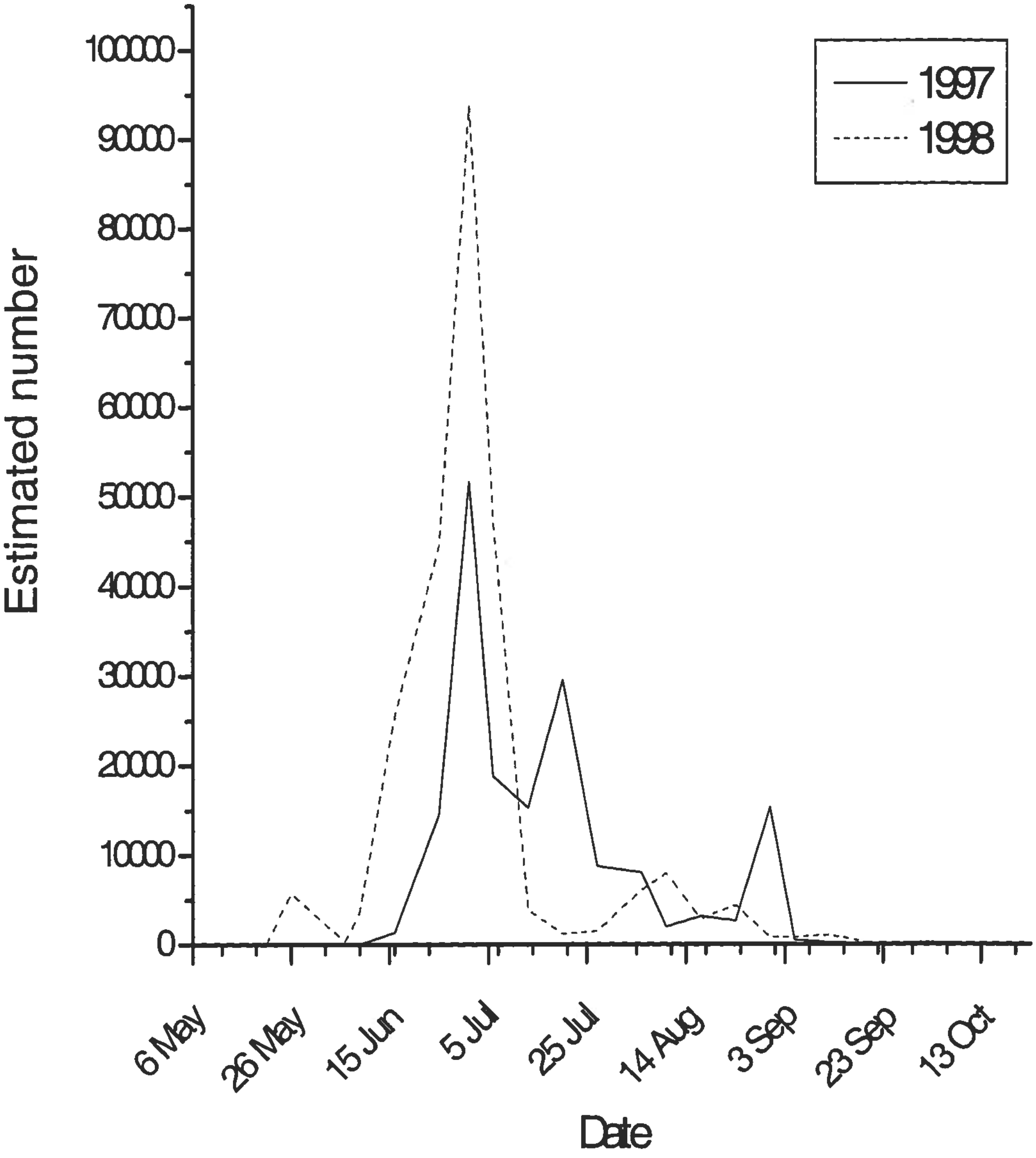

Estimated number
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
6 May
26 May
15 Jun
5 Jul
25 Jul
14 Aug
3 Sep
23 Sep
13 Oct
Date
1997
1998

Figure 5. Mean (± SE) number of female *Hydropsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

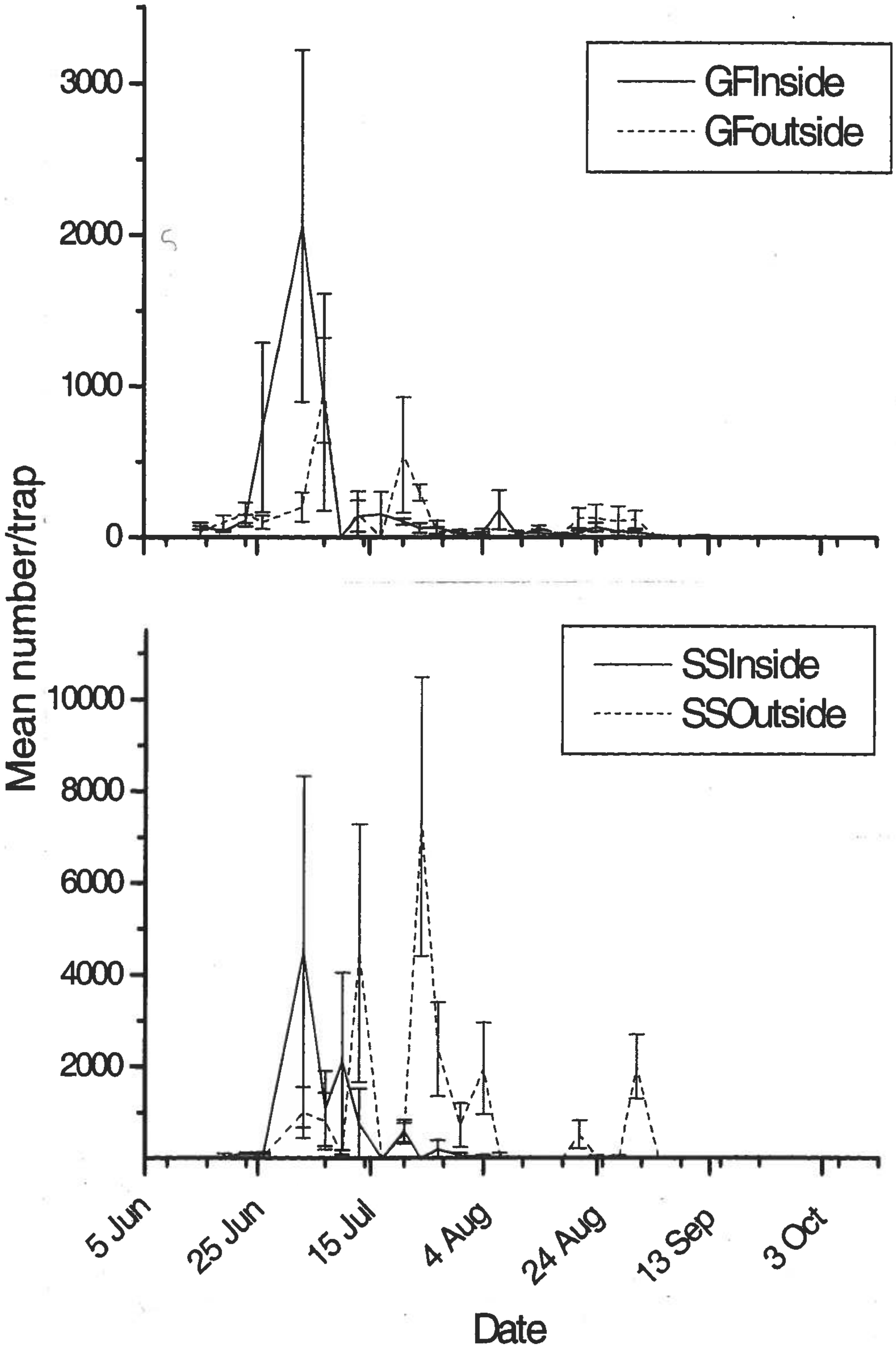

GFInside
GFoutside
SSInside
SSOutside
Mean number/trap
3000
2000
1000
0
10000
8000
6000
4000
2000
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
3 Oct
Date

Figure 6. Mean (± SE) number of female *Hydropsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

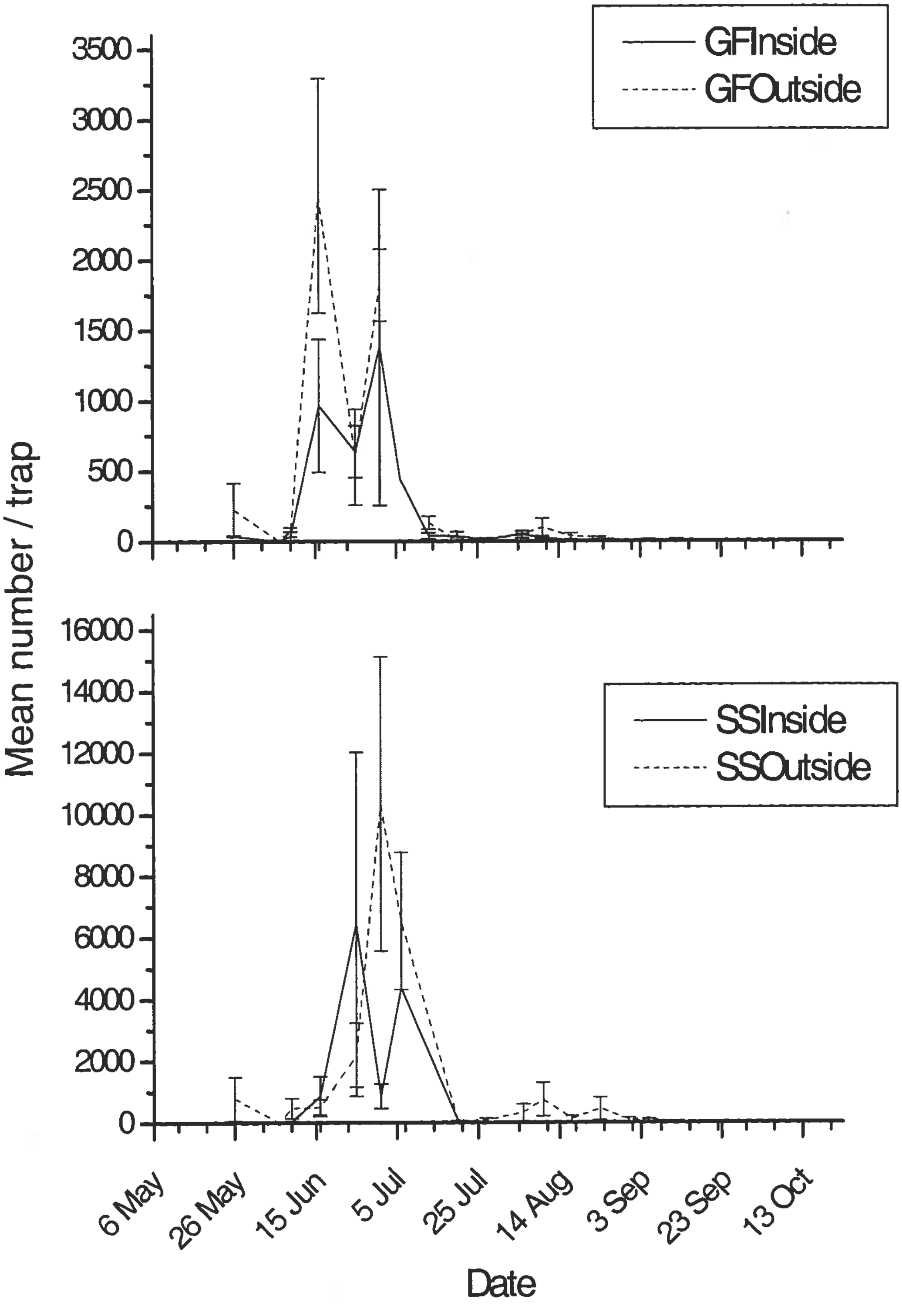

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
3500
3000
2500
2000
1500
1000
500
0
16000
14000
12000
10000
8000
6000
4000
2000
0
6 May
26 May
15 Jun
5 Jul
25 Jul
14 Aug
3 Sep
23 Sep
13 Oct
Date

Figure 7. Mean (±SE) number of female *Cheumatopsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

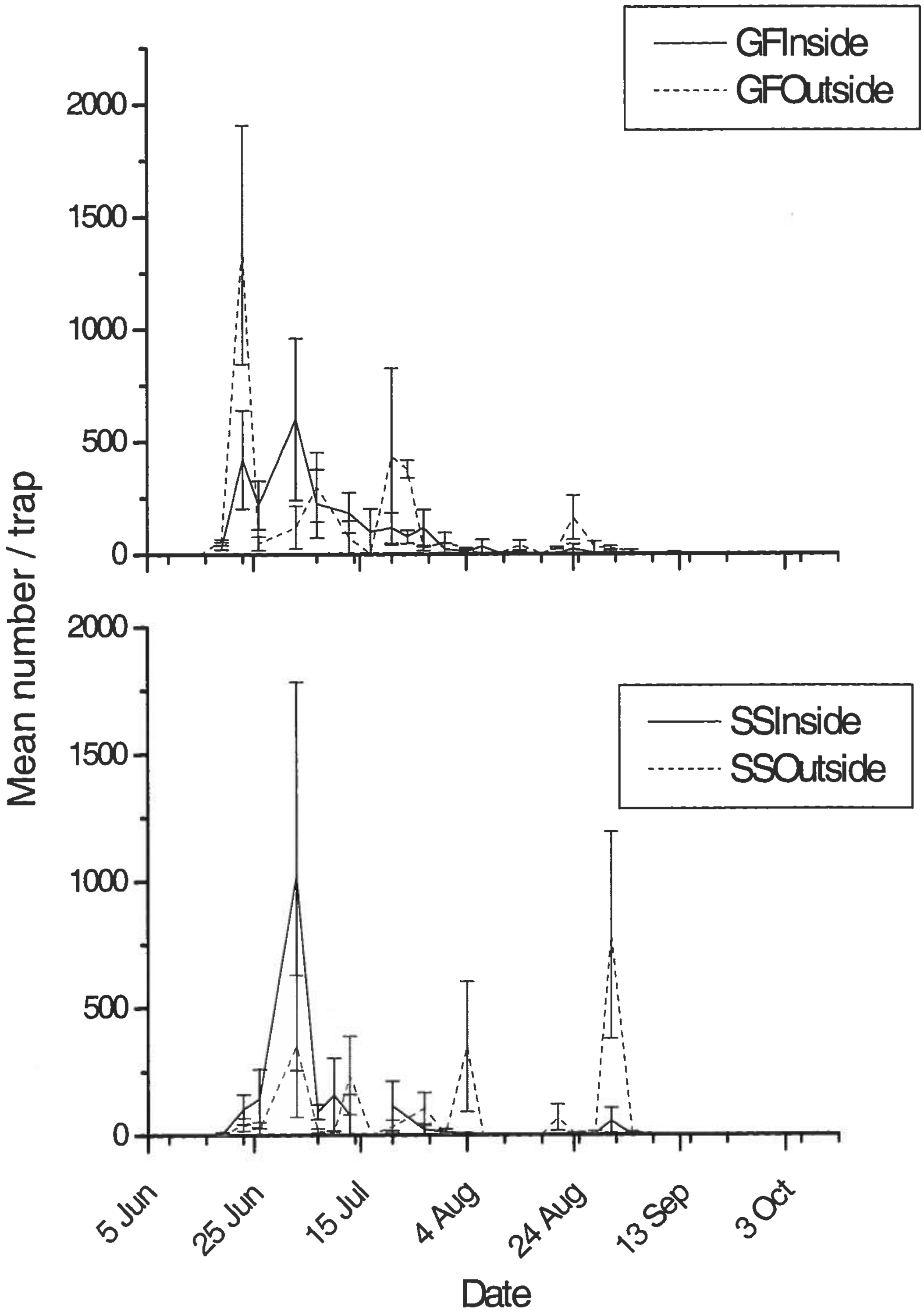

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
0
500
1000
1500
2000
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
3 Oct
Date

Figure 8. Mean (± SE) number of female *Cheumatopsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

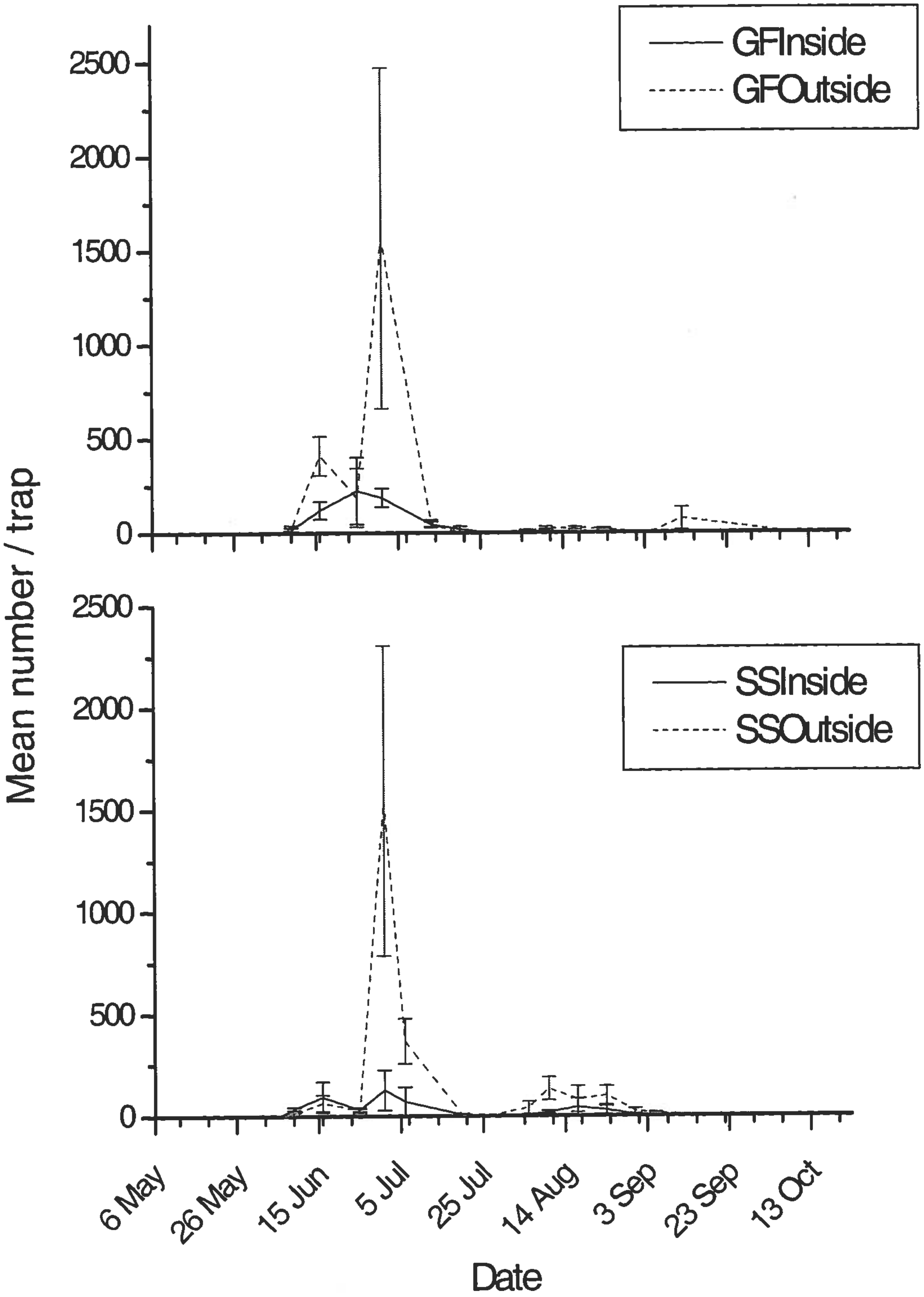

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
2500
2000
1500
1000
500
0
6 May
26 May
15 Jun
5 Jul
25 Jul
14 Aug
3 Sep
23 Sep
13 Oct
Date

Figure 9. Mean (± SE) number of male *Hydropsyche simulans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

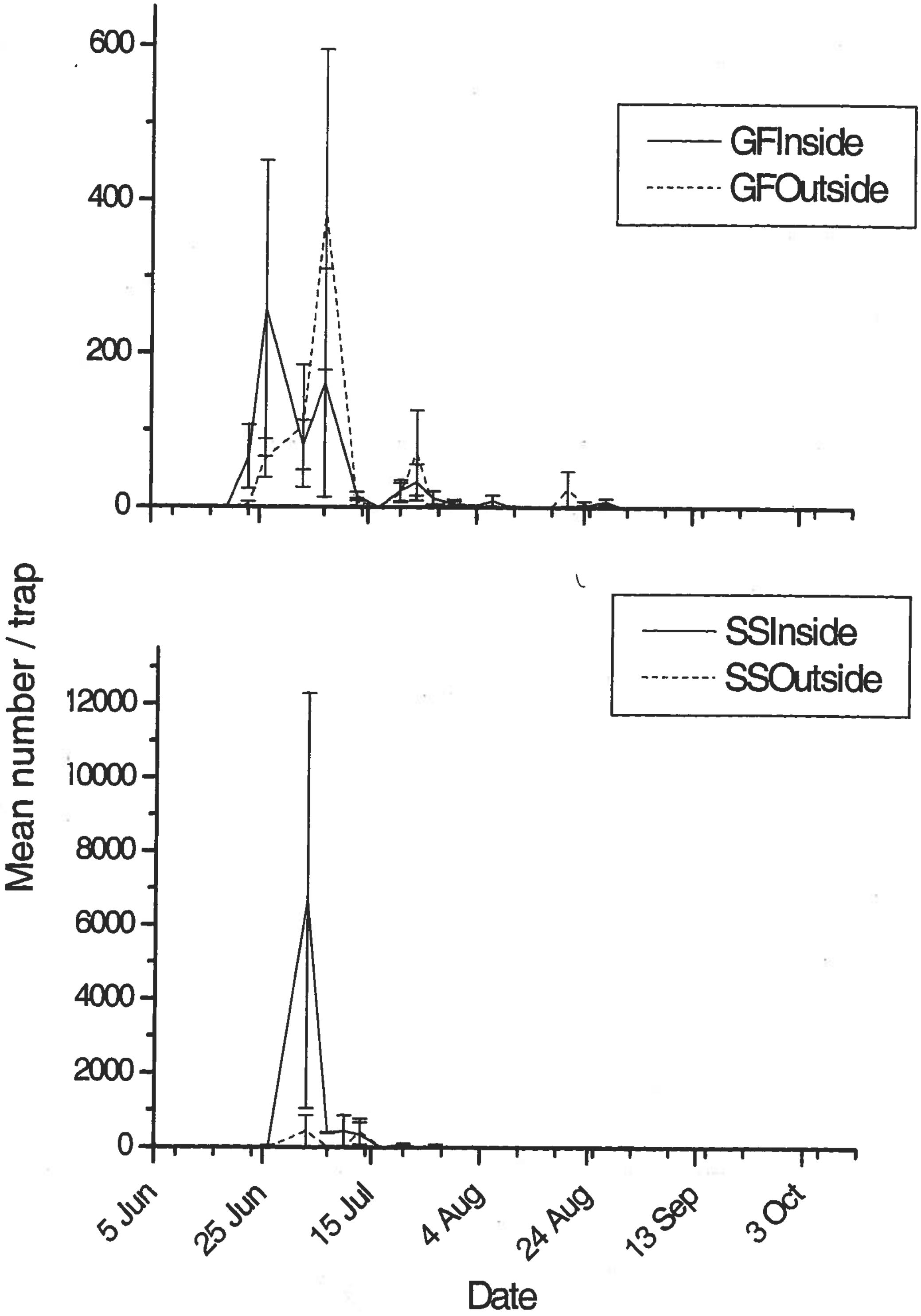

600
400
200
0
GFInside
GFOutside
Mean number / trap
12000
10000
8000
6000
4000
2000
0
SSInside
SSOutside
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
3 Oct
Date

Figure 10. Mean (± SE) number of male *Hydropsyche simulans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

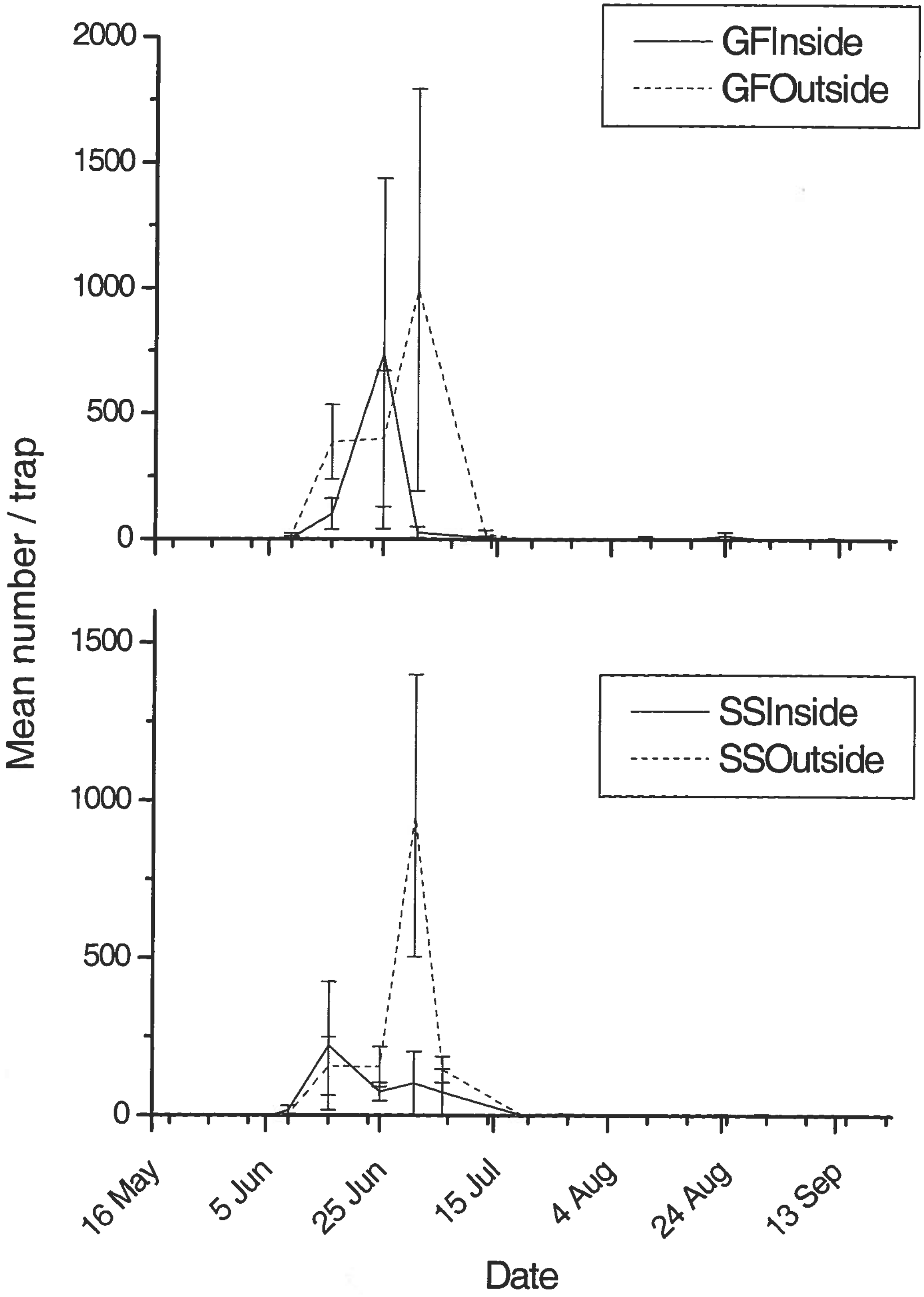

2000
1500
1000
500
0
GFInside
GFOutside
1500
1000
500
0
SSInside
SSOutside
Mean number / trap
16 May
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
Date

Figure 11. Mean (± SE) number of *Neureclipsis valida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

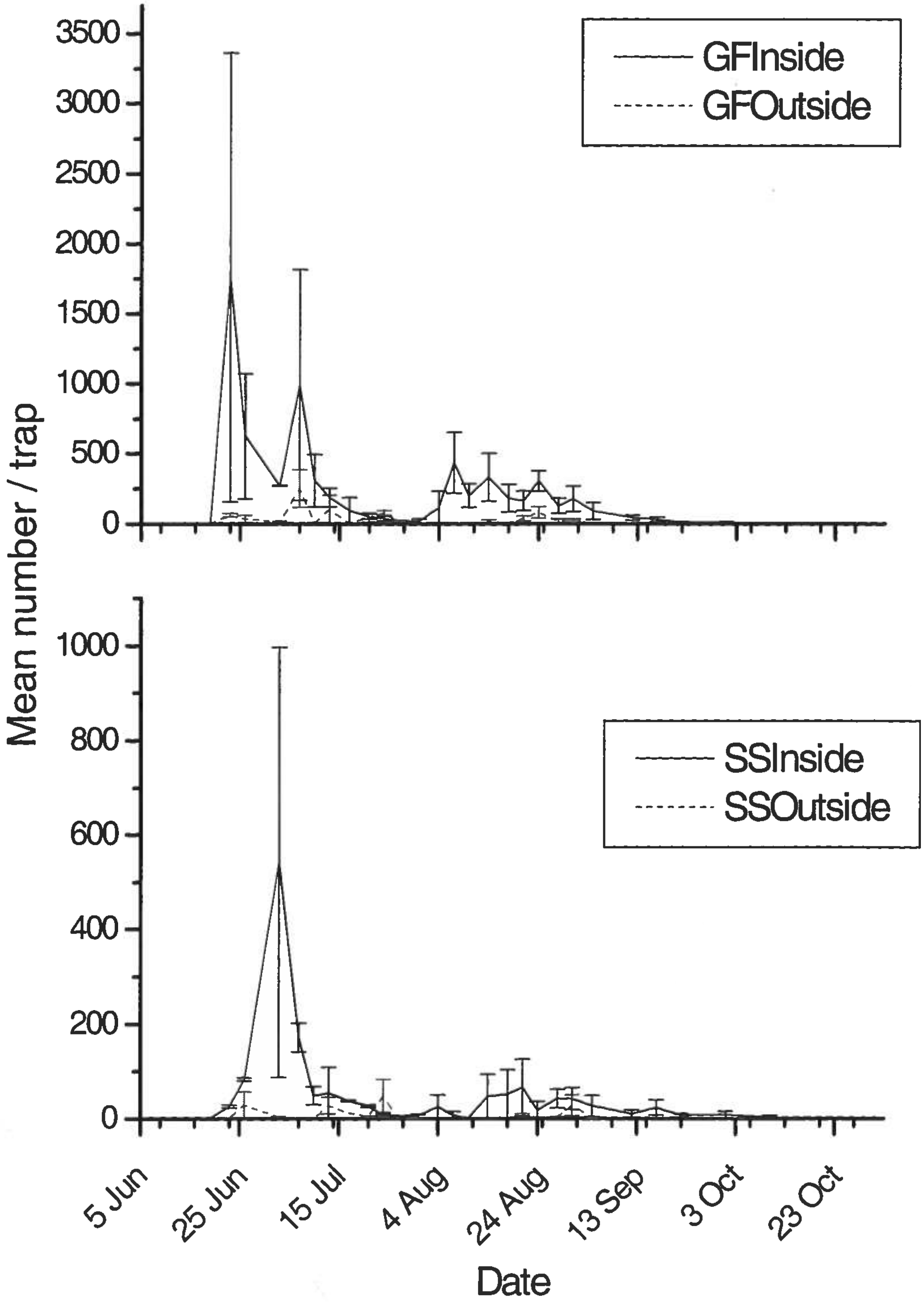

Mean number / trap
3500
3000
2500
2000
1500
1000
500
0
GFInside
GFOutside
1000
800
600
400
200
0
SSInside
SSOutside
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
3 Oct
23 Oct
Date

Figure 12. Mean (± SE) number of *Neureclipsis valida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

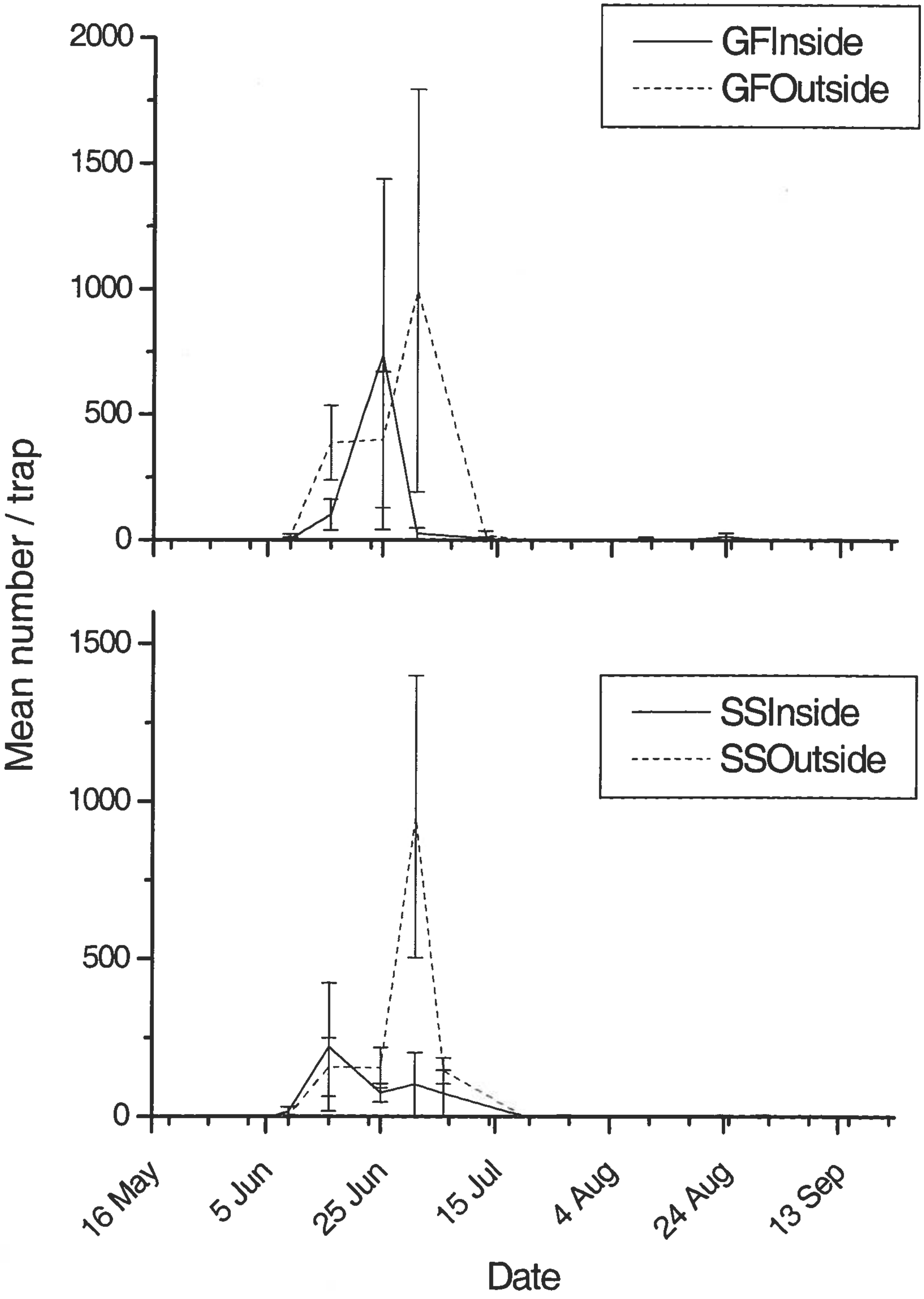

2000
1500
1000
500
0
GFInside
GFOutside
1500
1000
500
0
SSInside
SSOutside
Mean number / trap
16 May
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
Date

Figure 13. Mean (± SE) number of male *Hydropsyche alternans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

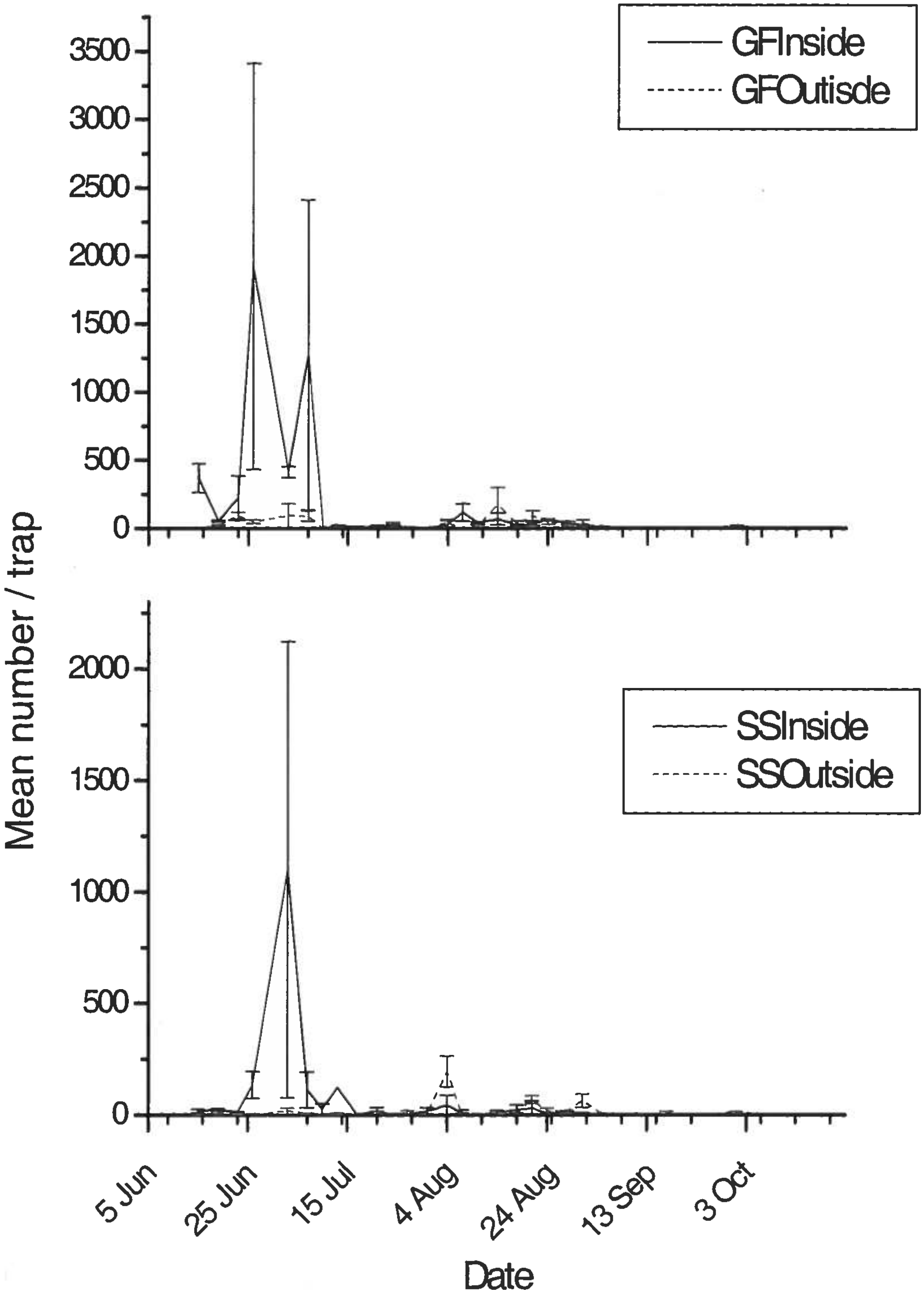

GFInside
GFOutisde
SSInside
SSOutside
Mean number / trap
0
500
1000
1500
2000
2500
3000
3500
0
500
1000
1500
2000
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
3 Oct
Date

Figure 14. Mean (± SE) number of male *Hydropsyche alternans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

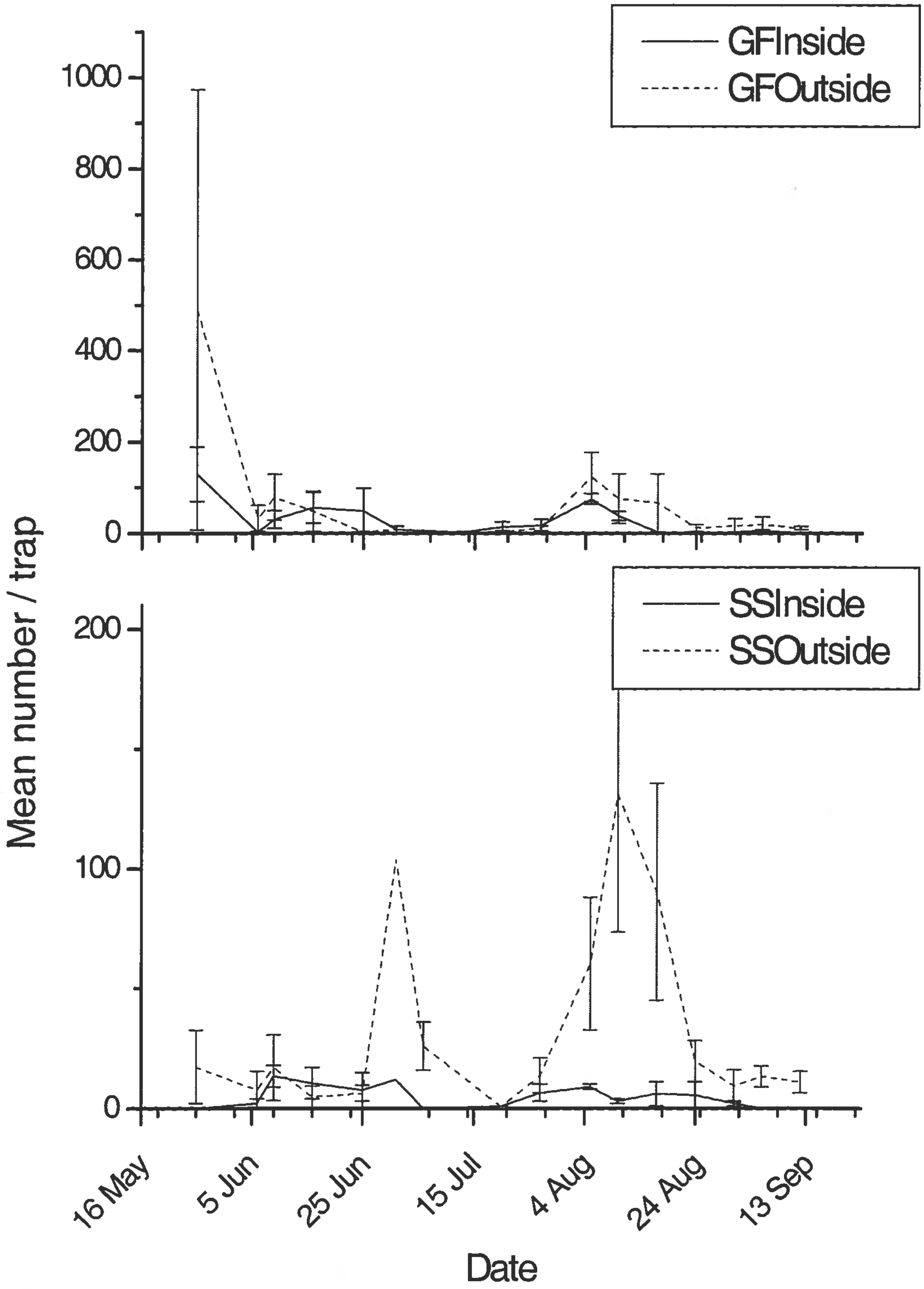

GFInside
GFOutside
1000
800
600
400
200
0
SSInside
SSOutside
200
100
0
Mean number / trap
16 May
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
Date

Figure 15. Mean (± SE) number of *Psychomyia flavida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997.

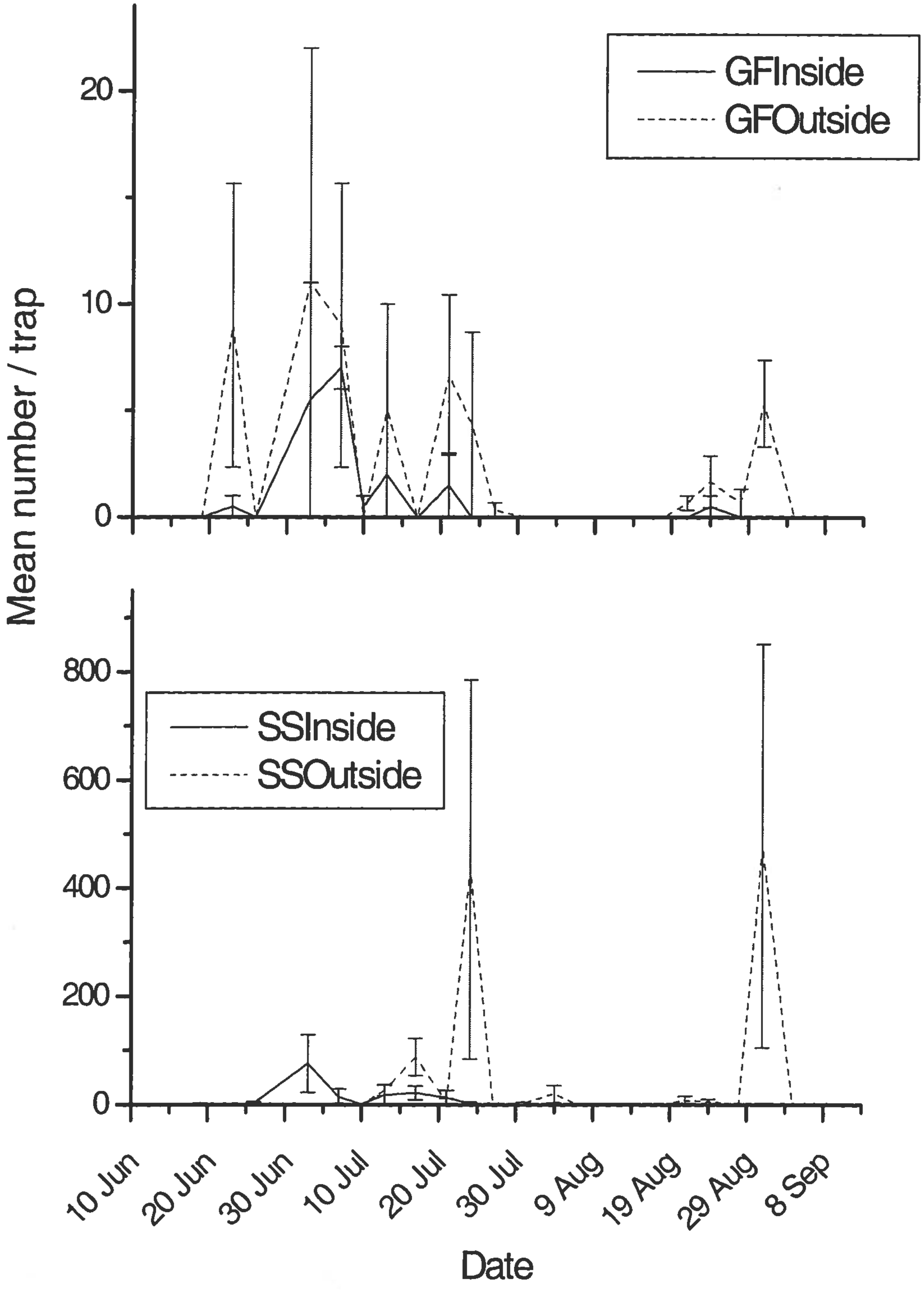

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
0
10
20
0
200
400
600
800
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
Date

Figure 16. Mean (± SE) number of *Psychomyia flavida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998.

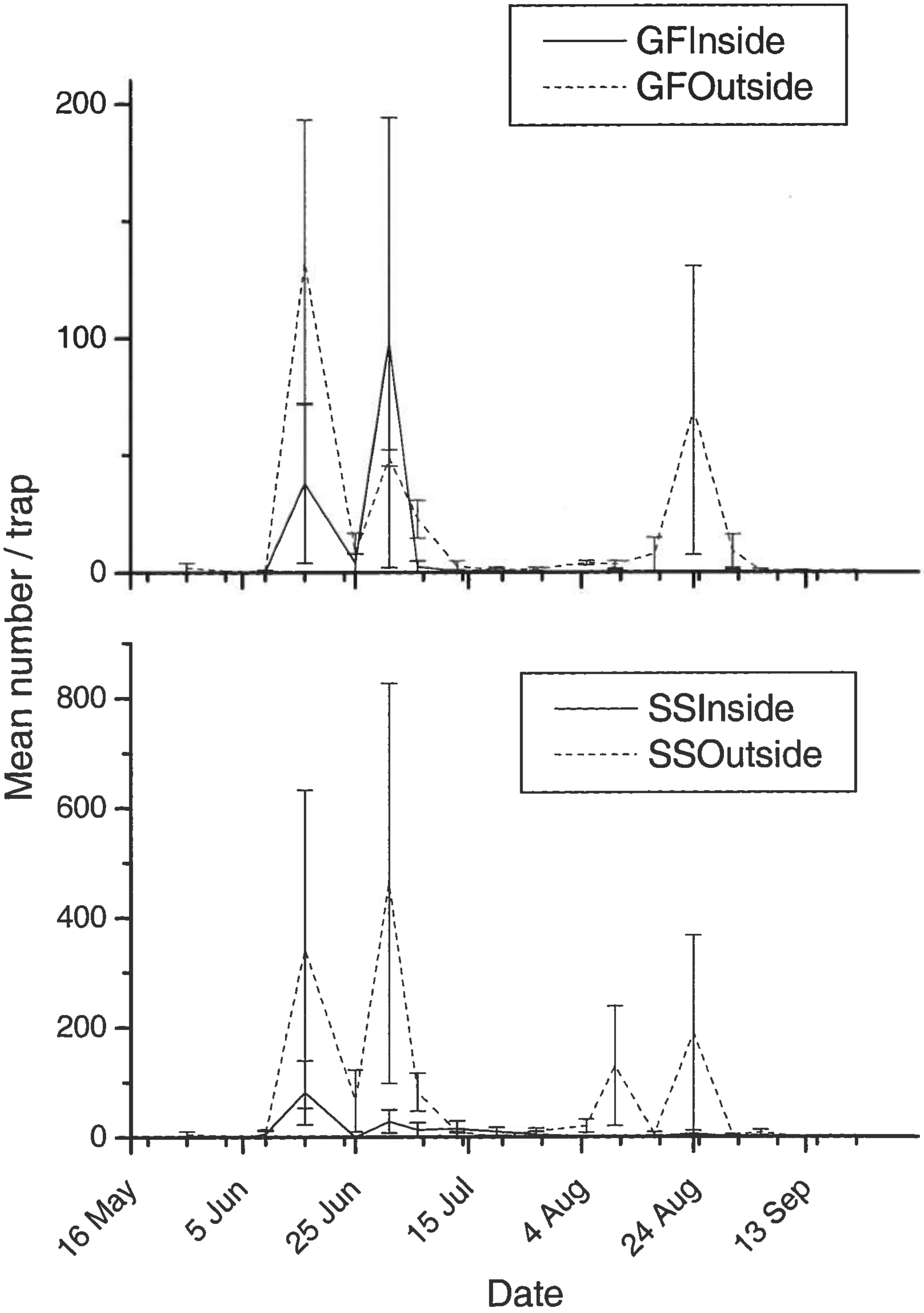

GFInside
GFOutside
SSInside
SSOutside
200
100
0
800
600
400
200
0
Mean number / trap
16 May
5 Jun
25 Jun
15 Jul
4 Aug
24 Aug
13 Sep
Date

Figure 17. Mean (± SE) hourly number of female *Hydropsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

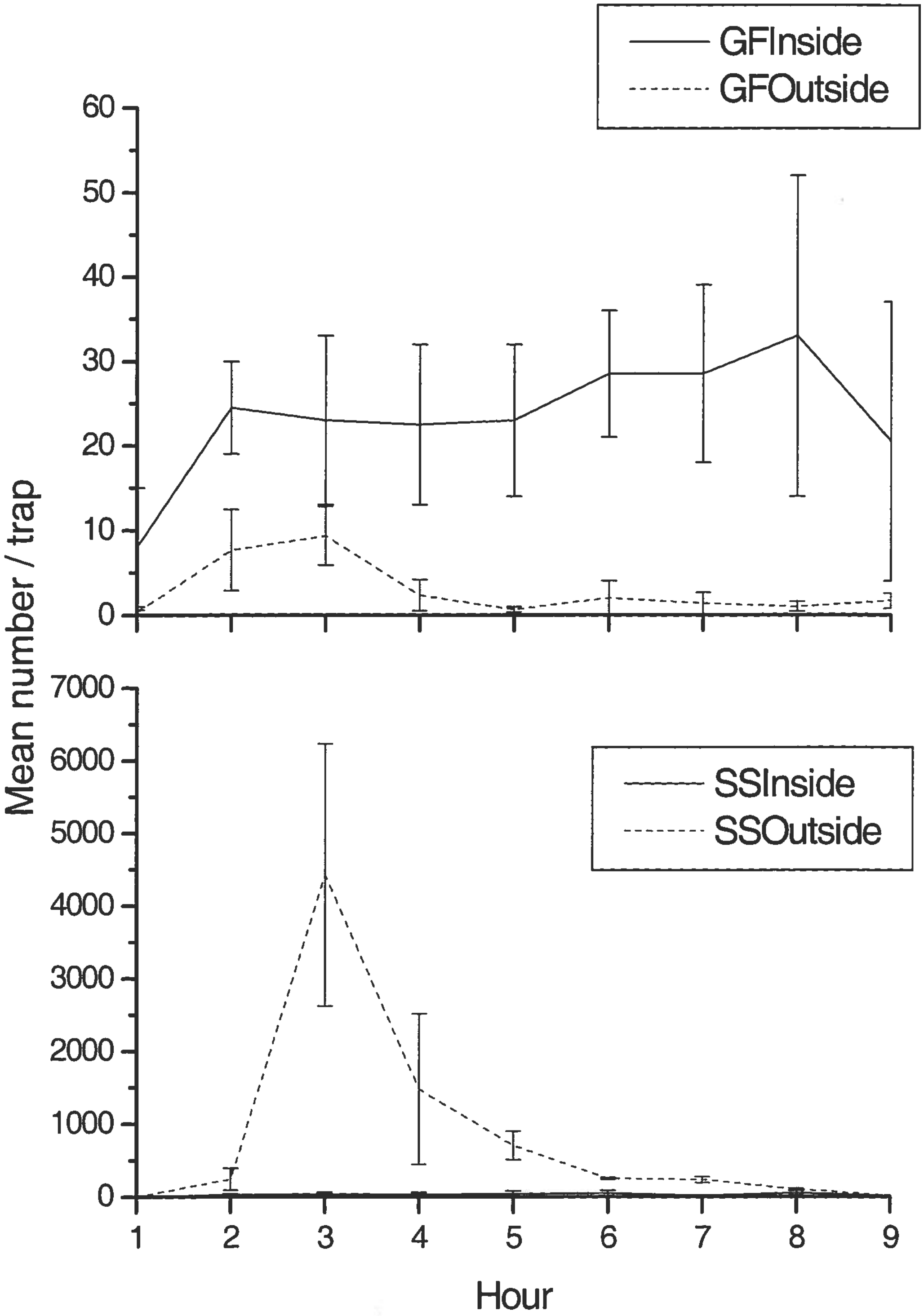

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
10
20
30
40
50
60
0
1000
2000
3000
4000
5000
6000
7000
1
2
3
4
5
6
7
8
9

Figure 18. Mean (± SE) hourly number of female *Hydropsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

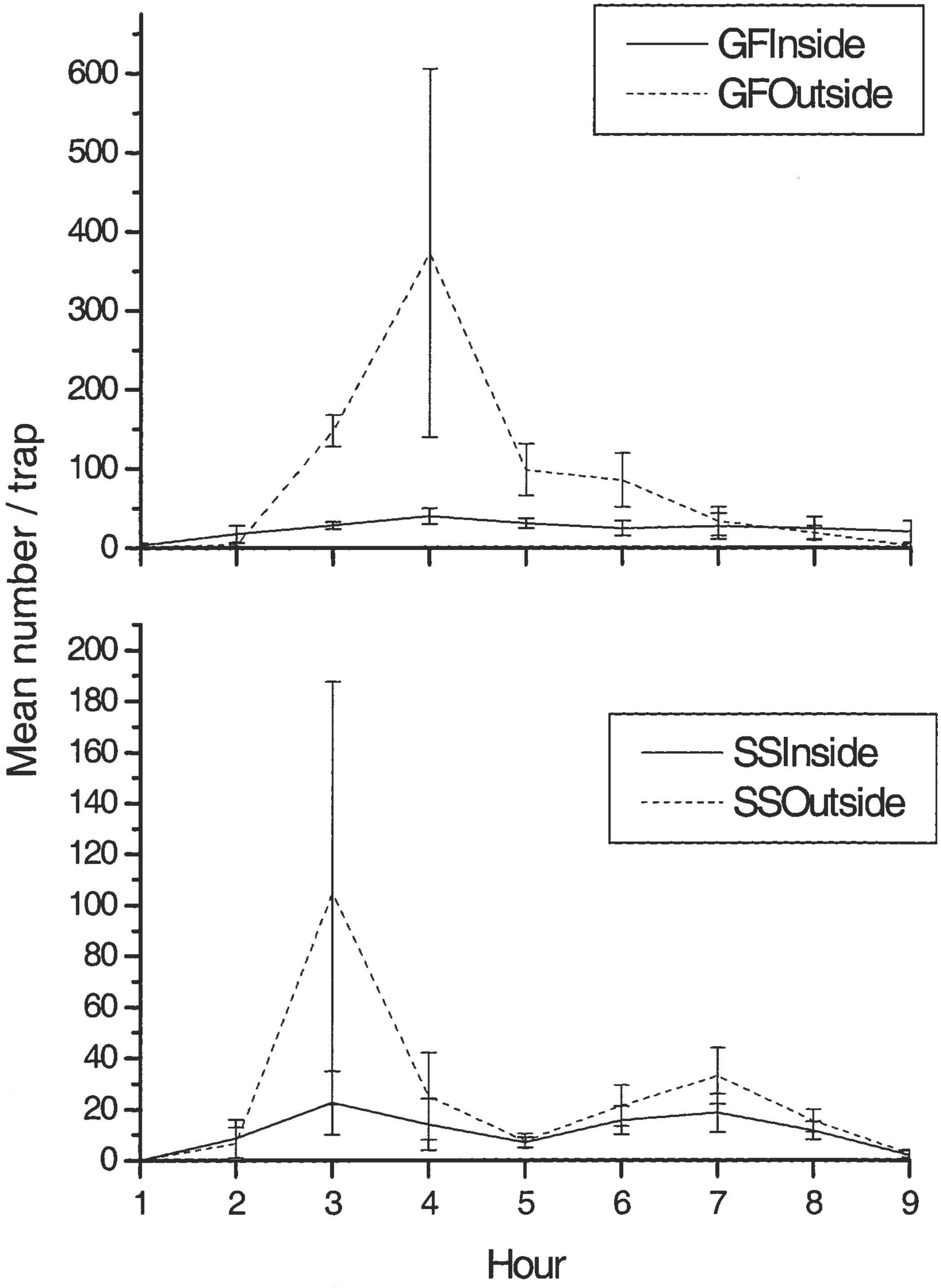

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
100
200
300
400
500
600
20
40
60
80
100
120
140
160
180
200
1
2
3
4
5
6
7
8
9

Figure 19. Mean (± SE) hourly number of female *Cheumatopsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

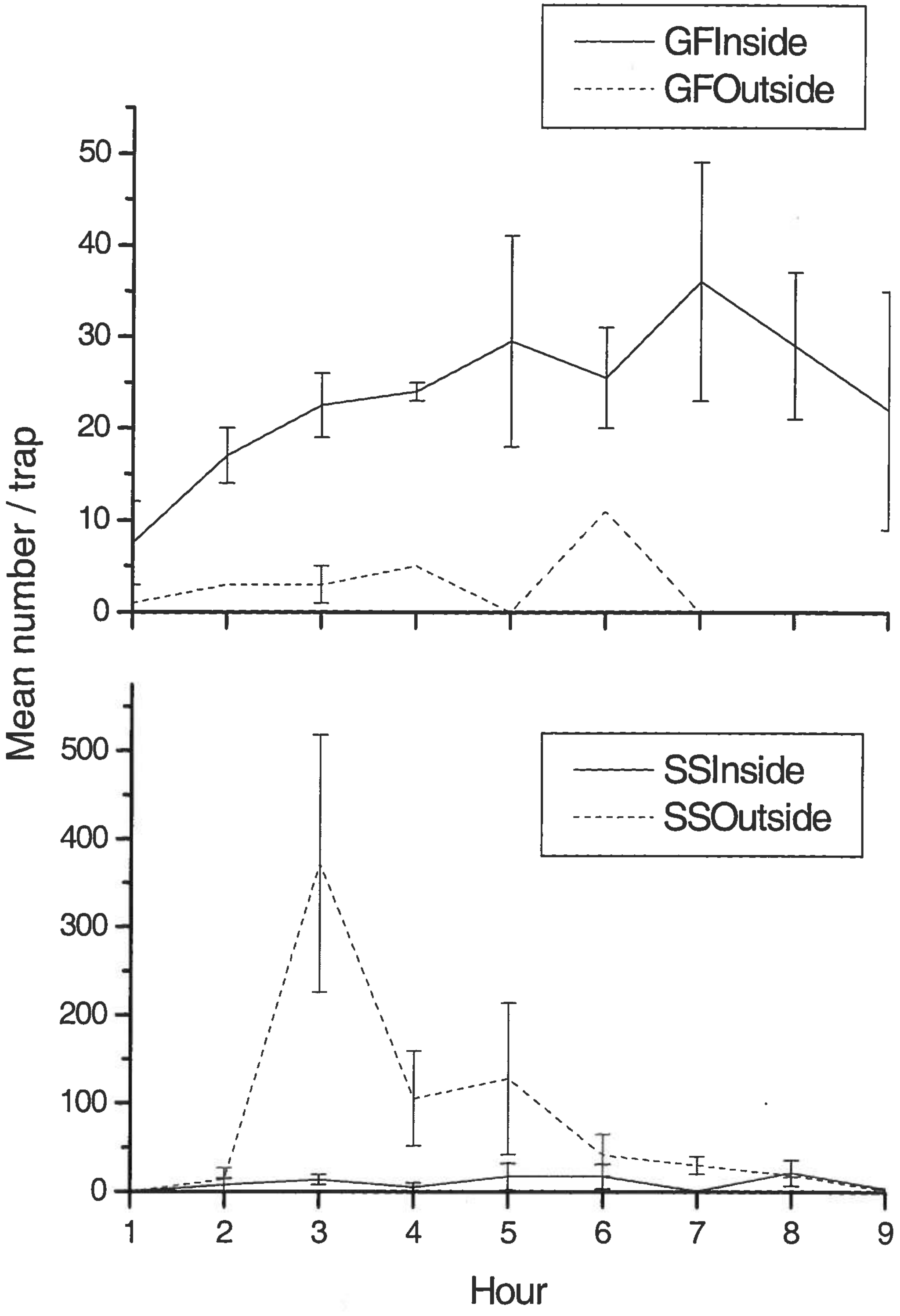

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
0
10
20
30
40
50
0
100
200
300
400
500
1
2
3
4
5
6
7
8
9
Hour

Figure 20. Mean (± SE) hourly number of female *Cheumatopsyche* spp. caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

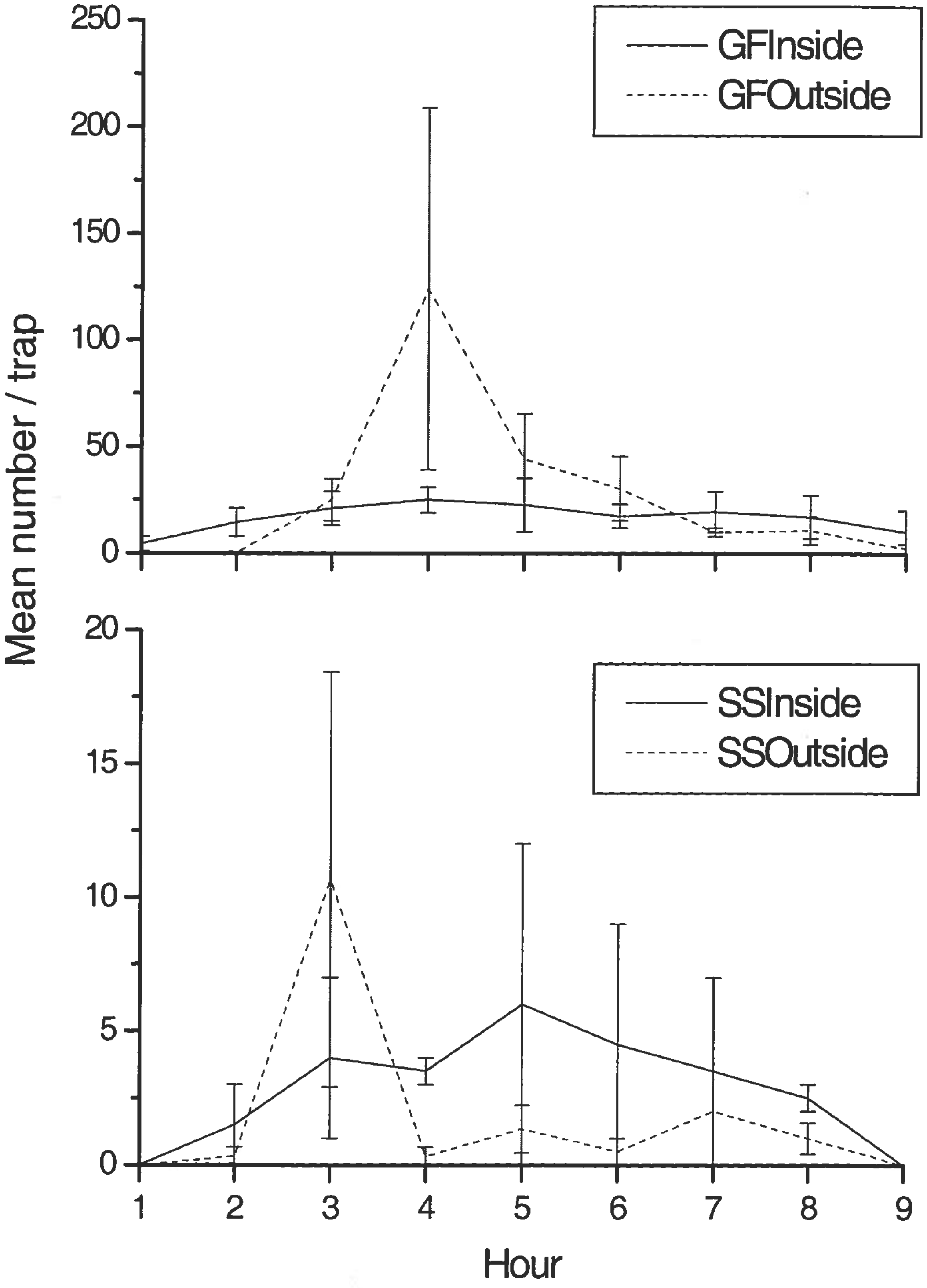

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
50
100
150
200
250
0
5
10
15
20
1
2
3
4
5
6
7
8
9

Figure 21. Mean (± SE) hourly number of male *Hydropsyche simulans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

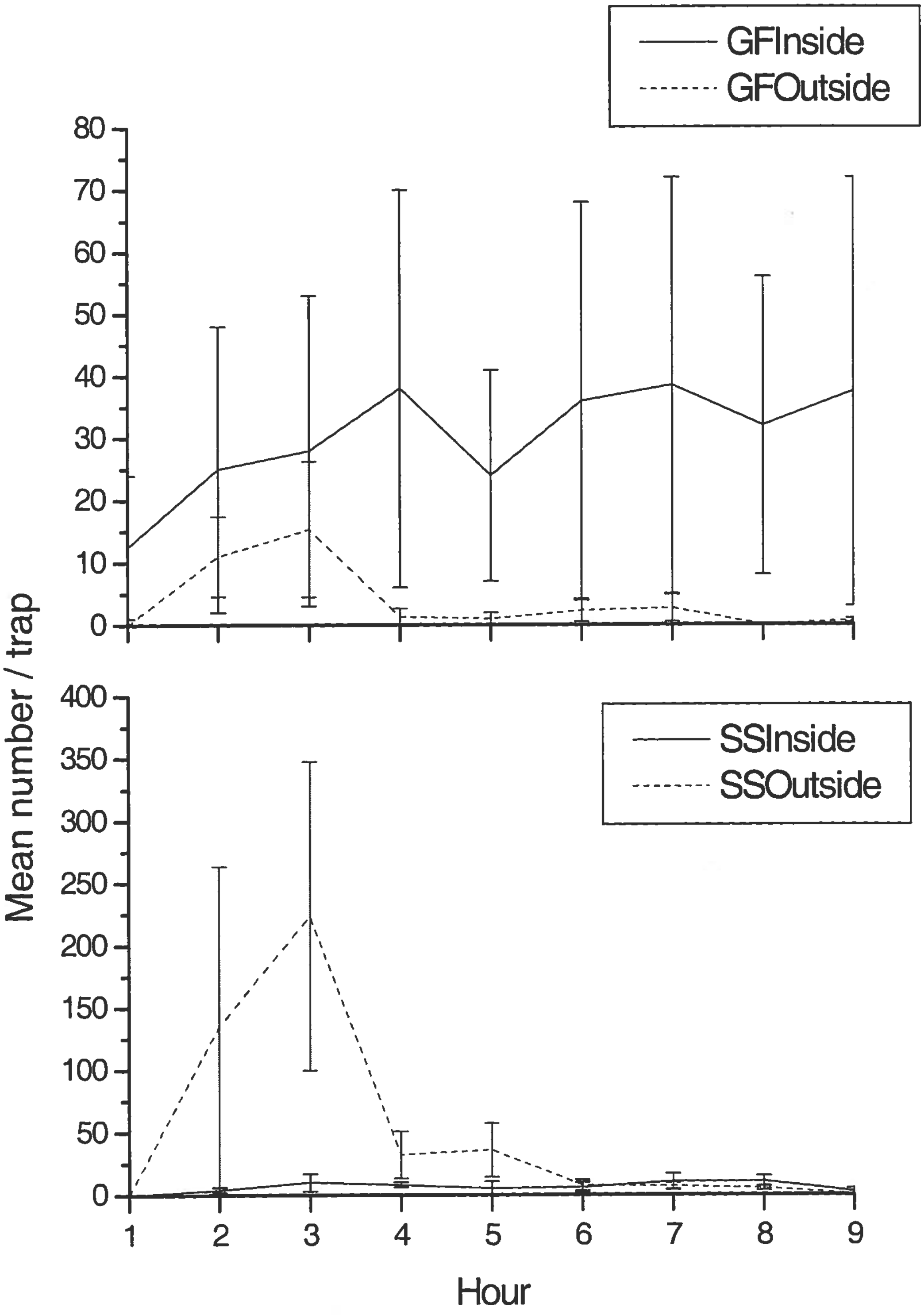

GFInside
GFOutside
0
10
20
30
40
50
60
70
80
Mean number / trap
400
350
300
250
200
150
100
50
0
SSInside
SSOutside
1
2
3
4
5
6
7
8
9
Hour

Figure 22. Mean (± SE) hourly number of male *Hydropsyche simulans* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

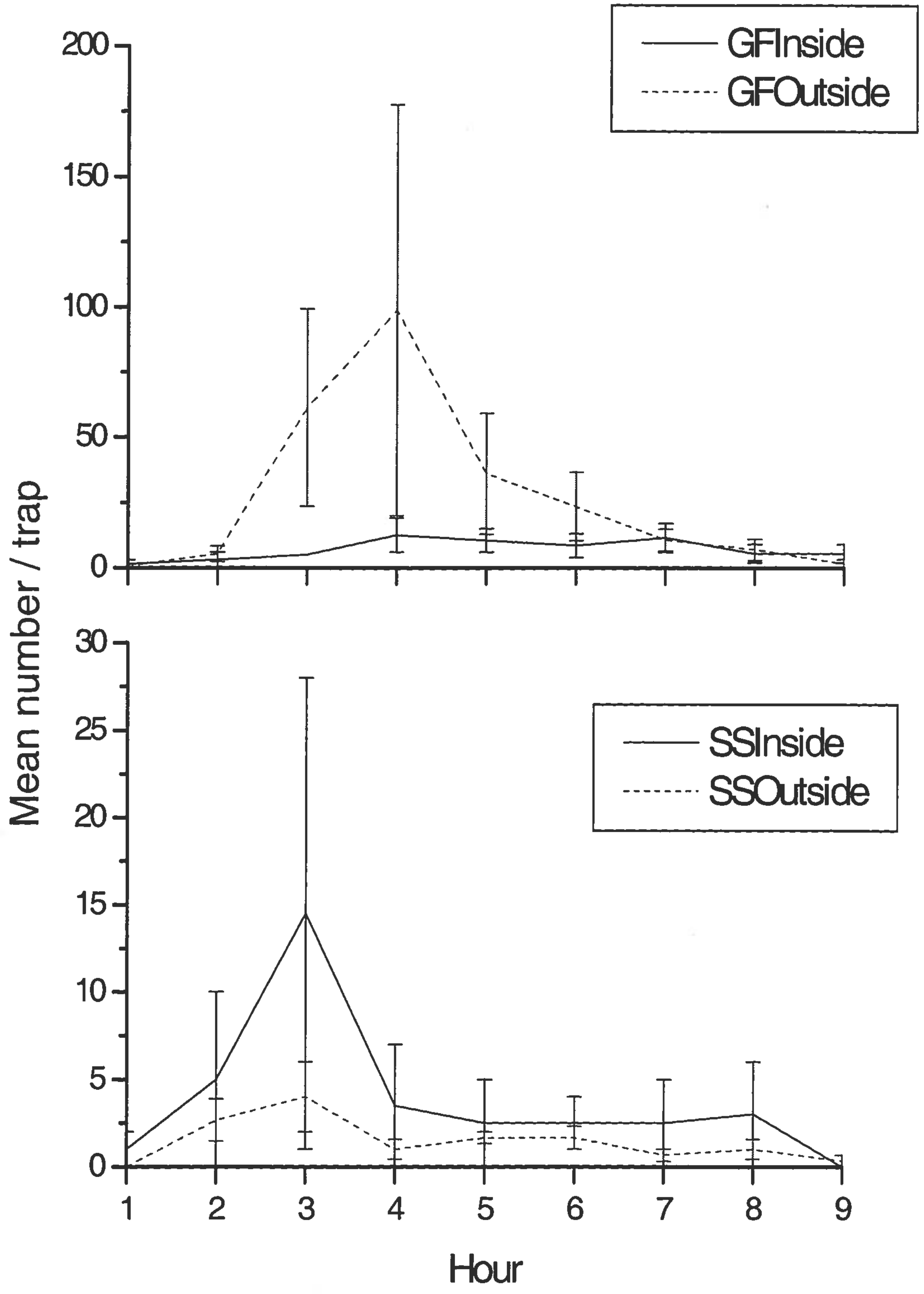

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
200
150
100
50
0
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9

Figure 23. Mean (± SE) hourly number of *Neureclipsis valida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

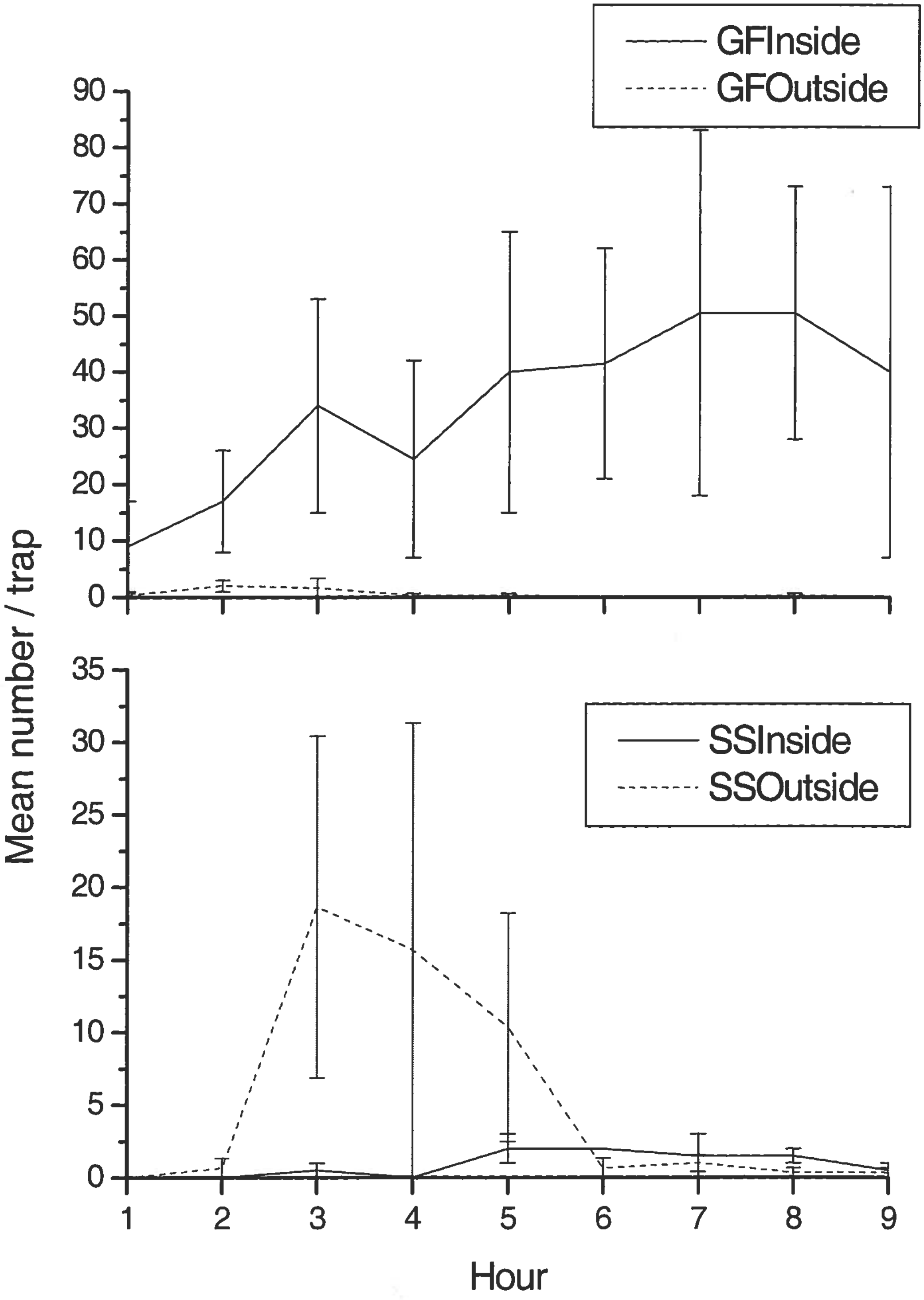

GFInside
GFOutside
90
80
70
60
50
40
30
20
10
0
35
30
25
20
15
10
5
0
SSInside
SSOutside
Mean number / trap
1
2
3
4
5
6
7
8
9
Hour

Figure 24. Mean (± SE) hourly number of *Neureclipsis valida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

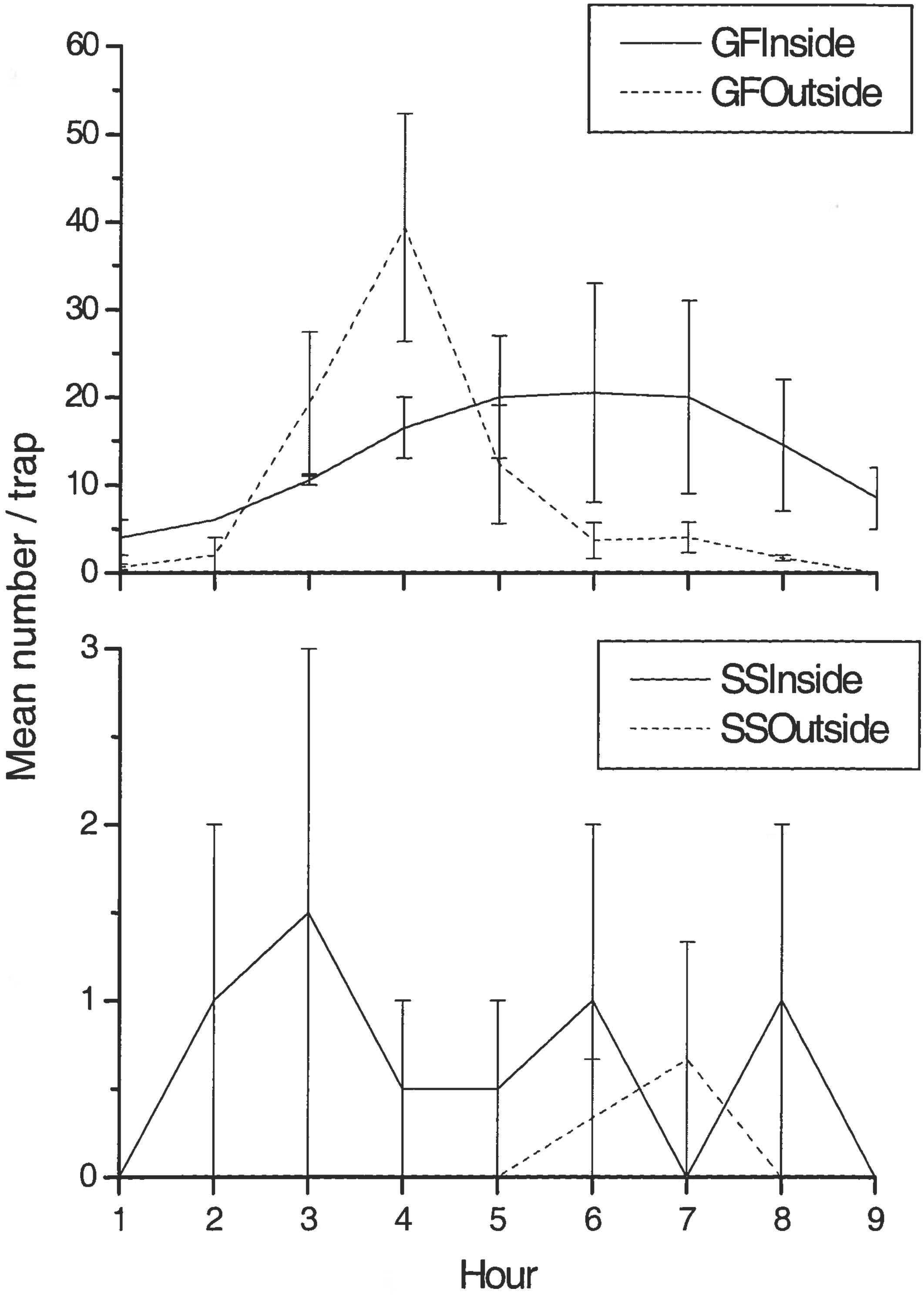

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
10
20
30
40
50
60
0
1
2
3
1
2
3
4
5
6
7
8
9

Figure 25. Mean (± SE) hourly number of *Psychomyia flavida* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

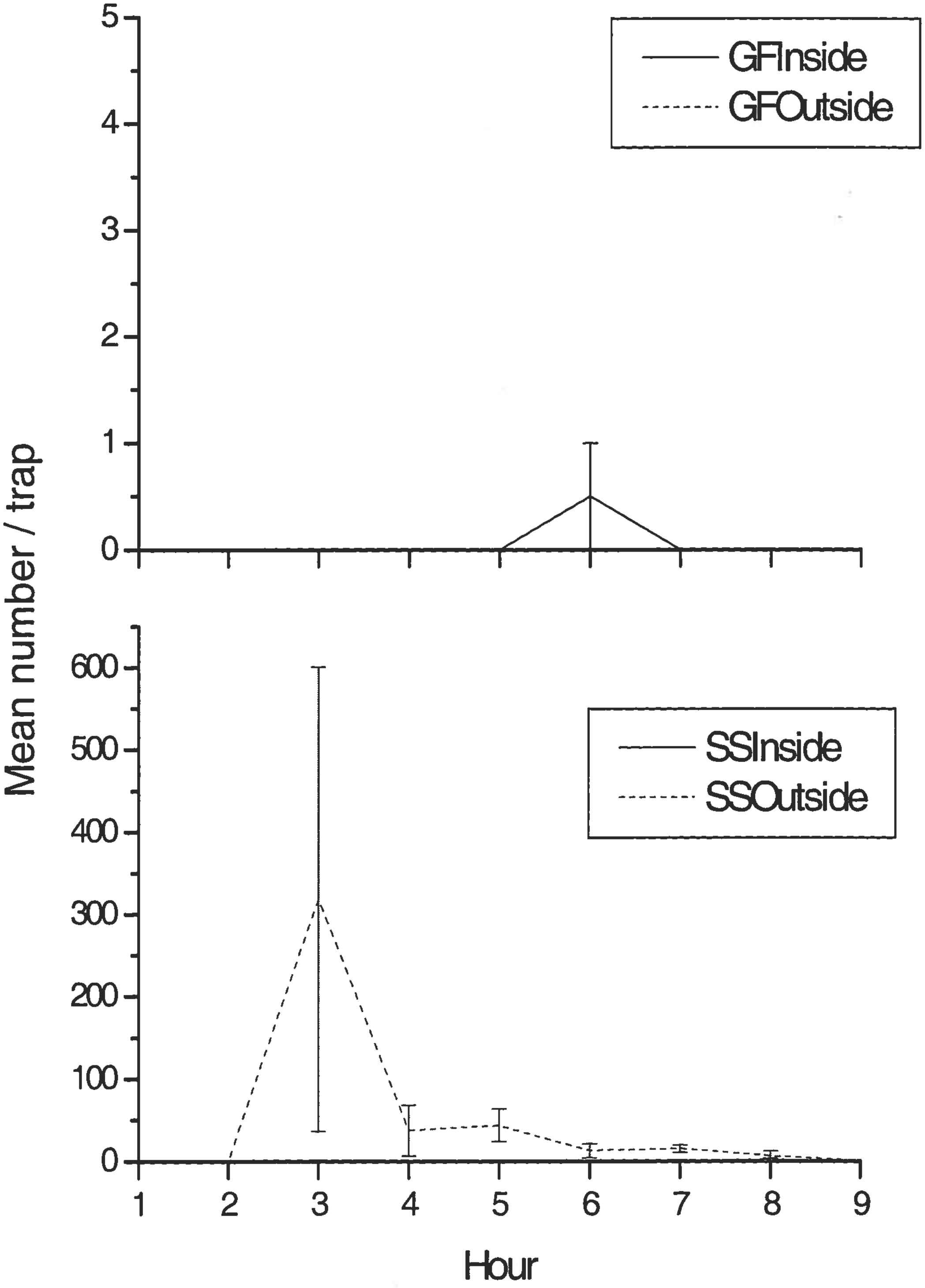

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
1
2
3
4
5
0
100
200
300
400
500
600
1
2
3
4
5
6
7
8
9

Figure 26. Mean (± SE) hourly number of *Oecetis inconspicua* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

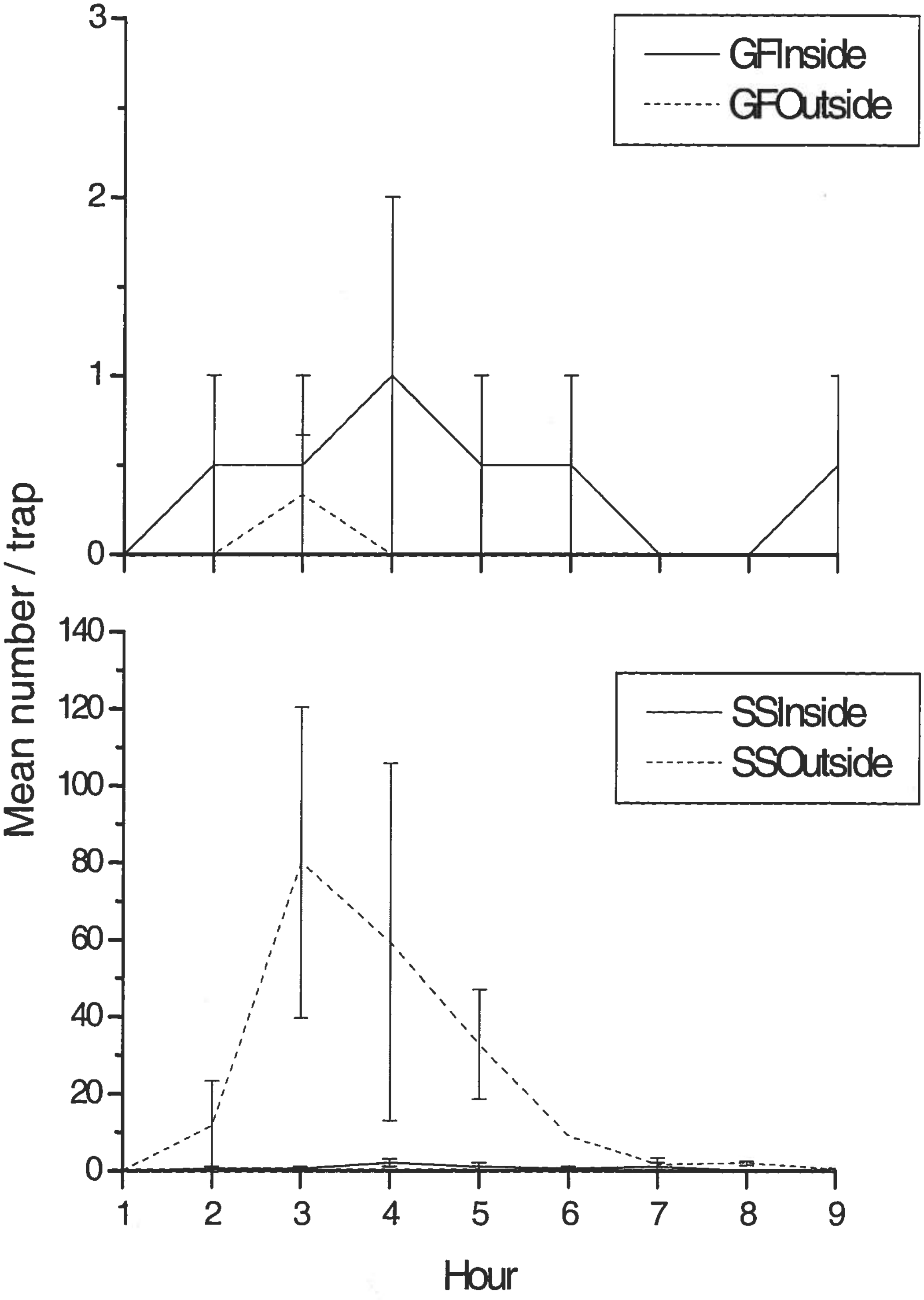

GFInside
GFOutside
SSInside
SSOutside
3
2
1
0
140
120
100
80
60
40
20
0
Mean number / trap
1
2
3
4
5
6
7
8
9
Hour

Figure 27. Mean (± SE) hourly number of *Neureclipsis crepuscularis* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

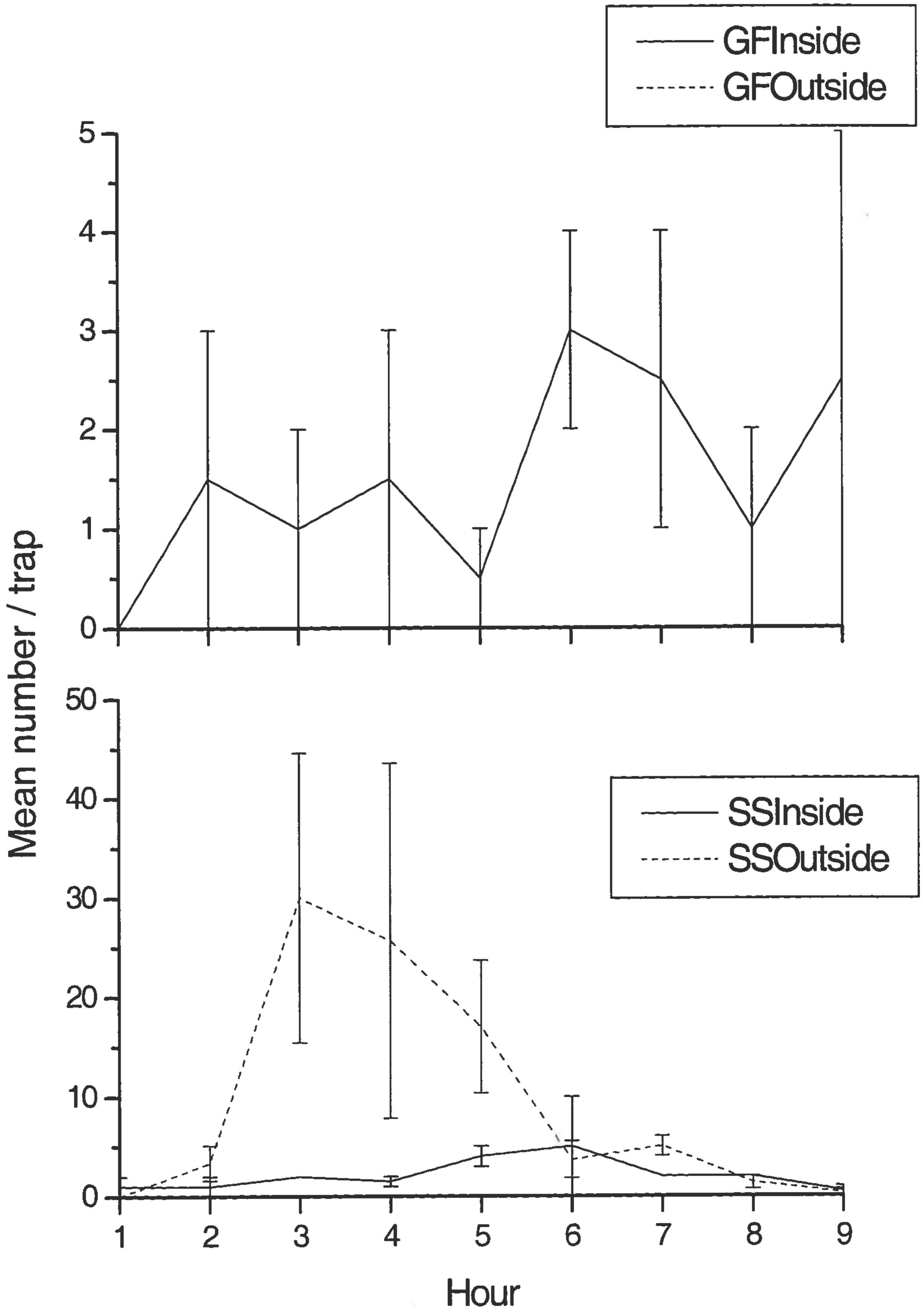

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
1
2
3
4
5
0
10
20
30
40
50
1
2
3
4
5
6
7
8
9

Figure 28. Mean (± SE) hourly number of *Neureclipsis crepuscularis* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

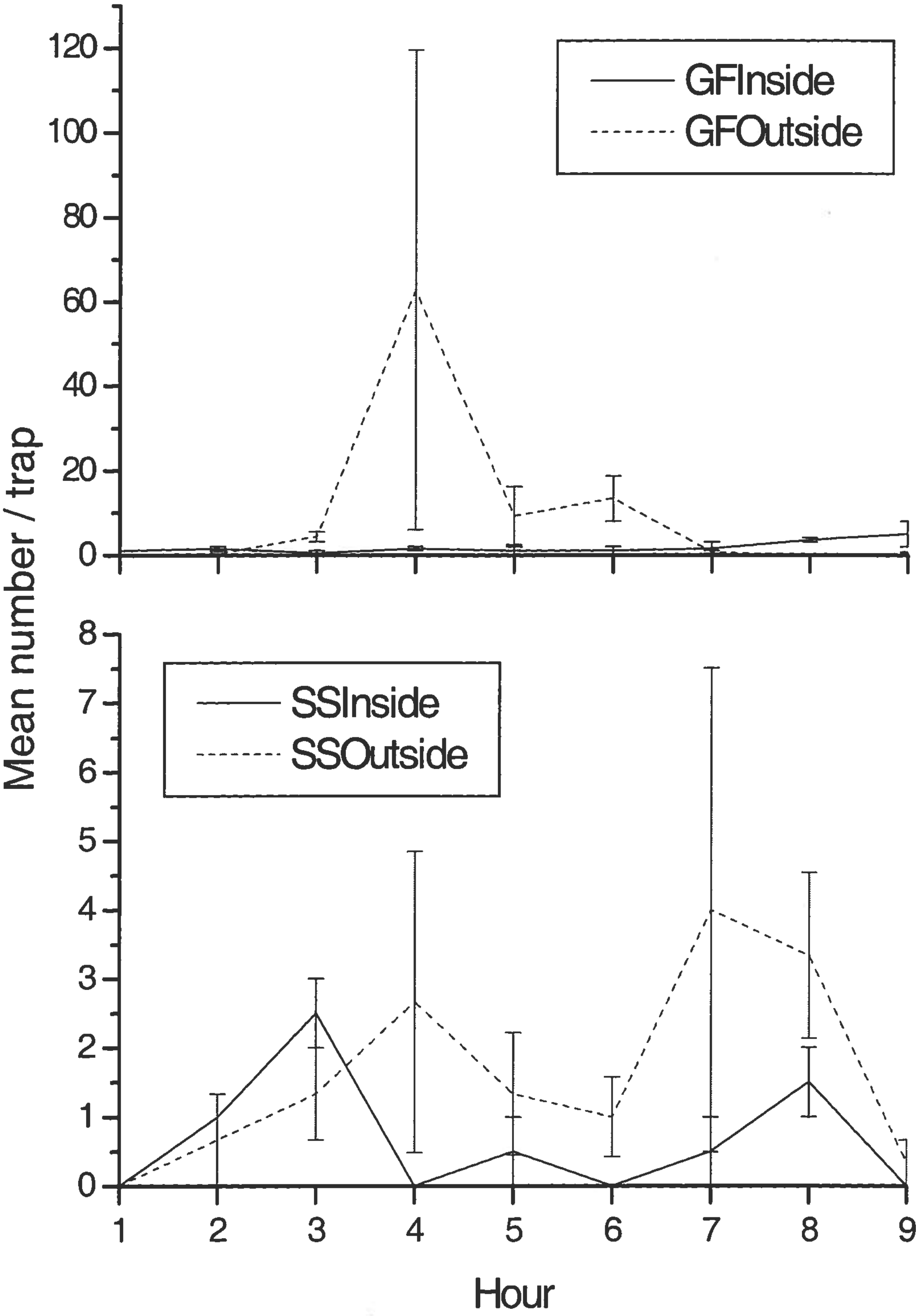

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9

Figure 29. Mean (± SE) hourly number of male *Cheumatopsyche gracilis* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

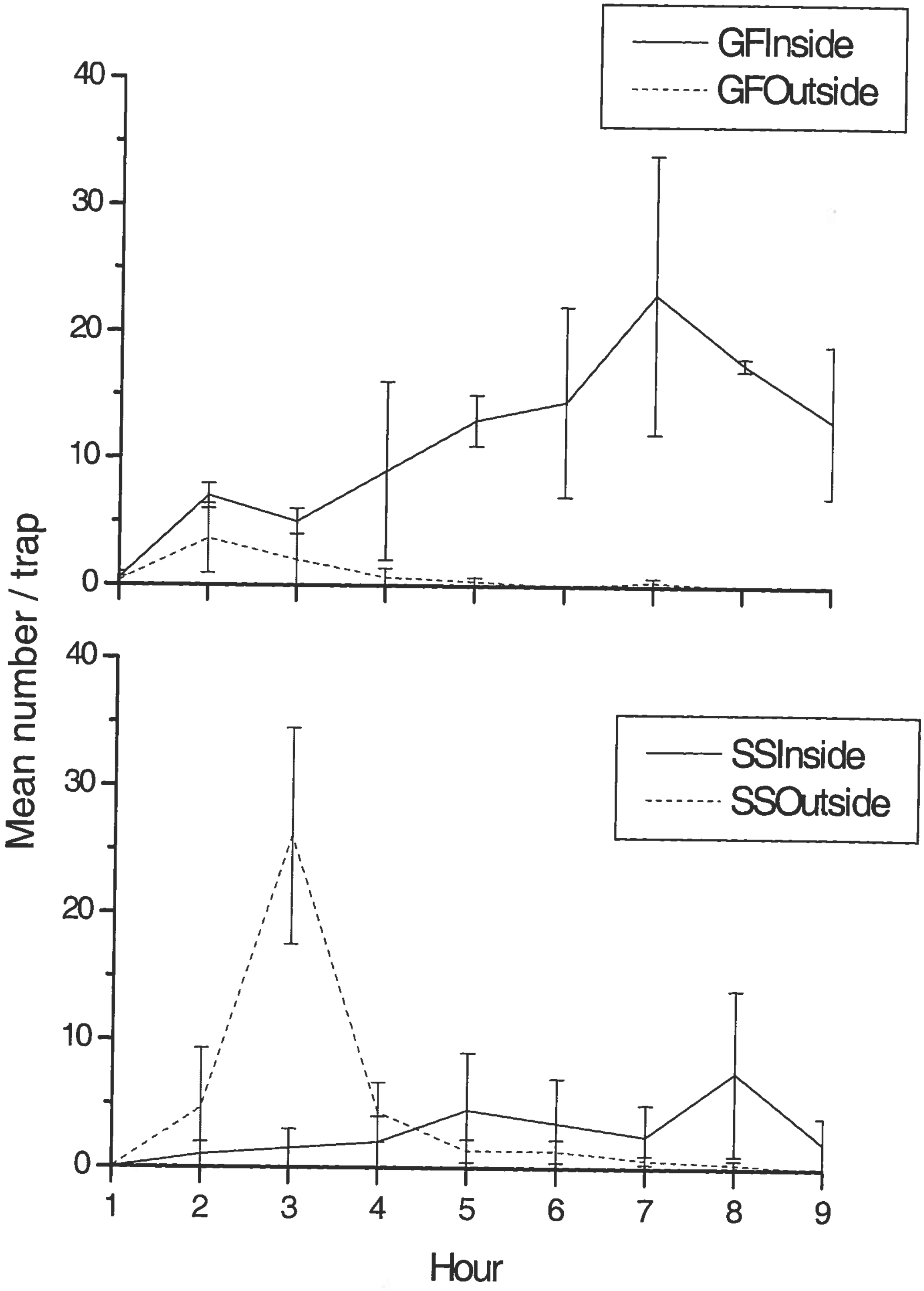

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
Hour
0
10
20
30
40
1
2
3
4
5
6
7
8
9

Figure 30. Mean (± SE) hourly number of male *Cheumatopsyche gracilis* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

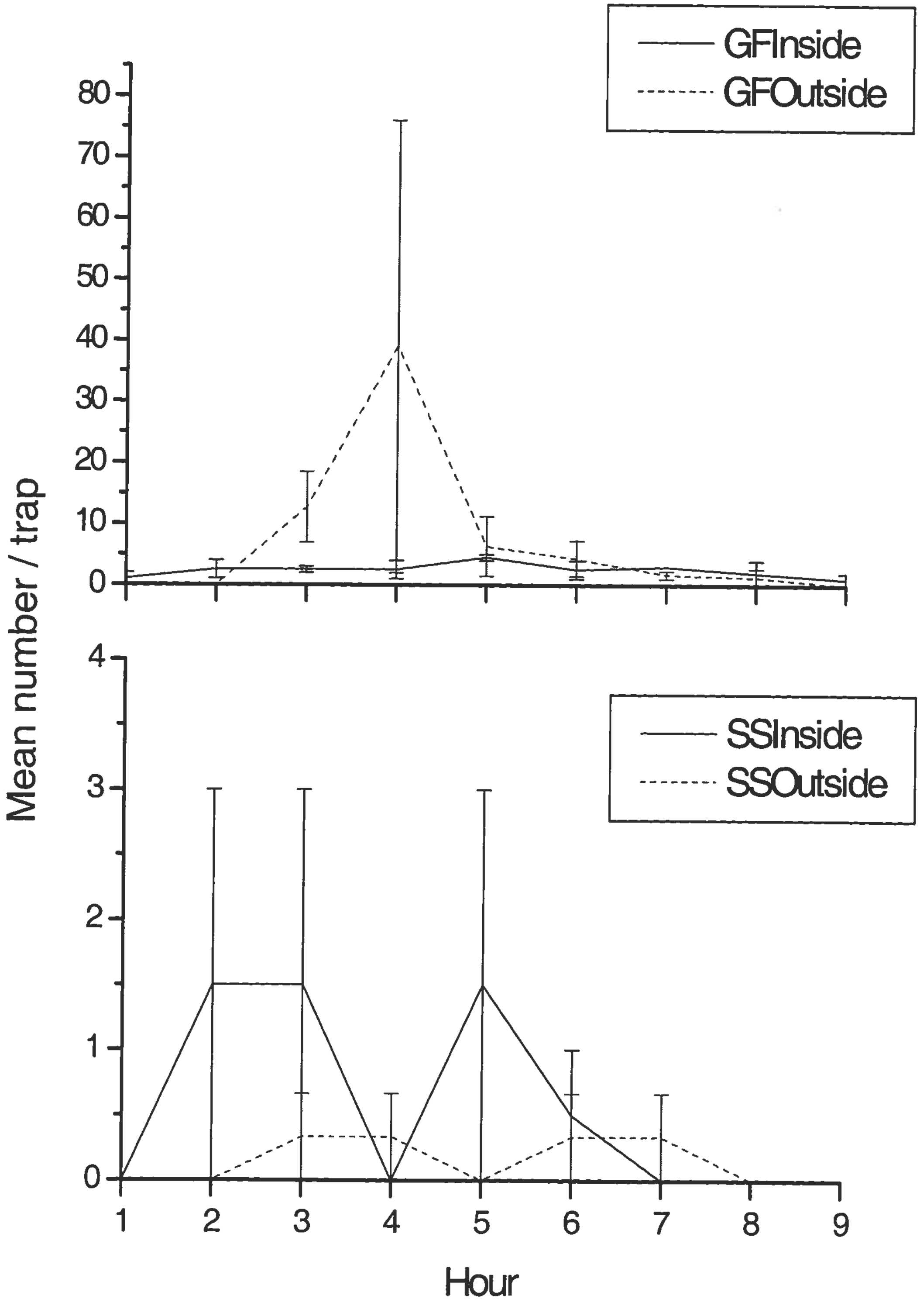

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
80
70
60
50
40
30
20
10
0
4
3
2
1
0
1
2
3
4
5
6
7
8
9
Hour

Figure 31. Mean (± SE) hourly number of male *Cheumatopsyche speciosa* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1997. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

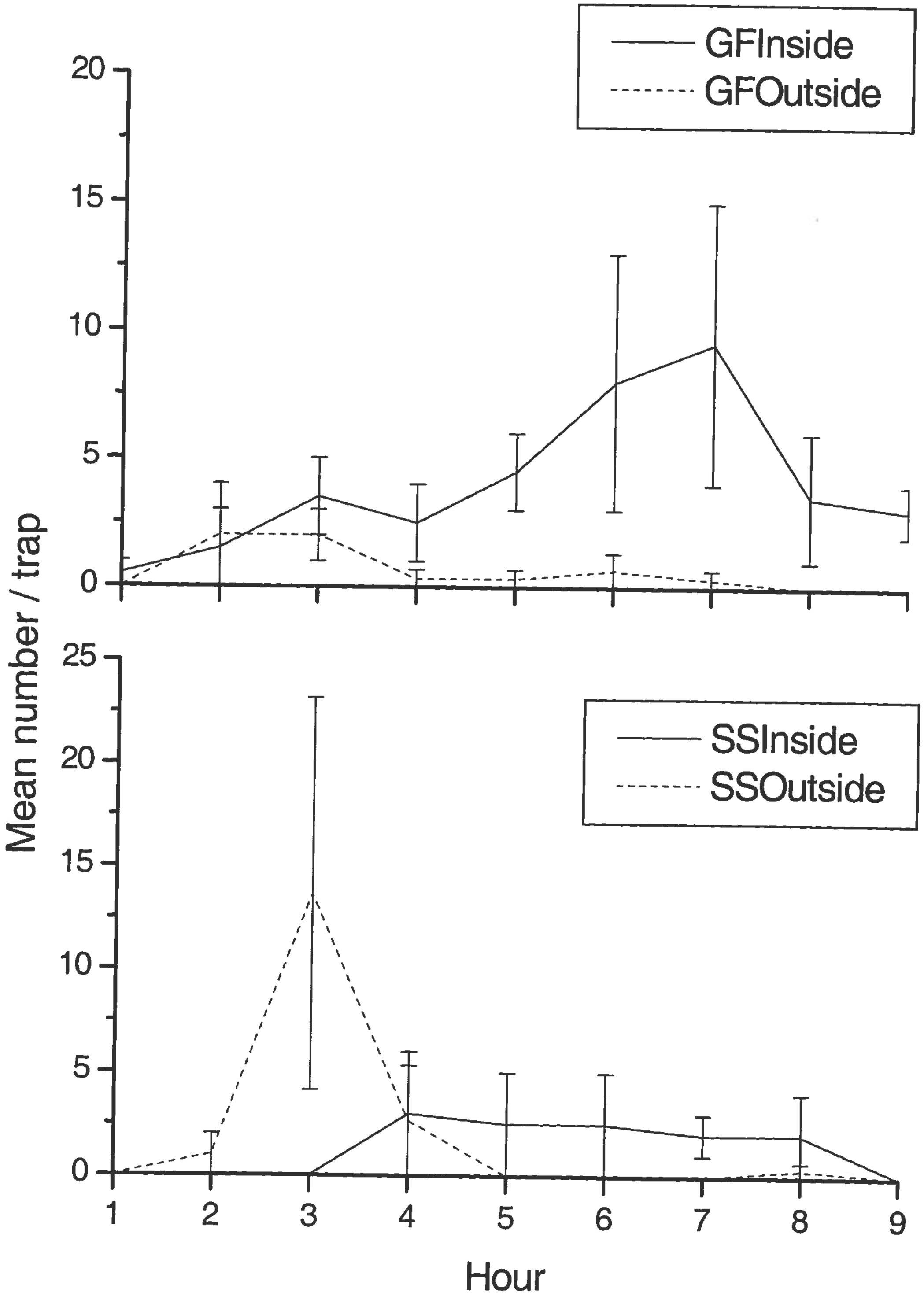

GFInside
GFOutside
SSInside
SSOutside
20
15
10
5
0
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Mean number / trap
Hour

Figure 32. Mean (± SE) hourly number of male *Cheumatopsyche speciosa* caught inside and outside of Great Falls (GF) and Seven Sisters (SS) Hydroelectric Generating Stations, Winnipeg River, Manitoba, Canada 1998. Hours expressed as 1 through 9 represent 2100 through 0600, respectively.

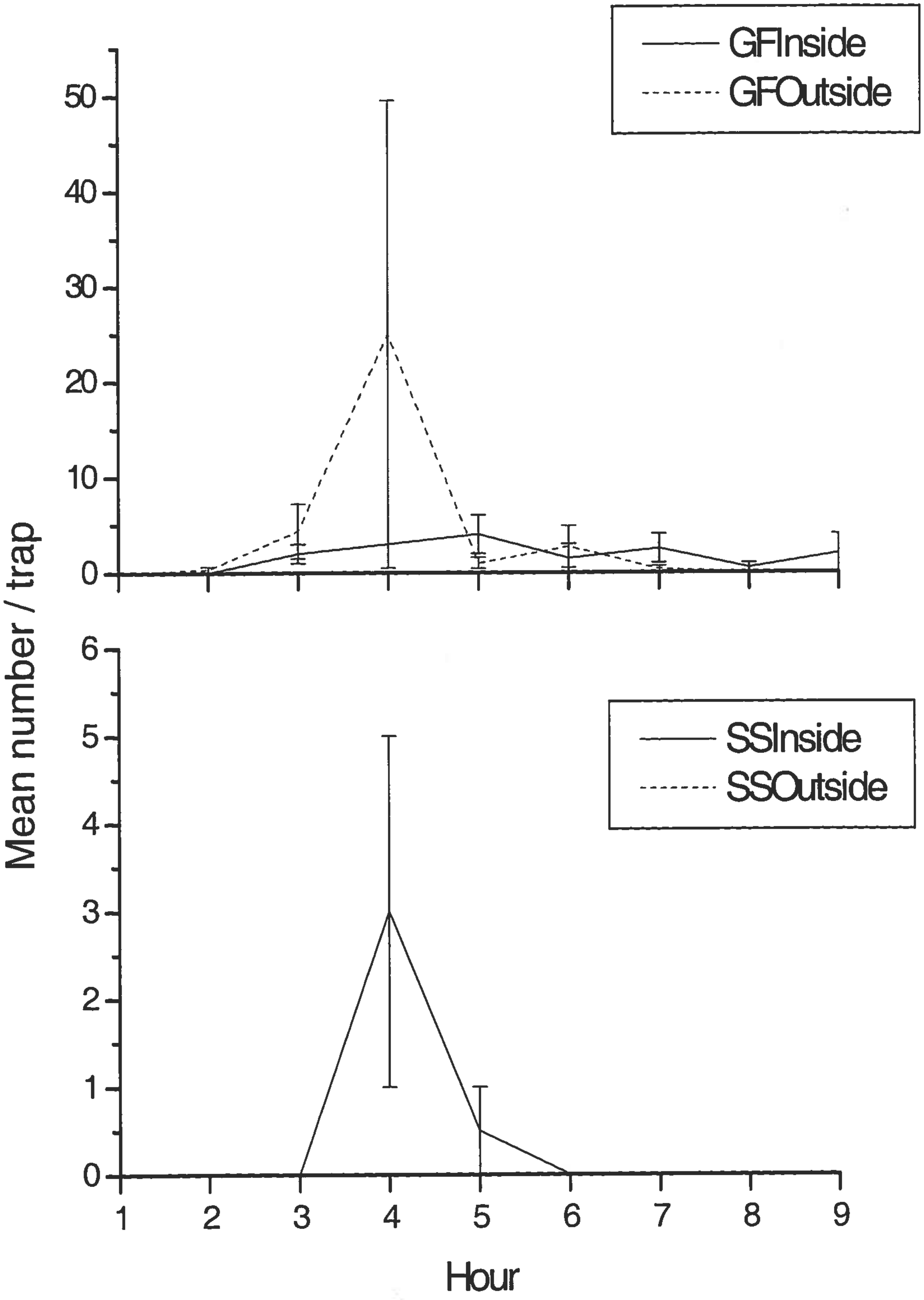
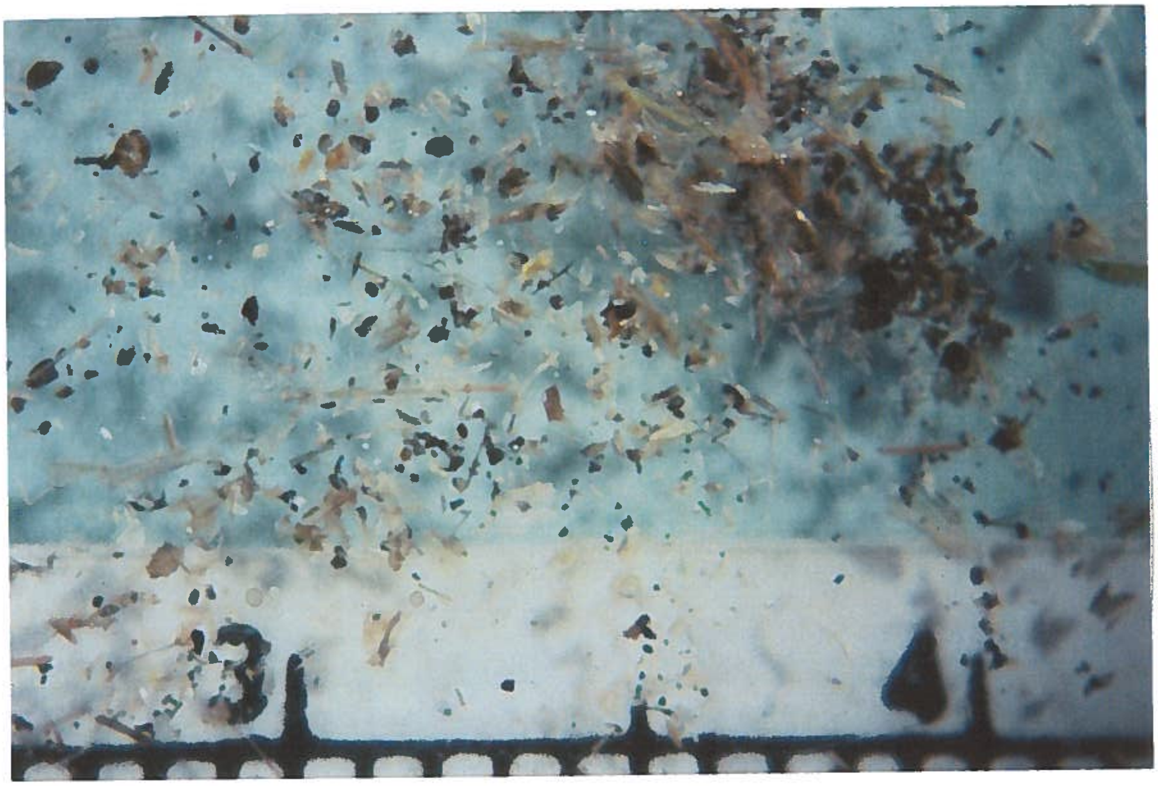

GFInside
GFOutside
SSInside
SSOutside
Mean number / trap
50
40
30
20
10
0
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
Hour

Figure 33. Insect particulates captured in nylon filter that was attached to a turbine cap at Seven Sisters Hydroelectric Generating Station, Winnipeg River, Manitoba, Canada 1998.


3
4

CHAPTER IV

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