PRELIMINARY STUDIES ON THE BITING FLIES (NEMATOCERA-BRACHYCERA) ATTACKING CATTLE IN NEWFOUNDLAND

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by

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ABSTRACT

The seasonal occurrence and abundance, host-seeking activity, and blood-feeding behaviour of the species of biting flies attacking cattle in Newfoundland was investigated using a newly designed cattle-baited trap. A Trueman-McIver segregating CO_2 trap was also employed to provide additional information during times when the cattle-baited trap was not in operation.

A total of 19,682 female biting flies (26 species) were collected in the cattle-baited (11,407) and CO_2 (8,275) traps, from May 26 to September 16, 1982. Simuliids were the most abundant family collected (cattle-baited trap = 10,747; CO_2 trap = 7773) comprising 94.1% of the total season's catch. The remaining families of biting flies, mosquitoes, tabanids and sand flies, contributed little to the population, comprising only 5.9% of the total season's catch. Sequentially mosquitoes (Family: Culicidae) and black flies (Family: Simuliidae) were the first to appear followed by the sand flies (Family: Ceratopogonidae) and finally the tabanids (Family: Tabanidae).

Prosimulium mixtum, most common in June and S. venustum/verecundum complex, most numerous in July, were the two most abundant black flies collected and the only two biting flies taken in numbers sufficient to adequately study host-seeking activity and blood-feeding behaviour; limited

information on remaining species was obtained. The host-seeking activity of _P. mixtum_ was usually restricted to the morning and afternoon, whereas _S. venustum/verecundum_ complex was most active in the morning and evening. Preliminary results suggest that although the host-seeking activity of _P. mixtum_ and _S. venustum/verecundum_ complex was greatly suppressed by wind speeds, temperatures, saturation deficiences and light intensities outside of certain ranges, such factors do not account for most of the variation observed in the number of these simuliids collected in the cattle-baited trap.

Mean temperature over the previous 24 hours appeared to greatly influence the blood-feeding behaviour of both groups, with changes in temperature showing a strong positive relation with changes in the proportion of blood-feds taken in the cattle-baited trap. The present temperature, mean temperature over the previous 24 to 48 hours, and light intensity might have had some influence on blood-feeding, but saturation deficit and wind speed appeared to have none.

The cattle-baited trap designed for this study is an effective method for the study of host-seeking activity and blood-feeding behaviour of at least simuliids under field conditions.

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I hate these bugs always flying around me and sucking my blood and they drive my cattle crazy, but I do suppose the Lord made them for a reason.

A southern Ontario farmer, 1979

INTRODUCTION

Biting flies (Diptera) and fly-borne diseases cause losses of billions of dollars annually to the world livestock industry (Fallis, 1980). The blood-feeding habits of these flies adversely affect the health and well-being of livestock, either directly through blood-loss and irritation or by the transmission of pathogenic organisms. This results in decreasing the efficiency of the animal production system and financial loss to producers (Fallis, 1980; NRCC, 1982; Steelman, 1976). An accurate assessment of the economic losses incurred in the Canadian livestock industry directly attributable to biting flies is not presently possible, but it is believed to be in excess of 100 million dollars annually (NRCC, 1982).

Many studies have been undertaken to determine the species of biting flies that attack cattle in Canada including Hudson (1983), Lewis and Leprince (1981) and Teskey (1960); however, such information is lacking in Newfoundland. The development of a cattle industry in Newfoundland would greatly benefit from a better knowledge of the species of biting flies attacking cattle. This is required to accurately assess their economic impact on production and if necessary, this data will be needed to plan appropriate control programs. In this first study, the purpose is to determine the species of biting flies that attack cattle in the St. John's vicinity and to gain information on their seasonality, blood-feeding behaviour, and diurnal pattern of host-seeking activity. A preliminary study was also undertaken to elucidate the influence of weather and other factors on blood-feeding behaviour and host-seeking activity. The results of this study may also have applications to other boreal regions of Canada where cattle production is under development.

LITERATURE REVIEW

A. BITING FLIES AND LIVESTOCK

1. Introduction

Biting flies are important pests of livestock due to the blood-feeding habits of the adults. In the case of the lower biting flies, which are included in the suborders Nematocera and Brachycera, only females will take blood, whereas both sexes take a blood-meal in the Cyclorrhapha or higher flies (James and Harwood, 1969). Because of this blood-feeding behaviour, biting flies adversely affect the health and well-being of livestock in the following ways: (1) by swarming around the heads of livestock, causing stress and annoyance (2) by causing blood loss which may result in anemia (3) by causing dermatitis and allergic reactions (4) by inducing systemic shock resulting in death (5) by transmitting pathogenic organisms (Bram, 1978; Cupp and Gordon, 1983; Fallis, 1980; James and Harwood, 1969; Steelman, 1976).

These detrimental effects have a variety of negative impacts on the efficiency of the animal production system (NRCC, 1982) and can be summarized as follows: (1) reduced rate of weight gains and growth (2) reduced milk production in cattle (3) mortality of livestock (4) reduced reproduction efficiency in breeding stock (5) increased management costs and inefficient land use (6) transmission of disease-causing organisms. Drummond et al. (1978) has estimated that ruminant production could be increased on a world-wide basis by 50% if efficient control of arthropod vectors and parasites of livestock could be achieved.

Steelman (1976) pointed out that previous literature reporting the qualitative and quantitative losses due to adult biting fly activity contributes little to the development of modern pest management systems for the control of livestock pests. This is because little information exists that relates the intensity of attack to losses in animal productivity, either directly through blood loss and irritation or indirectly by the establishment of disease cycles. Stern (1973) and Sylven (1968) stated that the establishment of economic thresholds and disease vector thresholds have been essentially ignored by veterinarian entomologists; such thresholds are the basis for sound pest management systems. There is a critical need for research directed towards the development of pest management systems for the control of livestock pests (Steelman, 1976).

2. Black Flies (Family: Simuliidae)

Domestic animals throughout the world, especially cattle, are subject to massive attacks by black flies which may result in death. The number of flies attacking livestock may be so immense that when a hand is moved over the underside of an animal it may become completely covered with blood from crushed, engorged flies (Jamnback, 1973). Clinical signs resulting from the "bites" include necrosis of the skin near the lesion, focal hemorrhages in the corium, perivascular infiltration of eosinophils, and variable cutaneous and subcutaneous edema (Frese and Thiel, 1974).

The massive outbreaks of <u>Simulium colombaschense</u> Fabricius resulted in the deaths of 16,000 domestic animals in Rumania in 1923 and 13,900 animals in 1934 in Yugoslavia, Rumania and Bulgaria (Steelman, 1976). An undetermined black fly species killed cattle and severely injured sheep in Germany from 1918 to 1920 (Jamnback and Collins, 1955). Death of cattle caused by black flies in Europe has also been reported by Eckert and Pohlenz (1974), Gräfner et al. (1976), and Zanin and Rivosecchi (1975). In the Volinsk region of Russia, a massive outbreak of black flies resulted in 4,500 sick and 237 dead cattle in five days (Lukjanov and Ivanenko, 1965).

Early settlers in North America were aware that black flies could severely debilitate their livestock (Riley, 1887). In 1874, the state of Tennessee alone lost $500,000 worth of livestock from the attacks of <u>Cnephia pecuarum</u> (Riley) (Lugger, 1896). At one time this species was the most important pest of cattle in the Mississippi Valley, but increased pollution and the construction of levies has greatly reduced its numbers (James and Harwood, 1969; Jamnback, 1971). Until recently, cattle, horses and mules were coated with oil, mud or molasses and smudgepots placed around the tail in an effort to control this and other black fly species (Hearle, 1938; Washburn, 1905). The present economic impact of black flies as a pest of cattle in the United States is estimated at a loss of $30 million annually (Anonymous, 1979).

The most important pest of cattle and other livestock in western Canada is Simulium arcticum Malloch (Fredeen, 1977a). Simulium arcticum was recognized more than 50 years ago as a serious pest of horses and cattle (Cameron, 1918; Hearle, 1938). From 1944 to 1947 outbreaks resulted in more than 1,000 livestock fatalities (mainly cattle) in Saskatchewan, and more than 600 of these occurred in the first four days of a single outbreak in 1946 (Fredeen, 1977a; Rempel and Arnason, 1947). Since the initiation of chemical control in 1948 (Arnason et al., 1949), the number of fatalities due to S. arcticum has greatly decreased (Fredeen, 1977a). Bulls, especially newly imported stock, appeared to be most susceptible to the attacks of and toxins injected by S. arcticum (Fredeen, 1969, 1977a). Post-mortem examination of cattle killed suggested that death was due to shock and direct toxic action (Rempel and

Arnason, 1947).

Ten other species of black flies are considered to be economically important pests of Canadian livestock. These include Prosimulium fulvum (Coquillet), Simulium griseum Coquillet, S. defoliart Stone and Peterson, and S. luggeri Nicholson and Mickel in western Canada, S. vittatum Zetterstedt, S. venustum Say, S. decorum Walker, and S. tuberosum (Lundström) coast to coast, and P. mixtum Syme and Davies and S. parnassum Malloch in eastern Canada (Fredeen, 1973).

Repeated black fly attacks will also have secondary effects on animal production systems, which include decreased milk production, weight loss or decreased weight gains, and reduction in breeding activities (NRCC, 1982). During heavy black fly attacks, cattle stop grazing and either leave the pasture to seek refuge in barns and other buildings or huddle together to protect as much of their bodies as possible from black flies (Anderson and Voskuil, 1963; Fredeen, 1969; Golini et al., 1976; Khan, 1981). Under such conditions decreased weight gain and milk production will occur as a result of high blood loss and decreased grazing time (Cupp and Gordon, 1983). Muradov et al. (1975) reported that cattle protected from biting fly attacks (black flies and mosquitoes) gained 13% more weight than those exposed to flies. Decreased growth rates have been recorded in pastured cattle during outbreaks of S.

arcticum and S. venustum in western Canada (Fredeen, 1958, 1977b; Haufe, 1980). Fredeen (1981), seen in NRCC (1982), noted that calves subjected to severe black fly attacks weighed 45 kilograms less at selling time than their counterparts in areas where black flies were much less numerous. Khan (1981) found that although unprotected cattle gained less weight than protected cattle, such cattle were able to make compensatory gains when black fly activity decreased or ceased.

Serious attacks by black flies will also cause decreased milk production (Anderson and Voskuil, 1963; Hunter and Moorhouse, 1976a; Jamnback and Collins, 1955). A cow's udder may be so severely bitten that she will refuse to accept a milking machine or nursing calf (Fredeen, 1958; Khan, 1981; Ryan and Hilchie, 1982). Black fly attacks may also result in abortion, sterility and late calving (Fredeen, 1969; Jamnback and Collins, 1955; Ryan and Hilchie, 1982). The bites of black flies will also cause secondary infections and dermatitis (Anderson and Voskuil, 1963; Burghardt et al., 1951) which require treatment, thereby increasing the cost of cattle production. Swarming of black flies around the heads of cattle encourages stampeding, which leads to injured or dead animals and damage to fences and buildings (Fallis, 1980). Control measures also increase the cost of livestock production (NRCC, 1982).

Two additional losses incurred by black flies, as well as by other biting flies, are inefficient land use and lost revenue from future livestock endeavours (NRCC, 1982). In western Canada some livestock producers have shifted to less productive enterprises because of heavy animal losses from black fly outbreaks. Three proposed multi-million dollar livestock ventures in northern Canada were abandoned by entrepreneurs when adequate control measures for biting flies could not be ensured.

Of less importance is the role of black flies as vectors of diseases to livestock (Jamnback, 1973), which include filarial nematodes of cattle (Fallis, 1980; NRCC, 1982) and horses (Dalmat, 1955), Leucocytozoon of poultry (Fredeen, 1977a) and possibly the viral diseases eastern equine encephalitis (EEE), western equine encephalitis (WEE), and vesicular stomatitis of equines (Anderson et al., 1961; Ferris et al., 1955; Sanmartin et al., 1967, seen in Jamnback, 1973).

3. Mosquitoes (Family: Culicidae)

The annual loss to cattle production as a result of mosquito attack in the United States alone was estimated to be $25 million in 1965, of which $15 million was due to reduction in weight gains and $10 million attributable to decreased milk production (USDA, 1965). Large areas of irrigated farmland and the vast saltwater marshes along coastal North America frequently produce mosquitoes in such large numbers that livestock production is greatly retarded or economically unfeasible in these locations (Anthony and Chapman, 1978; Steelman, 1976). An outbreak of mosquitoes in Alberta in 1971 was estimated to have cost producers approximately $2 million in lost production among pastured cattle (Dixon, 1973). A similar outbreak two years later incurred losses of $30 million (Dixon, as pers. comm., (1974), seen in McLintock and Iversen, 1975).

Massive mosquito attacks will cause cattle to stop feeding (McLintock and Iversen, 1975), consequently weight gains are below normal (Sanders et al., 1968) and milk production may be reduced by 40% (Bishop, 1933; Hearle, 1938). Death of cattle directly attributable to mosquito attacks has also been reported (Bishop, 1933; Cameron, 1918; Hearle, 1938; Sanders et al., 1968).

In a two-year study, Steelman et al. (1972) found that feedlot steers (Angus and Hereford) fed on low-energy rations (60% roughage) but protected from mosquito attack gained more weight per head and sold for significantly higher prices than unprotected steers fed on the same rations. On the other hand, mosquito attacks only marginally reduced the economic value of steers fed on high-energy rations (20% roughage). This suggests that weight losses incurred by mosquito attacks may be at least partially compensated for by increasing the energy level of the rations fed to feedlot steers. In the second phase of this study (Steelman et al., 1973), it was shown that almost twice as many mosquitoes were required to cause significant losses in weight gains per day in Brahman steers as were required to cause similar losses in Herefords. Fallis (1980), commenting on this finding, stated:

> "This indicates the need to encourage long term genetic investigations directed toward the development of breeds that are resistant to, or not attractive to, bloodsucking arthropods. Results should not be expected quickly and costs of such experiments would be high."

At the present time, there are no diseases of consequence which are transmitted to cattle by mosquitoes in Canada (NRCC, 1982). However, mosquitoes are believed to mechanically transmit anaplasmosis to cattle in the United States (Steelman et al., 1968) and are known to be the biological vector of Rift Valley virus to cattle and other mammals in Africa (Haddow, 1956; Muspratt, 1956). The arboviruses which cause EEE, WEE and venezuelan equine encephalitis (VEE) in equines are vectored by numerous species of mosquitoes (Horsfall, 1962; James and Harwood, 1969; Reeves, 1962; Sudia and Newhouse, 1971). The viral disease equine infectious anemia is also believed to be transmitted by various species of biting flies, among which mosquitoes have been implicated (Greenburg, 1973; Stein et al., 1943).

4. Tabanids (Family: Tabanidae)

Adult female tabanids of most species attack mammals, primarily the Equinidae (horses), the Bovidae (cattle), the Cervidae (deer), the Camelidae (camels), and man (Chvála et al., 1972; Middlekauff and Lane, 1980), but will occasionally attack birds (Bennett, 1960; D. Davies, 1959) and reptiles (Chvála et al., 1972). These flies are considered to be an economically important pest of livestock; the annual loss to the American cattle industry alone was estimated in 1965 at $40 million (USDA, 1965). Present-day losses could be expected to greatly exceed this value. In some areas of the United States tabanids are considered the number one pest of livestock (Pechuman, 1981; Philip, 1931).

Tabanids take large blood-meals from their hosts and blood loss in domestic animals may constitute a severe problem (James and Harwood, 1969). The amount of blood taken from cattle during peak abundance of tabanids has been estimated to be from 75 cc to over 350 cc per animal per day, depending on the species present and their abundance (Cameron, 1926; Hollander and Wright, 1980; Philip, 1931; Tashiro and Schwardt, 1953; Webb and Wells, 1924). None of these estimates included blood which exudes from the bite after the fly has left, which may be as much as was removed by the fly itself (Anthony, 1962; MacCreary, 1940). The large wounds left by the bites of tabanids may also lead to secondary infection and screwworm attack (Jones and Anthony, 1964; Olsufjev, 1937, seen in Chvála et al., 1972; Schwardt, 1936).

Tabanids cause livestock great annoyance and under heavy attack, livestock will cease grazing and seek protection by crowding together in an effort to reduce the surface area exposed to these flies (Jones and Anthony, 1964; Lewis and Bennett, 1977; Lewis and Leprince, 1981; Magnarelli and Anderson, 1980; Schwardt, 1936). These flies may also cause livestock to stampede, resulting in death or injury and damage to fences and farm equipment (Horsfall, 1962; Webb and Wells, 1924).

Annoyance, cessation of grazing, and decreased vitality caused by blood loss from tabanid attacks result in decreased animal productivity (Anthony, 1962). Tabanids have been reported to cause decreases in milk production, in some cases as high as 100% (Chvála et al., 1972; Decker, 1955; Howard, 1916; Pechuman, 1981; Zumpt, 1949). Not only is the quantity, but also the quality of milk produced reduced (Bruce and Decker, 1951). Decreased weight gains attributable to tabanid attacks are also known to occur (Chvála et al., 1972; Hearle, 1938). According to Steelman (1976), further research is needed to show whether livestock are able to make compensatory gains in body weight after periods of tabanid attacks subside.

Tabanids are known to transmit both mechanically and biologically numerous diseases of livestock, excellent summaries of which are given by Anthony (1962) and Krinsky (1976).

5. Sand Flies (Family: Ceratopogonidae)

Three genera, Culicoides, Leptoconops and Forcipomyia (Lasiohelea) feed on warm-blooded vertebrates (Kettle, 1962, 1977) but only Culicoides are considered important pests of livestock. Although Culicoides are known to irritate livestock (Hearle, 1938; Lindquist and McDuffie, 1956), the greatest losses in livestock production result from the viruses, protozoans and helminths which they transmit (Fallis, 1980; Kettle, 1965; Steelman, 1976). Culicoides are known to vector the viral diseases bluetongue to cattle and sheep (Goltz, 1978; James and Harwood, 1969), African horse sickness (DuToit, 1944) and ephemeral fever of cattle (Davis and Walker, 1974a,b), filarial nematodes to horses and cattle (Fallis, 1980; Kettle, 1965) and Akiba to poultry (Akiba, 1960, seen in Kettle, 1965).

6. Other Biting Flies

Although there are other species of biting flies which will attack livestock, such as horn flies, stable flies and tsetse, these species are either absent from insular

Newfoundland or occur in relatively low numbers (Bennett, pers. comm., 1983; Colbo, pers. comm., 1983), and therefore are not discussed in the Literature Review.

7. The Influence of Meteorological Conditions

The number of host-seeking biting flies as well as their blood-feeding behaviour can be greatly affected by meteorological conditions (D. Davies, 1952; Fallis, 1964; Kettle, 1977; Pechuman, 1972; Roberts, 1978) which thereby influence the impact that these flies have on animal production. For example, low temperatures and high wind speeds tend to decrease the number of host-seeking simuliids, whereas moderate temperatures and light winds have the opposite effect (Lacey and Mulla, 1977; Wolfe and Peterson, 1960). As such, simuliids could be expected to be less detrimental to livestock during times of low temperature and high winds than at times when moderate temperatures and light winds prevail. It is important to consider existing weather conditions when assessing the impact of biting flies on livestock and planning control strategies.

B. BAITED TRAPS

1. Animal-baited Traps

The various methods used to collect adult biting flies which are attracted to animal hosts have been extensively reviewed by Bram (1978) and Service (1976, 1977, 1981), and the following account is a brief summary of these reviews. Traditionally, there have been three basic trapping techniques used to assess the numbers and species of biting flies attacking both wild and domestic animals. The simplest method, usually restricted to large animals, involves tethering the animal under study at a specific location while the collector either remains with the animal or periodically inspects it, removing flies as they land on the animal. The major problem with this technique is that the collector's presence may greatly influence the number and species of flies collected.

The second method commonly used consists of placing the animal in an enclosed structure composed of either cloth (bed nets) or wood (stable and Magoon traps). This structure is provided with various forms of entrances depending on the specific design which allow the flies entrance into the structure. After a predetermined length of time, the collector enters this enclosure and collects all flies present. Although the use of this trap effectively removes any influence the collector may have on the trapping results it creates several new problems. These include: (1) severe disruption of the blood-feeding behaviour of flies once inside this enclosure (2) in at least some cases, entrance into this enclosure may be accidental or in response to shelter and not a result of attraction to the host contained within and (3) many flies will not enter such structures.

A third method which has frequently been used to collect biting flies attracted to animals involves the use of either closure traps or descending nets. Closure traps have generally been used with small hosts such as birds and small mammals as bait. The animal host is usually placed in a cage constructed from chicken wire or hardware cloth and exposed to the biting fly population. After a specific length of time, the collector approaches and places a larger cage constructed of wood or screening over the bait. Various methods have been employed to remove the adult biting flies from the larger collection cage. Descending nets have been generally used for larger animals such as cattle. Essentially, they consist of a large tent suspended several feet above the host which is periodically lowered to completely enclose the animal. The collector then enters the tent and aspirates the flies that were attracted to the host at the time the tent was lowered. The major advantage of closure traps is that the animal under study is exposed to the adult biting fly population in a relatively normal manner and as such, the host-seeking activity of these flies is not severely disrupted. However, the suspension of a descending net over an animal bait, especially during daylight hours when shadows are cast, may deter host-seeking flies, particularly simuliids. Once the host has been covered, either by the closure trap or by the descending net, blood-feeding may be greatly inhibited.

Many other techniques have been employed to assess the numbers and species of adult biting flies attacking animals, depending upon the animal under study and the specific aims of the investigation. More detailed information regarding these techniques can be found in Bram (1978) and Service (1976, 1977, 1981).

2. CO_2 Traps

Traps of various designs which employ CO_2 (either from cylinder tanks or dry ice) have been extensively used to collect host-seeking flies (Bram, 1978; Service, 1976, 1977, 1981). These traps though effective for the study of host-seeking activity do not provide information on blood-feeding behaviour since living bait is not usually used.

MATERIALS AND METHODS

A. STUDY SITE

The study site was located on the Harding dairy farm approximately 16 km west of St. John's on the Trans-Canada Highway in an area locally known as Paddy's Pond. Field work was conducted from late spring to late summer of 1982. The predominant vegetation within the immediate area of the trapping site was a wet semi-fallow hay field with clumps of Scirpus spp., a second growth boreal coniferous forest, and a zone of scrub vegetation between the hay field and forest (Fig. 1). Several small streams (less than 1 m in width) were also present in the immediate area.

B. TRAPPING METHODS

1. Location of Traps

Adult biting flies were collected using a cattle-baited trap and a CO_2 segregating trap (see below). Both traps, located approximately 40 m apart, were placed in the border area between the zone of scrub vegetation and the coniferous forest (Fig. 1).

2. Cattle-baited Trap

(a) Trap design

The cattle-baited trap was designed for this study in an attempt to meet two criteria: (1) to present the bait to the adult biting fly population in a relatively normal manner, without the presence of a collector or the use of enclosed and/or suspended structures which may influence host-seeking activity, and (2) to provide information on blood-feeding behaviour in a field situation.

The cattle-baited trap consisted of three major components: a metal frame, an attached collapsible tent, and a wooden stable to contain the bovine bait (Fig. 2a). The metal frame was constructed of several sections that could be bolted together to permit easy transportation to and from the field. Essentially, the metal frame consisted of a rectangular base with three hoops spanning across the width of the rectangle (Fig. 2b).

The base of the metal frame was constructed from four straight lengths and four right-angled corner pieces of 4.3 cm diameter galvanized steel piping. When bolted together with electrical conduit connectors, these pieces formed a rectangle 2.4 m by 3.0 m in size (Figs. 2c,d). The three hoops were made from 2.1 cm diameter clad-type steel piping. Each hoop measured 2.1 m at the top of its arc and could be broken down into two straight side pieces and an upper curvature. To support the three hoops in an upright position, six pieces of coupling pipe, each measuring 13 cm long with an inside diameter of 2.4 cm, were welded to the rectangular base at various points to act as hoop sockets (Fig. 2c,d). The two ends of each hoop could then be fitted inside the hoop sockets.

The collapsible tent was custom-made by United Sail Workers of St. John's, Newfoundland, and was constructed from mosquito netting with a 30 cm wide white sail canvas bottom border (Fig. 2e). The shape of the tent was complementary to that of the metal frame but was approximately 6 cm smaller in all dimensions so as to fit on the inside of the frame. Three 8 cm wide strips of sail canvas were also sewn to the tent such that one canvas strip would lie in a position directly under each hoop of the metal frame (Figs. 2e,f). Twenty 1.5 cm diameter brass eyes were inserted in each canvas strip and each eye was in turn tied to a 5 cm diameter metal ring (Fig. 2f). Each metal hoop was guided through its appropriate set of twenty rings so that the tent would hang by these rings from the inside of the metal frame (Figs. 2e,f,g).

The stable which contained the bovine bait (Fig. 2a) was built from pieces of "two by fours" and measured 2.4 m long by 1.2 m wide by 1.2 m high. The front was provided with a swing gate to allow the bovine bait access to the stable.

Initially the collapsible tent lay folded along the bottom of one long side of the rectangular metal base with the canvas border of the opposite side lying uppermost (Fig. 2a). A sleeve was sewn along the entire bottom length of this leading canvas border. Inserted into this sleeve was a 3.6 m long copper rod (Fig. 2a) which when held at both ends, pulled and hoisted across the metal frame to the opposite side, pulled the collapsible tent with it (Fig. 2b) to completely enclose the stable and bovine bait. With a minimal amount of practice, the bovine bait could be completely enclosed in the collapsible tent in three seconds or less.

Once the tent was in the up position (Fig. 2e), additional 30 cm wide strips of sail canvas sewn to the bottom length of the canvas border on all four sides formed flaps lying flat to the ground completely around the inside perimeter of the tent (Fig. 2f). These flaps prevented adult biting flies from crawling out from under the tent. A metal zipper sewn into one end of the tent allowed the collector access to the inside for collection purposes (Fig. 2g)

(b) Trapping procedure

A Holstein bull calf was used as the bait. At the beginning of the trapping season this bull was 7 months of age and weighed approximately 160 kg, and 10 months old and approximately 250 kg at the end. At the start of each trapping session, the bovine bait was led from the barn (Fig. 1) to the cattle-baited trap (approximately 130 m) and placed inside the stable. During this time the collapsible tent was in the down position (Fig. 2a). The head of the bovine bait was tethered to the front of the stable to prevent excess movement, and hay and water were provided. Once the bovine bait was secured in the stable, the collectors would depart and take up a position at the weather station approximately 20 m away, leaving the bovine bait exposed to the adult biting fly population. After an exposure of 10 minutes, which will be referred to as a "sample time", two collectors would walk speedily to the cattle-baited trap and quickly hoist the tent over the stable to completely enclose the bovine bait and attracted adult flies.

Another 10-minute interval was allowed after the tent was in the up position to permit any blood-feeding flies to finish, after which time one or two collectors would enter the tent (Fig. 2g) and remove all captured flies. Ten minutes were also allotted for collection purposes (see below for collection procedure). After this collection interval, the tent was returned to the down position and the bovine bait once more exposed so that the elapsed time between the beginning of one sample time to the beginning of another was 30 minutes. The bovine bait was exposed twice again with a total of four sample times being completed during the course of one trapping session. A complete set of four sample times (one trapping session) will be referred to as a "sample period". Ideally, there were three such periods in a day, a morning, afternoon and evening sample period, each with a set of four sample times taken at predetermined times. However, due to the frequent occurrence of adverse weather, this was not always possible.

A day in which collections in all three sample periods (morning, afternoon and evening) were obtained - that is, 12 sample times - will be referred to as a complete "sample day" as opposed to an incomplete "sample day" in which collections during all three sample periods (12 sample times) were not obtained. An attempt was made to conduct three complete sample days per week, but this was rarely achieved due to adverse weather conditions.

Adult biting flies captured in the cattle-baited trap were removed using a commercially available Black and Decker "Dustbuster" hand-vacuum (Fig. 3). Only slight modifications were necessary to permit its use as an electrical field aspirator. These entailed the removal of the filter located at the distal end of the detachable nozzle and the internal flap near the apex. Inserted into the opening of the nozzle apex was a rectangular collecting bag approximately 8 cm by 15 cm in size (Fig. 3). The opening of the collecting bag could be secured to the nozzle apex by two small flaps which could be folded back on the top and bottom of the nozzle and held with an elastic band. After the collector had completed the collection, the bag with its contents could be removed from the nozzle opening, sealed with a spring clip and placed in a killing jar.

All biting flies collected were sorted and labelled in the field on the basis of family taxon and sample time. Before transportation to the laboratory black flies and Culicoides spp. were placed in vials of 70% alcohol. Mosquitoes and tabanids were placed in plastic pill bottles, and once in the laboratory, refrigerated while awaiting identification.

(c) Trapping schedule

Initial testing showed that the cattle-baited trap was difficult to operate in the dark, therefore the last (or fourth) evening sample time commenced approximately at sunset, when sufficient light was still available. In order to maintain the last evening sample at sunset throughout the trapping season, the number of hours after a reference sunset was used as a timing system. Under this system, the local (clock) time of a reference sunset is referred to as 0:00 or 24:00 hours standard sunset time (SST), and therefore one hour after this local time would be 1:00 hours

SST and 12 hours after this local time 12:00 hours SST. The local time of sunset varies throughout the spring and summer, and therefore the time of the reference sunset would also have to be altered. This was accomplished by selecting the local time of sunset on the Sunday of each week as the reference sunset time (0:00 or 24:00 hours SST), around which all sample times for that week would be based. Within any one week the difference in the local time of sunset from beginning to end would rarely vary by more than 10 minutes. The use of standard sunset time effectively positioned the last evening sample time throughout the trapping season very close to sunset.

Table 1 shows the standard sunset times and the approximately equivalent local time used in this study. Appendix A gives the exact local time of each weekly reference sunset. Systematic trapping using SST as the timing system was conducted on select days from May 26 to August 25, 1982.

(d) Trap bias

In order to determine if adult biting flies collected in the cattle-baited trap were actually attracted to the bovine bait and not the structural conformation of the trap itself, the following set of trials was initiated. On July 4 between the morning and afternoon sample periods, the bovine bait was placed in the trap and left for 5 minutes, after which the tent was hoisted to the up position and all flies captured in the trap were removed. The tent was then dropped to the down position and the bovine bait moved to a location approximately 30 m away. The tent was then returned to the upright position and all flies that may have been attracted to the immediate vicinity by the bovine bait during its removal were collected. The tent was again returned to the down position, the collector left the trapping area, and the cattle-baited trap minus the bovine bait exposed for 5 minutes. After this interval the tent was again brought to the up position and all flies captured were removed. The bovine bait was again placed in the trap and the entire trial repeated. This procedure was repeated twice again on July 7 and July 8, thus giving a total of 6 trials with the bovine bait present and 6 with it absent. The total numbers of flies collected under each condition (with or without the bovine bait) were then compared.

3. CO_2 Trap

(a) Trap design

A Trueman-McIver "segregating" CO_2 trap was employed to gain information on the host-seeking activity of adult biting flies during times when the cattle-baited trap was not in operation. The design and functional mechanism of this trap have been fully described by Trueman and McIver (1981) and only a brief description is given here. The trap consisted of a flat-top wooden pyramid approximately 1.2 m high with a 2.4 m wide square base (Fig. 4). The wooden pyramid was covered with a heavy black plastic, but unlike the original design, baffles extending from each side of the pyramid were not used. Internally a large fan (Fig. 4a) was placed at the top of the pyramid to which a cloth funnel was attached. The tapered end of the funnel was attached to a segregating mechanism which allowed the catch to be separated into 30 one-hour intervals. Each one-hour interval will be referred to as a "sample hour".

The segregating mechanism (Fig. 4b) consisted of 30 sample containers mounted to a rotating turntable. The turntable was connected to an electrical timer which when set rotated the turntable each hour, placing a new sample container under the funnel. Vaponette insect strips placed under the turntable killed all flies collected.

Adult biting flies were attracted to the CO_2 trap by CO_2 released from tanks at a rate of 500 ml per minute. The rate of flow was controlled by a flow-meter placed on a wooden platform directly above the fan (Fig. 4b). Flies thus attracted were sucked in by the fan, down the funnel and into the sample containers.

(b) Trapping procedure and schedule

In order to be comparable with the results of the cattle-baited trap, the CO_2 trap was also operated under the standard sunset time system (Appendix A) with each sample hour (i.e., each hour of operation) starting at the beginning of each hour SST. Therefore the last sample hour before sunset would be from 23:00 to 24:00 (0:00) hours SST and the first sample hour after sunset from 24:00 (0:00) to 1:00 hours SST. The CO_2 trap was operational approximately five days out of seven depending on local weather conditions and CO_2 supply, from June 6 to September 16, 1982. After each day of operation, which usually lasted between 20 to 24 hours (i.e., 20 to 24 sample hours), the contents of each sample container were removed, sorted by family taxon and sample hour, and transported back to the laboratory for identification.

C. MEASUREMENTS OF METEOROLOGICAL VARIABLES

To elucidate the effect of certain meteorological variables on host-seeking activity and blood-feeding behaviour, records were made during each sample time (taken with the cattle-baited trap) of ambient temperature, relative humidity, wind speed, reflected light intensity and cloud cover. All meteorological variables were measured at a field weather station located midway (20 m) between the cattle-baited and CO_2 traps (Fig. 1). Instruments for measuring meteorological variables included a hand-held anemometer for wind speed, a sling psychrometer for relative humidity and ambient temperature (dry bulb), and a Luna 6 light meter. Cloud cover was estimated visually and any precipitation was noted.

The following procedure was used throughout the trapping season to obtain measurements of the above meteorological variables. Shortly after the start of each sample time (approximately one minute), the maximum and minimum wind speeds 1 m above ground level were noted over a two-minute period; a mean was then calculated. Next the intensity of reflected light 30 cm above a gray Kodak neutral test card (18% reflectance) was measured, after which cloud cover was estimated. Following this, the relative humidity (RH) and ambient temperature (t) 1 m above ground level were taken and used to calculate the saturation deficit, using the formula:

$SD = es(1 - RH)$, where

es = saturation vapour pressure at temperature t
RH = relative humidity expressed as a fraction of one

Wind speeds were again measured during the last two minutes of the sample time and the mean obtained was averaged with the first. A recording thermograph also located at the weather station gave a continuous record of the ambient temperature 1 m above ground level.

D. LABORATORY PROCEDURE

For each sample time or sample hour, the number of each species of biting fly was recorded. The number of blood-feds collected in each sample time was also noted. Black flies were identified using the key provided by D. Davies et al. (1962). Due to the present difficulty in separating the adults of Simulium venustum Say complex from Simulium verecundum Stone and Jamnback complex in Newfoundland, the two were grouped together and referred to as S. venustum/verecundum complex. Tabanids were identified using the key provided by Pechuman (1981) and mosquitoes using the key of Wood et al. (1979). Voucher specimens of species identified were sent to the Biosystematics Institute in Ottawa and confirmed.

E. ANALYSIS OF DATA

Individual handling and analysis of each data set is given in the Results section where appropriate. Statistical procedures used to analyze the data included the t-test, the Pearson product-moment correlation coefficient, the Chi square test of independence, and regression analysis. Information on these various statistical procedures was obtained from Ferguson (1971), Robbins and Van Ryzin (1975), Ryan et al. (1976) and from consultation with Dr. A. Desmond, Department of Mathematics and Statistics, Memorial University, St. John's.

F. USE OF TERMS

In the past, terms have often been indiscriminately applied to describe the various steps involved from initial blood hunger to final engorgement, and as a result much confusion exists in the literature (see Sutcliffe and McIver, 1979, for example). In order to make meaningful comparisons with previous literature and for the sake of clarity, several terms will now be defined and adhered to for the purpose of this study. These terms are also found in the Glossary of Terms. As used here, "activity" refers to host-seeking activity, that is, adult females which are actively seeking a blood-meal. An index of this activity is the number of adult female flies collected in baited traps (in this case, the cattle-baited and CO_2 traps). The term "blood-fed" will denote those members of the host-seeking population which have successfully completed "biting" and "gorging". Here, "biting" and "gorging" will be used as defined by Sutcliffe and McIver (1979): (1) biting, entailing probing, piercing the skin, and tasting the blood, and (2) gorging, the active intake of the fluid meal. Gorging must be preceded by biting, but biting does not necessarily lead to successful gorging.

Various other terms which have been introduced in the Materials and Methods section, such as sample time and sample day, are also found in the Glossary of Terms.

GLOSSARY OF TERMS

ACTIVITY: Refers to host-seeking activity, that is, the act of searching for a blood-host by adult female flies. An index of this activity is the number of adult female flies collected in the cattle-baited and CO_2 traps.

BITING: Collectively refers to the act of probing, piercing the skin and tasting the blood of a host by adult female flies.

BLOOD-FED: Refers to adult female flies which have successfully completed biting and gorging.

GORGING: The active uptake of the blood-meal by adult female flies. Gorging must be preceded by biting, but biting does not necessarily lead to successful gorging.

SAMPLE DAY: A complete sample day refers to a complete complement of 12 sample times (i.e. 3 sample periods), obtained with the cattle-baited trap over the course of a single day at predetermined standard sunset times as opposed to an incomplete sample day, with less than a full complement of 12 sample times.

SAMPLE HOUR: Operation of the Trueman-McIver CO_2 segregating trap for one 60-minute interval, at a predetermined standard sunset time.

SAMPLE PERIOD: A set of 4 sample times obtained with the cattle-baited trap at predetermined standard sunset times. Ideally, there were 3 such periods in a sample day, a morning, afternoon and evening sample period, each with a set of 4 sample times.

SAMPLE TIME: One ten-minute exposure of the bovine bait to the adult biting fly population. Each sample time was taken at a predetermined standard sunset time.

STANDARD SUNSET TIME (SST): The timing system under which the cattle-baited and CO_2 traps were operated. Refers to the number of hours after a reference sunset, which was designated as 24:00 (or 0:00) hours SST. The local clock time of sunset on the Sunday of each week was selected as the reference sunset around which all samples for that week were based.

RESULTS

A. CATTLE-BAITED TRAP: BIAS AND PERFORMANCE

A minimum of 26 species of biting flies in four families were collected in the cattle-baited trap from May 26 to August 25, 1982. These include:

Black flies (Family: Simuliidae)

- *Cnephia ornithophilia* Davies, Peterson and Wood
- *Eusimulium spp.*
- *Prosimulium mixtum* Syme and Davies
- *Simulium decorum* Walker
- *S. venustum/verecundum* complex
- *S. vittatum* Zetterstedt
- *Stegopterna mutata* (Malloch)

Mosquitoes (Family: Culicidae)

- *Aedes abserratus* (Felt and Young)
- *Ae. canadensis* (Theobald)
- *Ae. decticus* Howard, Dyar and Knab
- *Ae. hexodontus* Dyar
- *Ae. punctor* (Kirby)
- *Culiseta impatiens* (Walker)

Tabanids (Family: Tabanidae)

Chrysops excitans Walker

C. frigidus O.S.

C. furcatus Walker

C. mitis O.S.

C. sordidus O.S.

C. zinzalus Philip

Hybomitra frontalis (Walker)

H. lurida (Fallen)

H. minuscula (Hine)

H. zonalis (Kirby)

Sand flies (Family: Ceratopogonidae)

Culicoides obsoletus group

Culicoides spp.

C. yukonensis Hoffman

During the normal trapping schedule, several observations were made regarding the general operation of the trap. With the possible exception of *Culicoides spp.*, these include:

(1) Due to the speed (3 seconds or less) in which the collapsible tent was hoisted up, the vast majority of biting flies swarming around the bovine bait or engaged in blood-feeding appeared to be captured within the tent, with very few escaping.

(2) Few or no biting flies entered into or escaped from the collapsible tent when the collector(s) entered the tent during each collection interval.

(3) Virtually all biting flies captured in the tent could be removed during each collection interval with the aid of the hand vacuum.

(4) Blood-feeding behaviour of several species of biting flies, especially S. venustum/verecundum complex (Table 16), did not appear to be severely disrupted while enclosed in the tent.

Table 2 shows the total number of black flies collected in the cattle-baited trap with and without the bovine bait. The remaining families of biting flies were sparsely collected during the trap bias trials and therefore are not considered. The mean number of black flies collected per trial ($n = 6$) in the cattle-baited trap with the bovine bait ($\bar{x} = 21.0 \pm 13.0$) was significantly greater ($p < .01$) than the mean number collected ($\bar{x} = 1.3 \pm 1.86$) without the bovine bait ($t = 3.68$, approximate $df = 5$). This suggests that the majority of black flies were attracted to the bovine bait rather than to the structural conformation of the trap.

B. BLACK FLIES (Family: Simuliidae)

1. Comparison between the Cattle-baited and CO_2 Traps

A comparison between the results obtained in the cattle-baited and the CO_2 traps was made to investigate the assumption that under the conditions of this study, changes in the number of host-seeking black flies collected in the cattle-baited trap would be reflected in the CO_2 trap, and therefore, that the CO_2 trap would be an indicator of host-seeking activity at times when the cattle-baited trap was not in use.

(a) Relative abundance

A contingency table was constructed to test the hypothesis that each trap, over the course of the trapping season, collected a given species in equal proportion (Table 3). The total number of each species (or species complex) collected in the cattle-baited trap on each complete sample day from June 13 to August 16 during the sample times 12:30, 13:30, 17:30, 18:30, 22:30 and 23:30 hours (SST) were compared with the total number collected during the sample hours 12:00-13:00, 13:00-14:00, 17:00-18:00, 18:00-19:00, 22:00-23:00, and 23:00-24:00 hours (SST) in the CO_2 trap. Flies collected in the cattle-baited trap during the remaining sample times (12:00, 13:00, 17:00, 18:00, 23:00

and 24:00 hours SST) were excluded from the contingency table so as not to bias the comparison by favouring the first half of the hour. Only complete sample days were considered so as not to weight a particular time of day.

The Chi square statistic was not significant (χ^2 = 3.16) at p>.05, suggesting that each trap collected a given species (or species group) in equal proportion.

(b) Daily activity

Comparisons between the daily catch in each trap for P. mixtum, S. venustum/verecundum complex and St. mutata are given in Table 4. Few S. vittatum and S. decorum were collected in the CO_2 trap and therefore were omitted from this comparison. The total number of each species (or species complex) collected in the cattle-baited trap on each complete sample day during the sample times 12:30, 13:30, 17:30, 18:30, 22:30 and 23:30 hours (SST) was correlated with the corresponding total catch in the CO_2 trap during the sample hours 12:00-13:00, 13:00-14:00, 17:00-18:00, 18:00-19:00, 22:00-23:00 and 23:00-24:00 hours (SST). Flies collected in the cattle-baited trap during the remaining sample times (12:00, 13:00, 17:00, 18:00, 23:00 and 24:00 hours SST) were omitted so as not to favour the first half of the hour.

Significant correlations (r) between the number of flies collected in the cattle-baited and CO_2 traps were found for <u>P. mixtum</u> ($r = .855$, $p<.01$) and <u>S. venustum/verecundum</u> complex ($r = .971$, $p<.01$). A significant correlation ($r = -.134$, $p>.05$) was not found with <u>St. mutata</u> (Table 4).

(c) Diurnal activity

Comparisons between the diurnal activity as determined by the cattle-baited and CO_2 traps for <u>P. mixtum</u> and <u>S. venustum/verecundum</u> complex are shown in Tables 5 and 6. <u>S. vittatum</u>, <u>S. decorum</u> and <u>St. mutata</u> were collected in numbers too low for this comparison. The number of flies collected in the cattle-baited trap in the morning (12:30, 13:30 hours SST), afternoon (17:30, 18:30 hours SST) and evening (22:30, 23:30 hours SST) sample times were correlated with the equivalent morning (12:00-13:00, 13:00-14:00 hours SST), afternoon (17:00-18:00, 18:00-19:00 hours SST) and evening (22:00-23:00, 23:00-24:00 hours SST) hourly catches in the CO_2 trap. For both <u>P. mixtum</u> and <u>S. venustum/verecundum</u> complex only sample days (complete or otherwise) in which the cattle-baited trap collected 30 or more flies were used in the above correlations. This was done to avoid correlating the results of the two traps during times in which few or no flies were on the wing. Cumulative correlation coefficients were calculated at various points over the season in order to detect any changes in the resultant r values with time (Tables 5, 6).

It can be seen in Tables 5 and 6 that all r values calculated were significant ($p < .05$) and positive. R values were usually lowest for the afternoon catches and highest for the morning and evening. The r values for the afternoon catches of S. venustum/verecundum complex and evening catches of P. mixtum remained remarkably consistent, but decreased markedly for the morning catch of S. venustum/verecundum complex as the season progressed. Remaining r values for each time of day did not vary greatly over the season.

2. Species Present and Seasonal Occurrence

(a) Species present

The numbers and species of black flies collected at the Harding farm, near Paddy's Pond, St. John's, in the cattle-baited and CO_2 traps are listed in Tables 7 and 8. Systematic trapping was instituted on select days with the cattle-baited trap from May 26 to August 25 and with the CO_2 trap from June 6 to September 16, 1982. From 12:00 to 24:00 hours (SST) a total of 337 and 701 samples were taken with the cattle-baited and CO_2 traps respectively. An additional 751 samples were taken with the CO_2 trap from 24:00 to 12:00 hours (SST).

All simuliids collected (18,520) in both traps were female. From 12:00 to 24:00 hours (SST) mammalophilic species comprised 99.80% of the total catch in the cattle-baited trap (Table 7) and 98.95% in the CO_2 trap (Table 8). The two most abundant simuliids, S. venustum/verecundum complex and P. mixtum made up 95.50% and 93.48% of the mammalophilic catch in the cattle-baited and CO_2 traps respectively. S. venustum/verecundum complex was the most abundant simuliid(s), approximately twice as abundant as P. mixtum (Tables 7, 8). The remaining mammalophilic species collected from 12:00 to 24:00 hours (SST), S. vittatum, S. decorum and St. mutata, contributed little to the population, comprising 4.49% and 6.53% of the mammalophilic catch in the cattle-baited and CO_2 traps respectively (Tables 7, 8).

From 24:00 to 12:00 hours (SST) approximately 90% of the flies collected in the CO_2 trap were of the S. venustum/verecundum complex (Table 8). Prosimulium mixtum was the second most numerous species, amounting to approximately 5% of the flies collected.

Cnephia ornithophilia and Eusimulium spp. are of little concern since these species are ornithophilic in nature (see Fallis, 1964) and were taken in low numbers (Table 7, 8). Their presence in the cattle-baited trap is thought to be a general response to CO_2 emissions from the bovine bait.

(b) Seasonal occurrence

Seasonal variation in the daily mean number of mammalophilic black flies as determined by the cattle-baited and CO_2 traps is shown in Figures 5 and 6. The results of the cattle-baited trap (Fig. 5) are based on the mean number of flies collected per sample time (12:00-24:00 hours SST), on complete sample days only (May 26 to August 16). Those of the CO_2 trap (Fig. 6) are based on the mean number of flies collected per sample hour from 12:00 to 24:00 hours (SST) from June 6 to September 16. _Simulium decorum_ was taken in very low numbers (Tables 7, 8) and therefore excluded from the above results. _Simulium vittatum_ was collected in low numbers in the CO_2 trap (Table 8) and consequently omitted from these results. A summary of the seasonal occurrence and abundance for all mammalophilic species collected in each trap is given in Figure 7.

Black fly activity was low in late May, but increased greatly during June (Figs. 5a, 6a). Activity continued at a high, though fluctuating, level until early August with another small peak of activity in mid-August. Little activity was observed from mid-August to mid-September at which time the trapping schedule was concluded.

Prosimulium mixtum was the predominant species during June (Figs. 5b, 6b). Peak numbers occurred on June 14 in the cattle-baited trap and on June 18 in the CO_2 trap. Relatively few P. mixtum were in the field during July with activity ending by the beginning of August.

S. venustum/verecundum complex was not collected during late May and was taken in low numbers throughout most of June (Figs. 5c, 6c). Maximum activity occurred in July with a second minor peak in mid-August. Peak numbers occurred on July 20 in the cattle-baited trap and on July 16 in the CO_2 trap. This species complex was present in low numbers from mid-August to mid-September, at which time the trapping schedule ceased.

Conflicting results were obtained for St. mutata in the cattle-baited and CO_2 traps. Maximum activity as determined by the cattle-baited trap occurred during late June to early July (Fig. 5d), whereas early to mid-June was the time of maximum catch in the CO_2 trap (Fig. 6d). Stegopterna mutata was collected in the field from late May to late July.

Simulium vittatum showed two peaks of activity, a minor peak in late May and a larger peak in late July (Fig. 5e). Simulium vittatum was active in the field until mid-September (Fig. 7).

Simulium decorum was present in very low numbers from early July to mid-September (Fig. 7).

3. Diurnal Activity and the Influence of Meteorological Conditions

In order to elucidate the relationship between weather and host-seeking activity the numbers of P. mixtum and S. venustum/verecundum complex collected in the cattle-baited trap under various meteorological conditions were compared.

(a) Prosimulium mixtum Syme and Davies

The results of the cattle-baited trap for several select days with meteorological data are shown in Figures 8 to 11. Specific days illustrate prevailing trends in activity from June 7 to July 8, when 3,313 P. mixtum (97.6% of the season's catch in the cattle-baited trap) were collected in 132 sample times.

For each of the three weeks of maximum catch in the cattle-baited trap, weeks four, six and seven (the dates of each week are given in appendix A), sample times with the largest catches were summed until the total number of flies in these samples approached 75% of the total weekly catch (Table 9). Activity was considered high in these sample times and low in remaining sample times. The range of each meteorological condition observed during these high activity sample times was tabulated for each week. Weeks were considered separately to avoid difficulties presented by population changes; within each week changes were considered minimal because of the short time span involved.

Once each weekly range was determined, the three weekly ranges for each meteorological condition were pooled (Table 10). Thus for each meteorological condition, ambient temperature, saturation deficit, wind speed and reflected light intensity, the pooled ranges may be considered as the "meteorological limits of high activity" such that both high and low activity could occur within the confines of each limit, but only low activity was observed outside these limits. These limits or ranges apply only to the aforementioned weeks, four, six and seven, when 3,004 flies (88.5%, of the season's catch in the cattle-baited trap) were collected in 120 samples times (Table 9).

Correlation coefficients (r) were calculated for the degree of association between activity and ambient temperature, saturation deficit, wind speed and reflected light intensity. Data collected with the cattle-baited trap in weeks four, six and seven were used to calculate all r values (Table 11). Each of the three weeks was analysed separately to avoid difficulties presented by population changes. During each week all samples taken were used to calculate each r value.

Since each meteorological condition under consideration might influence activity, extreme unfavourableness in any one condition may act to inhibit activity during times when other conditions are favourable. This will obviously put certain constraints on the calculated r values. In order to at least partially compensate for this, correlation coefficients were also calculated (Table 11) for each meteorological condition while omitting those sample times in which any of the remaining conditions fell outside the meteorological limits of high activity determined in Table 10. Meteorological conditions within these limits were not greatly suppressive towards activity as attested to by the large number of flies collected (Table 9).

The results of the CO_2 trap were not considered in detail on a daily basis since temperature was the only meteorological condition monitored on a nearly continual basis.

To quantify the diurnal pattern of host-seeking activity of *P. mixtum* in spite of day to day variations, the numbers of flies collected from each trap from June 7 to July 8 were tabulated by sample time (cattle-baited trap) or sample hour (CO_2 trap) and means calculated for each (time or hour). From June 7 to July 8, 3,313 flies (97.6% of the season's catch) were collected in the cattle-baited trap and 1,992 flies (97.2% of the season's catch) in the CO_2 trap. Calculated means are presented graphically (Fig. 12) and each graph can be considered as a "generalized pattern of diurnal activity", indicating when high or low activity most commonly occurred.

Unless otherwise stated, all results refer to those of the cattle-baited trap.

(i) Ambient temperature

Prosimulium mixtum was sparsely collected in the cattle-baited trap below 11 °C or above 22 °C (Table 10; Figs. 8, 9, 11). Between these temperatures activity was variable. Activity showed a low positive correlation (r = .303, p<.05) with temperature during week four when all sample times during this week were used in the correlation (Table 11). No other significant correlations (p>.05) were found.

With one exception, *P. mixtum* was always collected in low numbers with the CO_2 trap (6 flies or less per sample hour) when the mean hourly temperature (an average of the hourly maximum and minimum temperatures) fell below 9.5 °C. Above this mean temperature activity was variable.

(ii) Saturation deficit

High activity was observed at saturation deficiencies as high as 12.6 mm Hg., although the majority of sample times with high activity were associated with saturation deficiencies below 8 mm Hg. (Table 10; Figs. 8 to 11). Although all correlation coefficients between activity and saturation deficit were negative none were significant at p>.05 (Table 11).

(iii) Wind speed

High activity was observed at wind speeds as high as 9.5 km/h (Fig. 8) whereas speeds exceeding this value were invariably associated with low activity (Table 10). When conditions of temperature, saturation deficit and reflected light intensity were similar, sample periods with higher winds had fewer flies than comparable periods with lower speeds. The total morning catch on June 14, with a mean wind speed of 3 km/h, was five times greater than that of June 13, with a mean wind speed of 8 km/h (Fig. 13). Remaining meteorological conditions were similar on both mornings.

Significant negative correlations between activity and wind speed were found during weeks four ($r = -.428$, $p<.05$) and six ($r = -.557$, $p<.01$) when only those sample times were used in which remaining meteorological conditions fell within the meteorological limits of high activity (Table 11). All remaining correlations were not significant ($p>.05$).

(iv) Reflected light intensity

Activity dropped sharply under conditions of extremely low light intensity. On June 17 (Fig. 10) and July 8 (Fig. 11) the number of flies collected in the last evening sample, which commenced at sunset, was considerably lower than the preceding sample, during which time only light intensity showed any appreciable change.

Activity was negatively correlated with light intensity during week four (r = -.407, p<.05) when only those sample times were used in which the remaining meteorological conditions fell within the meteorological limits of high activity (Table 11). All remaining correlation were not significant (p>.05).

(v) Precipitation

An approaching thunderstorm during the evening sample period of June 17 provided an opportunity to observe the influence of this condition on black fly activity. Thunderclouds were noticed shortly before the second evening sample at which time activity surged (Fig. 10). In no other sample time were as many P. mixtum collected. Temperature, wind speed and saturation deficit did not change greatly during this time (i.e., between the first and second sample times), although reflected light intensity fell from 5,500 to 1,120 lux. No rain fell during the sample period. The cattle-baited trap was not operated during heavy rain though P. mixtum was known to be active under conditions of heavy fog (Fig. 11).

(vi) Diurnal pattern of host-seeking activity

The evening sample period of June 17 was taken under exceptional circumstances (see above) resulting in an unusually large number of individuals. The results of this sample period along with the corresponding sample hours in the CO_2 trap (22:00-23:00 and 23:00-24:00 hours SST) have therefore been omitted from the generalized graphs of activity, as their inclusion would distort the predominant pattern of activity.

The results of the cattle-baited trap (Fig. 12a) indicate that P. mixtum was most active in the morning and afternoon sample periods. Activity was usually low in the evening sample, especially near sunset. The results of the CO_2 trap (Fig. 12b) essentially reflect those of the cattle-baited trap. The majority of flies were collected from 8:00 to 20:00 hours approximate local time (11:00 to 23:00 hours SST) with peak activity occurring from 14:00 to 19:00 hours approximate local time (17:00 to 22:00 hours SST). Activity greatly diminished near sunset and remained at a very low level throughout the night and early hours of the morning (20:00 to 8:00 hours approximate local time; 23:00 to 11:00 hours SST).

(b) Simulium venustum/verecundum complex

The same method of analysis that was employed for P. mixtum was adopted here. The results of the cattle-baited trap for several select days are given in Figures 14 to 17. These days illustrate prevailing trends in activity from June 28 to July 31 when 6,107 S. venustum/verecundum complex (89.2% of the season's catch in the cattle-baited trap) were collected in 161 sample times.

The meteorological limits of high activity for each meteorological condition are shown in Table 13. Flies collected in the cattle-baited trap during weeks six, seven and nine (the dates of each week are given in appendix A) were used to determine these limits (Table 12). The results of July 26 have been included in week nine as a low number of sample times (n = 24) was obtained in this week. During these weeks a total of 5,877 flies (85.8% of the season's catch) was collected in 113 sample times (Table 12).

Correlation coefficients (r) were calculated for the degree of association between each meteorological condition (ambient temperature, wind speed, saturation deficit and reflected light intensity) and activity (Table 14). Data collected with the cattle-baited trap during weeks six, seven and nine (including July 26) were used to calculate all r values.

The generalized patterns of diurnal activity are presented in Figure 18. The activity pattern as determined by the cattle-baited trap (Fig. 18a) is based on data collected from June 28 to July 31 (6,107 flies = 89.2% of season's catch) and that of the CO_2 trap (Fig. 18b) from June 28 to August 4 (4,431 flies = 85.9% of the season's catch).

(i) General comments

A distinct depression in afternoon activity was observed on July 8 (Fig. 16) and July 20 (Fig. 17) at which time temperature, saturation deficit, wind speed and reflected light intensity were at their highest point of the sample day. It was noticed that on July 20 a marked decrease in all meteorological conditions measured during the last afternoon sample time coincided with a substantial increase in activity (Fig. 17). On most days peak activity occurred in the morning and/or evening sample periods. On July 7 (Fig. 15) when meteorological conditions did not change greatly from morning to afternoon no periodicity in activity was observed.

(ii) Ambient temperature

Little activity was observed below 11 °C or above 22 °C (Table 13; Figs. 14, 16, 17); between these temperatures activity was variable. A positive correlation (r = .486,

$p<.05$) between activity and temperature was found during week seven when only those sample times were used in which the remaining meteorological conditions fell within the meteorological limits of high activity (Table 14). No other significant correlations ($p>.05$) were found.

Flies were never taken in large numbers in the CO_2 trap (11 flies or less per sample hour) when the mean hourly temperature fell below 10 °C or above 23.5 °C. Between these temperatures activity was variable.

(iii) Saturation deficit

High activity was noted under saturation deficiencies as high as 9.8 mm Hg. (Table 13; Fig. 16). Activity was negatively correlated ($r = -.368$, $p<.05$) with saturation deficit during week seven when all sample times during this period were used (Table 14). Although all other correlations were negative none were significant ($p>.05$).

(iv) Wind speed

High activity was associated with wind speeds of 8 km/h or less (Table 13; Figs. 14, 16, 17). Winds exceeding this speed were invariably associated with low activity. Activity was negatively correlated with wind speed during weeks six ($r = -.741$, $p<.01$) and seven ($r = -.549$, $p<.01$)

when only those sample times were used in which remaining meteorological conditions fell within the meteorological limits of high activity. Significant correlations were also found for both weeks six ($r = -.334$ $p \leq .05$) and seven ($r = -.534$ $p < .01$) when all samples times obtained during these weeks were used (Table 14). Significant correlations ($p > .05$) were not found during week nine.

(v) Reflected light intensity

Activity sharply declined under conditions of extremely low light intensity. On July 8 (Fig. 16) and July 20 (Fig. 17), the number of flies collected in the last evening sample, which commenced at sunset, was considerably lower than the preceding sample, during which time only light intensity changed appreciably. On most evenings sampled the last sample time yielded the lowest number of flies.

Activity showed a negative correlation with reflected light intensity during week seven ($r = -.457$, $p < .01$) and nine ($r = -.331$, $p < .05$) when all samples collected were taken into account (Table 14). All remaining correlations were not significant ($p > .05$).

(vi) Precipitation

The cattle-baited trap was not in operation during heavy rain, but S. venustum/verecundum complex was known to be active in heavy fog (Fig. 16) as well as during light rain.

(vii) Diurnal pattern of host-seeking activity

The results of the cattle-baited trap (Fig. 18a) indicate that S. venustum/verecundum complex was most active in the morning and evening with a distinct depression in afternoon activity. The results of the CO_2 trap (Fig. 18b) also show a bimodal pattern of activity consisting of a large morning peak (6:00 to 11:00 hours approximate local time; 9:00 to 14:00 hours SST) and a smaller evening peak (19:00 to 21:00 hours approximate local time; 22:00 to 24:00 hours SST). Activity declined after sunset and continued at a low level throughout the night and early hours of the morning (21:00 to 6:00 hours approximate local time; 24:00 to 9:00 hours SST).

(c) Other species

Stegopterna mutata, S. vittatum and S. decorum were collected in very low numbers and as such little can be said about their diurnal activity, except to mention that the first two species were least abundant in the cattle-baited trap during the afternoon sample period (Table 15).

4. Blood-feeding Behaviour and Influencing Factors.

(a) Proportion blood-fed

The numbers and proportions of blood-fed simuliids (proportion = the number of blood-feds collected : the total number of simuliids collected) collected in the cattle-baited trap are presented in Table 16. Blood-fed flies were determined by examining the abdomen for the presence of blood. Simulium venustum/verecundum complex had the highest proportion of blood-feds (p = .694) while St. mutata had the lowest (p = .056). The proportions of blood-fed P. mixtum (p = .348) and S. vittatum (p = .237) were between these two extremes. Simulium decorum was collected in very low numbers, therefore a proportion was not calculated; some individuals were observed to have imbibed blood (13/24). Cnephia ornithophilia and Eusimulium spp. did not take blood from the bovine bait.

(b) Factors influencing blood-feeding behaviour.

The influence of adult size, time of day, calendar date, and various meteorological factors on the blood-feeding behaviour of P. mixtum and S. venustum/verecundum complex was investigated. Stegopterna mutata, S. decorum and S. vittatum were all taken in numbers too low for the purpose of this study.

(i) Meteorological conditions

The proportion of blood-fed P. mixtum and S. venustum/verecundum complex in each complete sample period was correlated with several meteorological conditions. These included mean sample period saturation deficit, wind speed, reflected light intensity and temperature, mean temperature over the previous 24 hours (time zero designated as the start of the sample period), and mean temperature over the previous 24 to 48 hours. Only complete sample periods with 30 or more flies of either P. mixtum or S. venustum/verecundum complex were considered. This was done in order to maintain an equal number of observations per sample period and to ensure a reasonable estimate of the proportion blood-fed. All means used for each meteorological condition were calculated as the average of the maximum and minimum values observed.

It can be seen in Table 17 that significant correlations were found between the proportion of blood-fed P. mixtum and mean sample-period temperature ($r = .541$, $p<.05$), mean 24-hour temperature ($r = .852$, $p<.01$), mean 24 to 48-hour temperature ($r = .569$, $p<.05$), and mean sample period light intensity ($r = -.691$, $p<.01$). Regressions of the proportion blood-fed on mean 24-hour temperature and proportion blood-fed on mean light intensity were computed, the two independent variables (temperature and light) being chosen for their higher r values (Table 17). Each of these two independent variables was analysed separately as the response to light was that of an immediate behavioural response. On the contrary, the response to mean 24-hour temperature was a function of time which was most likely, at least in part, mediated by changes in metabolism. Due to the large values of light intensity obtained, this variable was expressed as reflected light intensity/100 to facilitate the regression model.

The regression of the proportion of blood-fed P. mixtum on mean 24-hour temperature (R^2 = 70.7%) is shown in Figure 19a, with details of the analysis found in Appendix B. The regression, significant (F = 37.12) at p<.01, gives the regression equation y = −.0378 + .0344x, where y = proportion blood-fed (per sample period) and x = mean 24-hour temperature. Figure 19b and Appendix C show the regression of the proportion blood-fed on light intensity (R^2 = 44.0%). The regression is significant (F = 12.79) at p<.01, with the resultant equation y = .543 − .0019x, where y = proportion blood-fed (per sample period) and x = mean sample period reflected light intensity/100.

Table 17 indicates that significant correlations were found between the proportion of blood-fed S. venustum/verecundum complex and mean sample period temperature (r = .634, p<.01), mean 24-hour temperature (r = .693, p<.01), mean 24 to 48-hour temperature (r = .447, p<.05), and mean sample period reflected light intensity (r

$= -.438$, $p<.05$). Regressions of the proportion blood-fed on mean sample period temperature (Fig. 20a; Appendix D) and on mean 24-hour temperature (Fig. 20b; Appendix E) were computed, the independent variables (temperatures) selected on the bases of their higher r values (Table 17). As with P. mixtum independent variables were considered separately.

The regression of the proportion blood-fed on mean sample period temperature ($R^2 = 37.4\%$) is significant ($F = 14.12$) at $p<.01$ with the resultant equation $y = -.0718 + .0407x$, where y = proportion blood-fed (per sample period) and x = mean sample period temperature. The regression of the proportion blood-fed on mean 24-hour temperature ($R^2 = 60.7\%$), significant ($F = 33.49$) at $p<.01$, gives the regression equation $y = .139 + .0314x$, where y = proportion blood-fed (per sample period) and x = mean 24-hour temperature.

(ii) Adult size

In order to examine the influence of size on blood-feeding, wing lengths of blood-fed and unfed P. mixtum females were measured. Simulium venustum/verecundum complex was not considered in this particular section as variation in size could be attributable to interspecific as well as conspecific differences. Wing lengths were measured from the end of the basal cell to the wing tip. Females used for measurements were randomly selected from samples taken with the cattle-baited trap during the normal trapping schedule. Results indicated no significant difference in the size of blood-fed or unfed *P. mixtum*. Unfed females (n = 100) had a mean wing length of 2.89 ± .21 mm while blood-fed females (n = 99) had a mean wing length of 2.92 ± .20 mm. This difference was not significant (t = 1.26) at $p > .05$.

(iii) Time of day and calendar date

The proportions of blood-fed *P. mixtum* and *S. venustum/verecundum* complex (Tables 18, 19) were tabulated by time of day (sample period) and calendar date (week). Only complete sample periods were used in order to maintain an equal number of observations per period. Furthermore for each time of day (morning, afternoon, or evening sample period) a weekly proportion was calculated for either *P. mixtum* or *S. venustum/verecundum* complex only if the week's total for that time of day (morning, afternoon, or evening) was 30 flies or greater. This was done in order to ensure a reasonable estimate of the proportion blood-fed.

Table 18 indicates that the proportion of blood-fed *P. mixtum* tended to increase as the season progressed, this tendency being especially noticeable during the afternoon. With *S. venustum/verecundum* complex the proportion of blood-fed flies during the morning and evening tended to increase until week nine (at which time the population was peaking) and thereafter declined (Table 19). This pattern was also apparent when time of day was not considered (weekly total of sample periods). Contrary to this, the proportion blood-fed during the afternoon fluctuated as the season progressed with no distinct pattern. The proportion of blood-fed *P. mixtum* was highest in the evening, while the morning and afternoon proportions had similar levels, both lower than the evening. The same pattern was seen with *S. venustum/verecundum* complex.

C. OTHER BITING FLIES

1. Mosquitoes (Family: Culicidae)

Table 20 lists the species of mosquitoes that were taken in each trap as well as the dates when each species was first and last collected. Surprisingly few mosquitoes (all female) were collected in either trap (cattle-baited = 363, CO_2 = 117) and as such, only a few general comments are made. Six species were collected in the cattle-baited trap; half of these being represented by a single specimen, and five species in the CO_2 trap (Table 20). Seven species were found in total. The identification of *Aedes cantator* (Coquillett), *Ae. decticus* and *Ae. hexodontus* have not yet been confirmed. The proportions blood-fed for the three most abundant species, Ae. abserratus, Ae. punctor and Cs. impatiens are given in Table 21. Data indicates that Ae. abserratus and Ae. punctor were much more aggressive feeders than Cs. impatiens. The single specimens of Ae. canadensis, Ae. hexodontus and Ae. decticus were all engorged.

In view of the low number of mosquitoes collected, nothing conclusive can be said about their diurnal activity except to mention that Ae. abserratus, Ae. punctor, and Cs. impatiens were much more abundant during the evening sample periods than either the morning or the afternoon sample periods (Table 22). It was also noted that approximately 89% (71/80) of the total Ae. abserratus catch in the CO_2 trap was collected from the hour prior to sunset to the first hour after sunrise. Remaining species were taken in very low numbers with the CO_2 trap (Table 20).

2. Tabanids (Family: Tabanidae)

Table 23 lists the species of tabanids that were collected in the cattle-baited trap as well as the dates when each species was first and last collected. In view of the low number of flies collected (106 females in total) only a few general comments can be made. Even fewer flies (12 females in total) were taken in the CO_2 trap and as such these results are not presented.

Ten species were collected from July 6 to August 17, half being represented by a single specimen. The four most abundant species, C. excitans, C. frigidus, C. furcatus and H. zonalis were all observed to have taken blood (Table 23). The only other species observed to have taken blood was C. zinzalus and this species was represented by a single specimen.

No tabanids collected were captured during the evening sample periods.

3. Sand Flies (Family: Ceratopogonidae)

A total of 191 Culicoides were collected in the cattle-baited trap (June 13 to August 25) and 373 in the CO_2 trap (July 20 to September 7). Identification of representative specimens indicated C. yukonensis Hoffman, C. obsoletus group and Culicoides spp. (?) were present in both traps. In consideration of the lack of specific taxonomic information and the relatively low numbers collected, only a few comments can be made.

Of the 191 Culicoides collected in the cattle-baited trap, 133 or approximately 70% of the total season's catch in the cattle-baited trap was collected during the evening sample period of August 9. Specimens identified as C. yukonensis and C. obsoletus group were engorged with an overall proportion blood-fed equal to .49 (93/191). Approximately 88% (329/373) of the season's catch in the CO_2 trap was taken between August 1 to August 31 with peak numbers (116) occurring on August 19. The majority of flies captured in the CO_2 trap (266/373, or 71% of the season's catch) were taken during the three hours prior to sunset and the four hours following sunrise.

DISCUSSION

A. CATTLE-BAITED AND CO_2 TRAPS: BIAS AND PERFORMANCE

The cattle-baited trap was found to collect many more black flies when the bovine bait was present as compared to the number collected when absent (Table 2), the difference being significant at $p < .01$. Therefore, black flies were attracted to the bovine bait rather than the structural conformation of the trap and the possible residual bovine odours. This plus the fact that all black flies collected (10,747) with the cattle-baited trap in the presence of the bovine bait over the course of the trapping season were non-gravid females, with each species showing at least some degree of blood-feeding, suggests that the majority of black flies collected were host-seeking. The remaining families, mosquitoes, tabanids and sand flies (Culicoides), were collected in too low numbers to compare numbers collected in the cattle-baited trap with and without the bovine bait, but the fact that during the normal trapping schedule only non-gravid females were collected and that blood-fed specimens were found for most species supports the assumption that these flies were also host-seeking.

The high proportion of blood-fed S. venustum/verecundum complex (approximately 70%) collected in the cattle-baited trap strongly suggests that the trap design did not greatly inhibit blood-feeding, of at least this complex. Similarly, the high proportion of blood-fed _Ae. abserratus_ (72%) and _Ae. punctor_ (68%) collected in the cattle-baited trap suggests the same is also true for these species.

On the basis of one trapping season, it appears that the cattle-baited trap can be effectively used to study the host-seeking activity and blood-feeding behaviour of black flies under field conditions. The remaining families, mosquitoes, tabanids and sand flies, were taken in too low numbers to draw any conclusions at this time, but the high proportion of blood-fed _Ae. abserratus_ and _Ae. punctor_ suggests that this trap could be useful for the study of mosquitoes as well.

With respect to the CO_2 trap, it was found that no flies were collected during times when the CO_2 cylinders were depleted, showing that the attraction of this trap was largely due to CO_2 and not due to other characteristics of the trap. It was also noted that all specimens collected (6,222) were non-gravid females with the exception of one female from the _S. venustum/verecundum_ complex which implies that females caught in this trap were host-seeking.

B. BLACK FLIES (Family: Simuliidae)

1. Comparison between the Cattle-baited and CO_2 Traps

The purpose of the CO_2 trap in this study was to act as a substitute host and to monitor both diurnal and seasonal changes in the host-seeking population at times when the cattle-baited trap was not in operation. Tables 4 to 6 show that when changes in the numbers of S. venustum/verecundum complex and P. mixtum caught in the cattle-baited trap occurred, similar changes were observed in the CO_2 trap. The CO_2 trap apparently reflected changes in the host-seeking activity of these populations towards cattle. While it cannot be assumed that this relationship would necessarily hold true under different circumstances (for example, if the two traps were located in different habitats), nevertheless, the similarity in the results obtained from these two traps warrants further investigation of this CO_2 trap in quantifying the diurnal and seasonal host-seeking activity of P. mixtum and S. venustum/verecundum complex and possibly other species of biting flies.

2. Species Present and Seasonal Occurrence

The Pickavance stream complex was the major breeding area in the vicinity of the trapping site, and the seasonal succession and abundance of the larvae therein have been intensely studied by Lewis and Bennett (1974). Given in Table 24 is a comparison of the above investigation and the present study. Although Ebsary (1973) and Lewis and Bennett (1973, 1974) reported that both Prosimulium fuscum Syme and Davies and P. mixtum occurred in Newfoundland, Colbo (1979), Peterson (1970) and Rothfels and Freeman (1977) concluded that only P. mixtum occurs on the island and hence the reference to P. fuscum is an error.

Lewis and Bennett (1974) failed to find S. vittatum and S. decorum in the Pickavance watershed whereas adults were collected by the present author, though infrequently, from both the bovine bait and the CO_2 traps (Tables 7, 8). These adults therefore were probably the result of immigration from other areas. The closest known breeding areas of S. vittatum, which in Newfoundland are primarily outflows from lentic bodies (Colbo, 1979), to the location of the traps, were at a distance of at least two kilometers. This distance from the trapping location may help explain the low catch of this species in view of the fact that it is considered common in Newfoundland (Ebsary, 1973; Lewis and Bennett, 1973). Simulium decorum was collected in only two streams by Lewis and Bennett (1973), both of these on the Avalon Peninsula and they considered this species to be uncommon.

Simulium tuberosum (Lundström) was relatively abundant in at least two streams of the Pickavance watershed (Lewis and Bennett, 1974) and larvae were also collected by the present author in one of these streams which was located less than ten meters from the CO_2 trap. Colbo (1982a) has collected adult S. tuberosum in CO_2-baited box traps elsewhere on the Avalon Peninsula. Therefore, the absence of the adults of this species from the present study is puzzling and no explanation can be given at this time.

According to Lewis and Bennett (1974), there were two periods when larval simuliids were abundant: an early spring peak composed largely of P. mixtum (referred to as P. mixtum/fuscum) and St. mutata, and a second late spring to early summer peak, S. venustum and S. verecundum being the major constituents. Accounting for the developmental time from larva to adult and with the exception of St. mutata the present findings (Figs. 5, 6) agree closely with those of these investigators. With respect to St. mutata, adults were collected in much lower numbers than one would have expected from the larval population indicated by Lewis and Bennett (1974), although this may have been the result of yearly population fluctuations or a possible low attraction the CO_2 and cattle-baited traps may have had for this species. What is of interest is the fact that adults of St. mutata demonstrated not one but two periods of peak abundance: one in mid-June as indicated by the CO_2 trap (Fig. 6d), and another in early July as indicated by the cattle-baited trap (Fig. 5d). This apparent discrepancy between the two traps will be discussed in detail under the subheading of St. mutata.

The seasonal succession of adult mammalophilic black flies presented here (Figs. 5, 6, 7) agrees with the larval and/or adult seasonal succession described by previous workers in Newfoundland (Colbo, 1982a; Ebsary, 1973; Lewis and Bennett, 1974). However, with the possible exception of the Maritime provinces (Lewis and Bennett, 1979a) and Quebec (Back and Harper, 1978, 1979; Wolfe and Peterson, 1959), the various species in Newfoundland tend to occur later in the season than their counterparts across eastern North America (Anderson and DeFoliart, 1961; Bruder and Crans, 1979; Cupp and Gordon, 1983; D. Davies et al., 1962; DeFoliart et al., 1967; Merritt et al., 1978; Stone, 1964; Stone and Jamnback, 1955). The long winter and late spring typical of Newfoundland result in stream systems which warm up later in the season than on the mainland thus delaying the emergence of the adult black fly population. It has been well documented that stream temperature greatly influences the developmental time of both the larval and pupal stages (Anderson and Dicke, 1960; Bruder and Crans, 1979; Colbo and Porter, 1981; Jobbins-Pomeroy, 1916; Puri, 1925; Ross and Merritt, 1978; Tarshis, 1968). Lewis and Bennett (1974) reported a delay in larval development in Newfoundland as compared to mainland North America and related this to stream temperature.

(a) Prosimulium mixtum Syme and Davies

This species was the second most abundant black fly collected, adults present from May 26 to August 1, with peak activity occurring in mid-June (Figs. 5b, 6b). Field observations indicated that adults were not present before the trapping schedule began. This species is univoltine (D. Davies and Syme, 1958; Ebsary, 1973; Jamnback, 1969; Lewis and Bennett, 1973, 1974; Peterson, 1970; Stone and Snoddy, 1969) and is considered to be abundant in Newfoundland (Ebsary, 1973; Lewis and Bennett, 1973).

Prosimulium fontanum Syme and Davies, P. mysticum Peterson, P. mixtum and P. fuscum form a complex of closely related North American species formerly under the single name P. hirtipes (Fries) (D. Davies and Syme, 1958; Peterson, 1970; Rothfels, 1956; Syme and Davies, 1958), a species now thought to be only European in distribution (L. Davies, 1957a). Because of these systematic changes, reports on the feeding habits and hosts of P. hirtipes in North America prior to 1960 must be considered in a broad sense, as they may involve one or all of the above species. Anderson and DeFoliart (1961) suggested that many of the early feeding records may not be particularly invalid, since at least P. mixtum and P. fuscum have similar feeding habits. Fredeen (1973) considered P. mixtum to be an important pest of domestic animals in Canada. The preferred livestock host of P. mixtum appears to be horses (Anderson and DeFoliart, 1961; Cupp and Gordon, 1983; Merritt et al., 1978; Stone, 1964), but records of P. hirtipes (which may have included P. mixtum) attacking cattle do exist (Downe and Morrison, 1957; Malloch, 1914). Mokry (1980) found that P. mixtum would attack cattle in Newfoundland.

L. Davies (1961), working with an anautogenous strain of P. mixtum, suggested that nulliparous females tend to disperse away from the stream of origin whereas parous females tend to remain in the vicinity of the streams in which they have recently oviposited. Prosimulium mixtum in Newfoundland, unlike its counterparts on the mainland, is autogenous (Lewis and Bennett, 1973) and therefore females attacking cattle for their first blood-meal would be parous. If L. Davies's (1961) relationship between the dispersal powers of nulliparous and parous females holds true for autogenous strains of P. mixtum, then this species could be expected to be troublesome to cattle in Newfoundland only near suitable breeding sites; however, such sites are very common in insular Newfoundland. Since no information presently exists on the dispersal habits of P. mixtum in Newfoundland, further investigation is warranted. L. Davies (1961) estimated that few P. mixtum survive to the third ovarian cycle and in this regard the autogenous form of *P. mixtum* in Newfoundland would have a low vector potential for any diseases which might accidentally be introduced into insular Newfoundland as few flies would survive to take a second blood-meal.

In light of the abundance of *P. mixtum* in Newfoundland (author's data; Ebsary, 1973; Lewis, 1973; Lewis and Bennett, 1973) and its avidity to take blood from cattle (ca. 35% blood-fed), it should be considered an important pest of cattle. Owing to this species' early appearance and univoltine nature, *P. mixtum* would only be a pest of cattle during the late spring and early summer. The extent of the economic impact of this species on cattle productivity requires further study.

(b) *Simulium venustum/verecundum* complex

Rothfels et al. (1978) identified 7 sibling species of *S. venustum* and at least 2 sibling species of *S. verecundum*, based on chromosome morphology. Rothfels (1981) listed 3 more sibling species of *S. venustum*. Because of the present difficulty in separating the adults of the *S. venustum* complex from the adults of the *S. verecundum* complex, the two are grouped together and referred to as *S. venustum/verecundum* complex. This complex was the most frequently collected group of simuliids, the adults being active, from June 8 to September 16 with peak abundance in

July. Simuliids designated as S. venustum are considered important pests of livestock in North America (Cupp and Gordon, 1983; Fredeen, 1973, 1977a) and there is an exhaustive list of its attacks on cattle, for example, Abdelnur (1968), Anderson and DeFoliart (1961), Cameron (1922), Gill and West (1955), Shemanchuk (1978), Stone (1964), Teskey (1960), and Washburn (1905). Downe and Morrison (1957), using serological techniques, found that S. venustum preferred horses over cattle. Ebsary (1973), Lewis and Bennett (1973) and Pickavance et al. (1970) found S. venustum to be the most abundant simuliid in insular Newfoundland. Simulium verecundum, though of less importance, will also attack cattle (Abdelnur, 1968; Cupp and Gordon, 1983).

In Newfoundland, the S. venustum/verecundum complex consists of at least five biologically and reproductively distinct sibling species in which only S. verecundum cytotype AA verecundum is thought to be multivoltine (Colbo, 1983, pers. comm.; Rothfels et al., 1978). Therefore the multivoltine nature of at least S. venustum in Newfoundland (Ebsary, 1973; Lewis and Bennett, 1973, 1974) may be due to successive generations of univoltine species. In the present study, only one distinct peak of adult activity was observed, this being in July. A minor peak was also noted in mid-August (Figs. 5c, 6c). The lack of clearly defined generations probably occurred as a result of considerable generation overlap, which in turn would have been influenced by factors such as rate of larval development, entrance of flies from other areas and the occurrence of more than one ovarian cycle (Peterson and Wolfe, 1958).

During peak abundance (July) 150 or more S. venustum/verecundum complex, averaging 70% blood-fed, were frequently taken from the cattle-baited trap during the ten-minute sample times. In consideration of the findings of D. Davies and Peterson (1956), L. Davies (1957b,c) and Hocking and Pickering (1954), it is likely that many black flies had fed and left before the end of each sample time so that the number of blood-fed black flies collected would have been lower than the number that actually took a blood-meal during each sample time. Unfortunately, it is not known what this difference might have been. During times of peak abundance, the bull (bovine bait) was visibly disturbed, vigorously shaking the head and flexing the skin while scratching its undersurface with the hindlegs. Visual observation of the bull's reactions during heavy attacks suggested that S. venustum/verecundum complex, like many other simuliids which feed on large mammals (Anderson and Voskuil, 1963; Cameron, 1922; L. Davies, 1957b; Fredeen, 1969; Guttman, 1972; Raybould, 1967), fed principally on the undersurface of the bull. On several occasions the bull was so irritated as to make repeated attempts to jump over the walls of the stable. This suggests that in Newfoundland cattle exposed to such black fly attacks are under stress, which could lead to a loss of productivity as has been reported elsewhere (Fredeen, 1958, 1977a; NRCC, 1982).

In comparing the peak abundance of S. venustum/verecundum complex (late June to late July) to the peak abundance of P. mixtum (early June to early July), it was found that S. venustum/verecundum complex outnumbered P. mixtum by a ratio of 2:1 in the total number collected in the cattle-baited trap, and by 4:1 in the total number blood-fed. The trapping effort in these two periods was very similar. The CO_2 trap also suggested a 2:1 ratio in favour of S. venustum/verecundum complex. Clearly, the number of black flies attracted to a host (in this instance cattle) is itself not a reliable index of a species' potential impact on the health and well-being of livestock, rather the total number of blood-fed females is important in assessing the significance of a given species of black fly as a vector of disease and as an irritant. Thus one would consider S. venustum/verecundum complex to be of an even greater detriment to cattle than P. mixtum than simply their abundance would indicate (2:1) because of the blood-feeding ratio of the former species compared to the latter (4:1).

(c) Stegopterna mutata (Malloch)

This species was collected in low numbers, with adults present from May 31 to July 26. One adult was also taken on May 24 before the start of the trapping schedule. Due to the reluctance of St. mutata to feed on the bovine bait (less than 6% of the total catch blood-fed), even large numbers attracted to cattle might be expected to have a small effect on cattle productivity. Stegopterna mutata has been reported to attack cattle elsewhere in North America (Abdelnur, 1968; Anderson and DeFoliart, 1961; Cupp and Gordon, 1983; Downe and Morrison, 1957; Stone, 1964). This species is univoltine in Newfoundland as well as elsewhere (Back and Harper, 1979; Bruder and Crans, 1979; Lewis and Bennett, 1979a; Stone, 1964; Stone and Jamnback, 1955).

The results of the CO_2 and cattle-baited traps were at variance, the former indicating peak abundance in mid-June (Fig. 6d) and the latter showing St. mutata most numerous in early July (Fig. 5d). An explanation to account for the discrepancy between the CO_2 and cattle-baited traps, assuming that only the triploid form exists in Newfoundland (Lewis and Bennett, 1973), is a shift in host preference from June to July. DeFoliart and Rao (1965) found that there was a shift in host selection by Simulium meridionale Riley away from birds to man in the autumn. El Bashir et al. (1976) noted that Simulium griseicolle Becker experienced a shift in host selection during the course of a single day. The interesting discrepancy found here will require more detailed studies to elucidate the correct explanation.

(d) <u>Simulium</u> <u>vittatum</u> Zetterstedt

<u>Simulium</u> <u>vittatum</u> showed two peaks of activity over the trapping season, a minor peak in late May, which was most likely underestimated due to the limited amount of trapping at this time, and a major peak in late July (Fig. 5e). Black flies collected in late May are almost certainly a separate generation from those of late July (Colbo, 1982a; Ebsary, 1973; Lewis and Bennett, 1973). Adults were taken in low numbers throughout the season (May 26 to September 15) which, in all likelihood was a function of location, since the closest suitable breeding site was approximately two kilometers from the trapping site.

<u>Simulium</u> <u>vittatum</u> is a common pest of livestock in North America and its attacks may cause severe dermatitis of the ears of horses and cattle (Fredeen, 1973). Numerous reports of this species attacking cattle are on record (Abdelnur, 1968; Anderson and DeFoliart, 1961; Anderson and Voskuil, 1963; Cameron, 1922; Cupp and Gordon, 1983; Hearle, 1932; Knowlton, 1935; Shemanchuk, 1978; Snow et al., 1958; Stone and Snoddy, 1969; Teskey, 1960).

In view of the abundance of S. vittatum in Newfoundland (Ebsary, 1973; Lewis and Bennett, 1973) and its willingness to take blood from cattle in this study (ca. 25% blood-fed), this species may be a potential pest of cattle in certains areas of the island.

(e) Simulium decorum Walker

This species was infrequently collected from July to September (47 in total) and is considered an uncommon species in Newfoundland (Lewis and Bennett, 1973). As such, this black fly most likely presents no threat to livestock productivity. Simulium decorum has been reported to attack cattle elsewhere in North America, often in large numbers (Anderson and DeFoliart, 1961; Cupp and Gordon, 1983; Lugger, 1896; Shemanchuk, 1978; Stone, 1964; Stone and Snoddy, 1969).

(f) Summary

Black fly activity on the Harding farm in the vicinity of Paddy's Pond, St. John's, during the summer of 1982, was most heavily concentrated in June and July. Prosimulium mixtum was the predominant black fly in June and S. venustum/verecundum complex the major pest in July. The bovine bait was relatively free from black fly attack in late May and throughout most of August. Since these results are based on only one season's observations, timing of peak activity and the relative abundance of each species could be expected to vary to at least some degree from year to year. Additionally, adults of certain species are known to have specific habitat preferences (Bennett, 1960; Craig and Pledger, 1979; D. Davies, 1978) and changes in location would greatly affect the numbers of these species collected. Simulium vittatum, for example, would probably have been collected in greater numbers had the trapping site been located near a lentic outflow (Colbo, 1979). Yearly fluctuations in weather patterns would also have an influence, hot dry summers shortening the length of the adult season (D. Davies, 1952), and cool wet summers favouring the development of large adult populations (Back and Harper, 1979).

According to Colbo (1983, pers. comm.) the initiation of the adult black fly season in Newfoundland can vary considerably from year to year. Although the initiation of the adult black fly season and the abundance of each species may vary yearly, the seasonal succession of these black flies remains relatively consistent, as the appearance of the adults of each species as a spring or summer black fly is (to a large degree) controlled by its overwintering habits (egg or larva) which remain relatively fixed from year to year in one area.

Many authors in the past have reported only on the occurrence and numbers of black fly species attacking cattle and qualitative descriptions of the damage incurred to livestock with little reliable information on the proportion or number of blood-fed black flies. Such results have only limited value in assessing the impact of a particular species on livestock productivity. The lack of information on blood-feeding of black flies on cattle has largely been due to trap designs or collection techniques which either deter the feeding of black flies or greatly bias the results that are obtained (see Service, 1977, 1981). Steelman (1976) has pointed out that little information exists on the intensity of attack required to cause significant economic losses and asks, how do we therefore justify control as related to livestock productivity. The cattle-baited trap designed for this study appears to be an effective method for estimating the number of host-seeking and blood-feeding black flies attracted to a host under field conditions. If this information was to be correlated with the various parameters of animal productivity Steelman's question may be answered.

3. Diurnal Activity and the Influence of Meteorological Conditions

Clarification of several areas of confusion in the literature concerning host-seeking activity and blood-feeding behaviour is required before discussing the current study. Many authors have described changes in "biting" or "feeding" with changes in time or weather without clearly indicating whether they were referring to actual changes in the number of black flies blood-feeding, or to changes in the number engaging in host-seeking activity. Even in papers where it is apparent what is meant by "biting" or "feeding", it is not always possible to discern if reported changes represent changes in the proportion of the host-seeking fly population which took a blood-meal or reflect an increased population of host-seeking black flies around the host. Peterson and Wolfe (1958) and Wolfe and Peterson (1960) make several references to increased biting in the morning and evening during which time the number of flies on the wing also peaked. In this case, the increased biting may simply reflect an increased number of host-seeking black flies rather than an increased willingness of the population to bite.

This issue is further complicated by the paper of Sutcliffe and McIver (1979) who separated blood-feeding behaviour per se into two phases: (1) biting, which entails probing, piercing the skin, and tasting the blood, and (2) gorging, or the active uptake of the fluid meal. Gorging must be preceded by biting, but biting does not necessarily lead to successful gorging. In the past, the terms biting and probing have also been used indiscriminately (Sutcliffe and McIver, 1979).

In order to make meaningful comparisons with previous literature in spite of the existing confusion, several terms have been defined in the Materials and Methods section under the heading "Use of terms" for the purpose of this study and are also found in the Glossary of Terms. Briefly, these terms are "activity" which refers to host-seeking activity, "blood-fed", "biting", and "gorging".

Wenk (1981) states that both an endogenous diurnal rhythm of appetitive behaviour and exogenous stimuli (for example, light, temperature, humidity, and host odour) activate the host-seeking flight of black flies. Once in flight, a black fly is oriented to the host by the qualities of the host itself, such as odour (Lowther and Wood, 1964; Thompson, 1976a,b), movement (Wenk and Schlörer, 1963), size (Anderson and DeFoliart, 1961), and colour (Bradbury and Bennett, 1974), which operate to bring the fly into close proximity of the host. The host-seeking activity is also influenced by other factors such as weather (Fallis, 1964). After a black fly has landed on a host, further stimuli promote blood-feeding behaviour (biting and gorging), which may include contact of tarsi and mouth parts with the host skin (Sutcliffe and McIver, 1979) and the presence of phagostimulants and factors specific to the host's blood (Mokry, 1980; Sutcliffe and McIver, 1975, 1979). Blood-feeding behaviour (biting and gorging), similar to host-seeking activity, may also be influenced by meteorological conditions (D. Davies, 1952).

The number of host-seeking females at a given time and location is dependent on the total female population and both exogenous and endogenous conditions. Likewise, the number of females which will take a blood meal is a function of the number of black flies finding a potential host coupled with various host characteristics and environmental conditions. Host-seeking activity and blood-feeding behaviour are most likely under separate controls (Mattingly, 1969; Mokry, 1980), although host-seeking must precede blood-feeding under natural conditions.

(a) Ambient temperature

<u>Prosimulium mixtum</u> showed a significant positive correlation ($p < .05$) between activity and temperature in one of the three weeks examined (Table 11). The marginal significance of this correlation coupled with the fact that all remaining correlations were insignificant ($p > .05$) suggests that the significant correlation was fortuitous with little or no biological significance. <u>Simulium</u>

venustum/verecundum complex was positively correlated ($p < .05$) in one of the three weeks examined and then only when the adverse effects of the remaining meteorological conditions were removed (Table 14).

The weak relationship between changes in activity and changes in temperature as indicated by the low or insignificant r values may be interpreted in one of two ways. First, flies respond only to an upper and a lower temperature limit, in this case, activity sharply declining outside the range of 11 to 22 °C. Between these limits, temperature has little influence on activity and thus fluctuations in activity would be governed by alternative extrinsic or intrinsic factors. This hypothesis is supported by the findings of Alverson and Noblet (1976), who found that activity was independent of temperature from 10 to 32 °C, but no simuliids were collected below 10 °C. Anderson and DeFoliart (1961) noted that the activity of ornithophilic black flies was severely restricted below 13 °C, but did not elaborate on the relationship between activity and temperature above this value.

The second interpretation which may account for the apparent weak relationship between changes in temperature and changes in activity is that P. mixtum and S. venustum/verecundum complex do in fact respond to temperature changes in some quantitative manner, but because of the large variation and erratic fluctuations in the other meteorological conditions, this relation becomes obscured in field data. Therefore, the influence of temperature was seen only at its extremes (below 11 °C and above 22 °C) in the present study. As L. Davies (1957b) concluded in his study of Simulium ornatum Mg.: "Presumably, the effect of temperature is complex and masked by other factors...". Evidence to support this is afforded by the fact that the activity of S. venustum/verecundum complex was found to be positively correlated with temperature in one of the three weeks examined (Table 14) when the adverse effects of remaining meteorological conditions were removed. In Sudan, where cyclic changes in meteorological conditions remain relatively fixed from day to day over long periods of time, El Bashir et al. (1976) noted that the activity of S. griseicolle decreased with an increase in temperature as well as an increase in wind speed and a decrease in humidity. Hunter and Moorhouse (1976b) observed that during the winter months the activity of Austrosimulium bancrofti (Taylor) increased with increasing temperatures (13 to 20 °C).

A further extension to this second hypothesis is that changes in temperature may result in changes in activity only over a particular range of temperatures or at different times of the year. Ogata (1954) concluded that the morning activity of S. venustum in Japan increased as temperature increased from 9 to 13 °C, after which the primary factor controlling activity was illumination. Lacey and Mulla (1977) believed that during the summer the major factor controlling the activity of S. vittatum is light, whereas during the fall, temperature and wind speed are of primary importance.

Whether temperature influences activity directly or only at its extremes might possibly be a function of species differences or prevailing climatic conditions. It is conceivable that various species may respond differently to temperature, as is suggested in the above discussion. The particular climatic framework in which a specific population is found could possibly influence its response to temperature. In a climatic zone in which the pattern of daily fluctuations in meteorological phenomena remains constant from day to day over long periods of time, such conditions (for example, temperature) may influence the diurnal pattern of activity in a cyclic fashion. On the other hand, in areas such as Newfoundland, in which meteorological conditions are often in flux over relatively short time spans (hours), a black fly could conceivably be continually modifying its response to temperature in view of the variation of other meteorological factors to the point where any direct relationship between activity and temperature is lost in field data.

Such relationships may also hold true for the response of black flies to other meteorological conditions. This type of interpretation produces a very complex relationship between climate and activity, as is reflected in the literature. The initial steps in confirming or refuting these possible relationships would require laboratory studies under controlled conditions.

(b) Saturation deficit

Prosimulium mixtum was collected in greatest numbers at saturation deficiencies from 0 to 12.6 mm Hg., although the majority of sample times with high activity were associated with saturation deficiencies of 8.0 mm Hg. or lower. Simulium venustum/verecundum complex was most active at saturation deficiencies from 0 to 9.8 mm Hg. Haufe (1966), quoting Govaerts and Leclercq (1946) and Wharton and Kanungo (1962), suggested that there was a continuous exchange between the internal water of an insect's body and external (atmospheric) water. If this is the case, increases in saturation deficit may promote water loss from the body of a black fly and vice versa, and through this mediate activity. It has been well documented that many insects will select a dry environment when hydrated and a humid environment when dessicated (Bentley, 1944; Haufe, 1964; Willis and Roth, 1950).

In the present study S. venustum/verecundum complex showed a midday lull in activity on July 8 (Fig. 16) and

July 20 (Fig. 17), during times of maximum saturation deficit. Light intensity, temperature and wind speed were also peaking at this time, making it impossible to discern if saturation deficit or a combination of factors caused the decrease in activity. D. Davies (1952) suggested that increases in saturation deficit, wind speed and temperature might promote water loss from a black fly's body, and if black flies are considered as black bodies, light may also have some influence. In the St. John's vicinity, summers tend to be wet and cool (Hare and Thomas, 1974), and thus saturation deficits are generally low. Under such conditions water loss would have a limited influence on activity, and the fact that all correlations between saturation deficit and activity were insignificant ($p>.05$) except on one occassion (Table 14) undoubtedly reflects this situation. However, although only one correlation was significant, all were negative, suggesting that if a relationship exists between activity and saturation deficit, it is inverse in nature.

Alverson and Noblet (1976), L. Davies (1957b), Ogata (1954), and Wolfe and Peterson (1960) all concluded that saturation deficit or relative humidity had little influence on activity. On the other hand, D. Davies (1952), and Lacey and Mulla (1977) suggested the opposite. These discrepancies may reflect upon the species studied and local climatic conditions.

(c) Wind speed

Of the meteorological factors measured, wind speed appeared to have the greatest effect on diurnal activity. Negative correlations between activity and wind speed for both P. mixtum and S. venustum/verecundum complex were found in two of three weeks examined (Tables 11, 14). With S. venustum/verecundum complex highly significant negative correlations ($p<.01$) were found for both weeks. The negative values of the correlation coefficients indicate that as wind increased the number of flies on the wing tended to decrease. Bennett and Coombs (1975) indicated that one of the most important factors determining the number of flies collected in a bird-baited trap in insular Newfoundland was wind. Lacey and Mulla (1977) concluded that during the fall wind was one of the major inhibitory factors governing the host-seeking activity of S. vittatum. Wind speed was found to have a major influence on the activity of Simulium spp. in studies conducted by Guttman (1972). L. Davies (1957b), Hunter and Moorhouse (1976b) and Ogata (1954) all found wind to influence the host-seeking activity of black flies, high wind speeds reducing activity. Wind may have a direct mechanical effect on activity and as suggested by D. Davies (1952), may promote water loss.

Prosimulium mixtum was most active between wind speeds from 0 to 9.5 km/h and S. venustum/verecundum complex at wind speeds of 0 to 8.0 km/h. The upper tolerance limits to high wind speed for *P. mixtum* (9.5 km/h) and *S. venustum/verecundum* complex (8.0 km/h), beyond which activity greatly diminished, agree closely with the findings of 8.0 km/h (Anderson and DeFoliart, 1961; L. Davies, 1957b), 9.0 km/h (Lacey and Mulla, 1977) and 12.0 km/h (Ogata, 1954), but are much lower than the findings of 24.0 km/h (D. Davies, 1952), and 45.0 km/h (Underhill, 1944) and higher than the 3.0 km/h reported by Wolfe and Peterson (1960).

The importance of wind to activity may be a function of location; wind could be expected to have little influence on activity in thickly wooded areas which would act as wind breaks, as opposed to in open pastures which would offer little protection from the wind. The cattle-baited trap was placed in the border area between a zone of low scrub vegetation and a second growth boreal forest, and thus was partially protected from the wind. Had this trap been placed deep in the woods, significant correlations may not have been found since wind speeds would likely be extremely low on most days. Wolfe and Peterson (1960) found that the effect of wind speed was more marked in a treeless locality than in a forested area. The influence of wind on activity may also depend on the physiological state of the black fly. L. Davies (1955) showed that wind reduced the activity of older flies more than the activity of newly emerged flies which were better adapted to wind-borne dispersal.

(d) Reflected light intensity

The influence of light was most pronounced at sunset and near sunrise. For example, the number of flies collected in the cattle-baited trap during the last evening sample time (which commenced at sunset) was almost invariably much lower than the preceding sample time (Figs. 10, 11, 16, 17). Between these two sample times, temperature, saturation deficit and wind speed often showed little change and would not account for the decline in activity. Therefore the sharp drop in activity may be a result of waning light. D. Davies (1952) found a similar effect. The decrease in activity often noted between the second and third evening sample times may also be attributable to waning light, but remaining meteorological conditions were often variable during these times. The CO_2 trap on several days collected large numbers of *S. venustum/verecundum* complex during the first three hours of daylight. In these respects, light intensity might be considered an important factor in the initiation or termination of activity.

Although black fly activity is generally considered to be restricted to the daylight hours (Service, 1981; Wenk, 1981), ending at the onset of darkness (Fallis, 1964;

Fredeen, 1973), exceptions do occur; Bennett (1960) and Peterson (1956) observed that a limited number of black flies were seeking a host after dark. Simuliids have been collected throughout the night by means of light traps (Raastad and Mehl, 1972; Williams, 1962), but L. Davies and Williams (1962) considered that light traps do not collect host-seeking adults. The results of the CO_2 trap indicate that though a drastic reduction in activity occurred near sunset, a small percentage of the population continued to seek a host after dark. The collections of P. mixtum in the CO_2 trap were often low before sunset, however this is believed to be a response to extremely low evening temperatures which usually prevailed during the month of June.

During peak populations of P. mixtum, only one of the three weeks examined showed a significant negative correlation ($p \leq .05$) with light, and then only when the adverse effects of remaining meteorological conditions were removed (Table 11). Significant low negative correlations were found between activity of S. venustum/verecundum complex and light intensity in week seven ($p < .01$) and week nine ($p < .05$), but only when all samples collected during these weeks were used to calculate the coefficients (Table 14). When the adverse effects of remaining meteorological conditions were compensated for by using only those sample times in which wind, saturation deficit and temperature were within the meteorological limits of high activity, the significance was lost.

An explanation for this loss of significance in these two weeks may be found by closer examination of the data. During week seven, when all samples were considered, about 50% (19/40) of the sample times were taken under conditions of high light intensity, 6,800 to 15,500 lux. On the contrary, when only those sample times in which remaining meteorological conditions were conducive to activity were used to calculate the coefficients, 80% (19/24) of these sample times had low light intensities, 5,500 to 2 lux. Of the remaining 16 sample times that were not used in this correlation (because the other meteorological conditions were outside the limits of high activity), 14 (88%) turned out to have high light intensity. Thus, in this situation, there was a very strong association between low light intensity and favourable meteorological conditions (19/24), and between high light intensity and unfavourable meteorological conditions (14/16).

It could be argued, therefore, that the significant correlation between light intensity and activity is an artefact resulting from a "real" association between activity and other meteorological conditions, which are associated with either low light intensity (favourable meteorological conditions) or high light intensity (unfavourable conditions). When the sample times with adverse meteorological conditions were excluded, in effect, most sample times with high light intensity were excluded, and the significant correlation between light intensity and activity was lost. This suggests that at the lower light intensities (5500 lux or less) changes in light do not greatly affect activity, except at extremely low light intensities as discussed above and suggested in Table 13. Similarly the low activity that was usually associated with high light intensity can be explained by the limiting effects of the remaining meteorological conditions (saturation deficit, wind speed, and temperature). The same argument holds true for week nine, which had a similar distribution of light intensities, whereas in week six high and low light intensities were equally distributed in both sets of correlations, neither being significant.

There are many explanations that could account for the low correlations between light and activity found in this study. Three will be briefly discussed. First, as is supported by this study, the major influence of light is to initiate activity with the onset of sunrise and to suppress activity at nightfall. Under such conditions, low or insignificant correlations would be expected. A second explanation which would account for the weak relationship between light and activity is that light may only be of importance during certain times of the day (Ogata, 1954) or year (Lacey and Mulla, 1977). Unfortunately, insufficient samples were taken in the present study to investigate this possibility. Finally, the weak relationship between light and activity may have been the result of great variation in remaining meteorological conditions which masked the influence of light. Whatever the exact mechanism(s) through which light acts on host-seeking activity, the results presented here as well as those found by other investigators (Anderson and DeFoliart, 1961; D. Davies, 1952; Hunter and Moorhouse, 1976b; Ogata, 1954) clearly indicate that light does indeed affect activity to a greater or lesser degree. According to Lacey and Mulla (1977) and Wolfe and Peterson (1960) light intensity is the most important factor controlling diurnal host-seeking activity, provided other meteorological conditions are not suppressive towards activity.

(e) Precipitation

During the approach of a thunderstorm, the activity of P. mixtum surged. The reason for this is not presently understood, but Wolfe and Peterson (1960) suggested that increases in activity during such times were a response to decreased light intensity due to cloud cover.

(f) Diurnal pattern of host-seeking activity

Prosimulium mixtum was usually most active from the mid-morning to the late afternoon, usually with a drop in evening activity (Fig. 12). This basic pattern, however, was found to be subject to some seasonal variation. During the early part of the trapping season, morning and evening temperatures were often below 11 °C. This resulted in low catches in the cattle-baited trap during these periods, and activity was largely confined to the afternoon (Fig. 8). As the season progressed, morning and occasionally evening temperatures increased to 11 °C or higher with a resultant increase in activity (Figs. 9, 10). By early July, afternoon activity was suppressed by temperatures exceeding 22 °C and a bimodal pattern consisting of a morning and evening peak emerged (Fig. 11). The reverse of this trend - a summer bimodal pattern of activity merging into one afternoon peak in the fall - was reported for S. vittatum in Colorado (Lacey and Mulla, 1977). One may postulate that the diurnal pattern of activity of P. mixtum may be subject to yearly changes, depending upon the temperature regime.

Simulium venustum/verecundum complex was most troublesome to cattle in the morning and evening (Fig.18). Activity was usually suppressed during the afternoon at which time saturation deficit, temperature, wind speed and reflected light intensity were usually at a maximum. Limited data also showed that S. vittatum and St. mutata had a similar bimodal pattern of activity. As with P. mixtum the diurnal activity of these species could be expected to change somewhat from year to year, depending on local climatic conditions. The diurnal pattern of these species might also change depending upon the type of habitat or vegetation zone (Duke et al., 1967; Wolfe and Peterson, 1960). The activity of both P. mixtum and S. venustum/verecundum complex declined sharply with the onset of darkness.

(g) Summary

Correlations between host-seeking activity and meteorological conditions were for the most part very low or insignificant. In one week (Table 11, week 7), P. mixtum activity could not be correlated with any of the measured meteorological conditions. In several sample periods, black flies were virtually absent despite apparently suitable meteorological conditions. The large number of flies collected before and after such periods indicated that this absence was not due to a major decline in the population. Bursts of activity were also noted under what appeared to be suppressive conditions. For example, on August 16, the number of S. venustum/verecundum complex collected in the cattle-baited trap increased from 0 in the first afternoon sample time to 63 in the second and subsequently decreased to 11 and 4 in the third and fourth sample times respectively. Weather conditions, including a high wind, showed little change. At present, no explanation can be given for the burst of activity in the second sample time.

Although host-seeking activity might be suppressed by wind speeds, temperatures, saturation deficiencies, and light intensities outside of certain optimum ranges (Tables 10, 13), these factors do not account for most of the variation observed in the number of flies seeking a host (Tables 11, 14). Of the meteorological factors measured, wind appeared to exert the greatest influence on activity. The observation that on July 7, when meteorological conditions varied little from the morning to the afternoon, the periodicity in the activity of S. venustum/verecundum complex was lost, may indicate that under certain circumstances, these conditions may greatly influence the diurnal pattern of activity, but this relationship was not sustained throughout the season. Lacey and Charlwood (1980) presented evidence that black flies were largely controlled by a circadian rhythm. The present study cannot directly support this hypothesis, but it is clear that factors besides those considered here influence activity, which may include circadian control.

It is becoming increasingly apparent (D. Davies, 1978; Dethier, 1957; Friend and Smith, 1977; Weitz, 1960) that the process from initial blood-hunger to final engorgement in haemophagus insects is a cumulative stepwise series of events and, as Hocking (1971) pointed out, a study which starts in the middle of this chain will yield different results from one which starts at the beginning. The poor correlations between activity and various meteorological conditions in the present study may have been due in part to the segmental approach concerned with only the latter stages of host-seeking rather than a holistic approach considering all events from blood-hunger to engorgement.

4. Blood-feeding Behaviour and Influencing Factors

(a) Proportion blood-fed

The proportion of blood-fed simuliids of each species studied is given in Table 16. Approximately 70% of the S. venustum/verecundum complex collected in the cattle-baited trap were blood-fed. Reworking the data of Shemanchuk (1978) showed that 37% of the S. venustum that were collected from a bovine bait were blood-fed. Of the S. venustum that landed on man, only 16-25% would bite (D. Davies, 1952), whereas only 6% attracted to moose would blood-feed (Craig and Pledger, 1979). Twenty-four percent of S. vittatum collected in the present study were blood-fed, which is lower than the 42% reported by Shemanchuk (1978), and higher than the 6.9% feeding on moose (Craig and Pledger, 1979).

In the above studies, different trapping techniques and hosts were employed and consequently, it is not surprising that their results also differ. According to Anderson and DeFoliart (1961), in comparing several different bird hosts, the more attractive a host was to ornithophilic black flies, the more willing they were to blood-feed, as measured by an increase in the percentage of engorged specimens collected. Therefore, the different results obtained by D. Davies (1952) using man as a host, Craig and Pledger (1979) using moose, and Shemanchuk (1978) using cattle may reflect differences in the attractiveness of these hosts to S. venustum. In the present study S. venustum/verecundum complex consisted of a heterogeneous population of at least 5 sibling species which may differ from those considered in the above studies (Rothfels et al., 1978). This may account for the difference in blood-feeding obtained here as opposed to the investigation of Shemanchuk (1978), who also used cattle as the bait.

(b) Factors influencing blood-feeding behaviour

Since blood-feeding was expressed as the number of blood-feds : the number of host-seeking females, variation in the proportion blood-fed would not be dependent upon variation in the number of host-seeking females. Therefore changes in the proportion blood-fed represent changes in the willingness of the host-seeking population to blood-feed. As previously mentioned, blood-feeding behaviour consists of two phases, biting and gorging, but the use of the cattle-baited trap did not permit independent observation of these two phases. As such, it is not known if changes in the proportion blood-fed reflect changes in the proportion biting, gorging, or both.

(i) Meteorological conditions

Mean 24-hour temperature was the meteorological factor most strongly correlated ($p<.01$) with blood-feeding. Regression analysis (Figs. 19a, 20b) showed that 70% and 60% of the sample period to sample period variation in the proportion blood-fed of P. mixtum and S. venustum/verecundum complex respectively was explained by mean 24-hour temperature. The positive slopes indicate that as mean 24-hour temperature increased, a greater proportion of the host-seeking population which came to the bovine bait was willing to blood-fed; more specifically, blood-feeding increased by approximately 3.0% for each 1 °C rise in mean 24-hour temperature. Outside the range of temperatures examined, it cannot be assumed that this relationship would hold true, especially at extremely high or low temperatures, which apart from any other effect, greatly suppress activity.

The response to mean 24-hour temperature may have been the result of a change in metabolic rate. Extrinsic factors are known to influence metabolism, and temperature is particularly important, metabolic rate increasing with temperature (Bursell, 1970; Chapman, 1971; Wigglesworth, 1950). Black flies sustained at a higher temperature would have a greater metabolic rate than similar black flies kept at a much lower temperature. As a consequence, black flies that experience a higher temperature could be expected to deplete energy reserves, as a result of a higher metabolic rate, at a much faster rate than black flies at lower temperatures. Although the blood-meal taken by a black fly is generally considered to be used mainly for ovarian development (Wenk, 1981), work with other biting flies has suggested that there is a relationship between low energy reserves, that is, flies deprived of food, and willingness to engage in one or all acts involved in blood-feeding behaviour (Brady, 1973; Dethier, 1954; Tarshis, 1959). The strong positive relationship between mean 24-hour temperature and blood-feeding might then be at least partially attributable to the following sequence of events:

increased mean 24-hour temperature → ↑ metabolic rate → ↓ energy reserves →
↑ willingness to blood-feed →
→ ↑ proportion of blood-fed flies

The above sequence is to some degree based on speculation, but it is believed that sufficient evidence has been presented from the literature to justify this sequence as a possible hypothesis explaining the relationship between mean 24-hour temperature and proportion blood-fed.

A significant positive correlation ($p < .05$) between proportion blood-fed and mean 24 to 48-hour temperature also existed for both P. mixtum and S. venustum/verecundum complex (Table 17), but this variable was highly correlated with mean 24-hour temperature (P. mixtum, $r = .788$ at $p < .01$; S. venustum/verecundum complex, $r = .784$ at $p < .01$). Therefore, it is possible that the weaker relationship between mean 24 to 48-hour temperature and blood-feeding was (at least partially) attributable to the much stronger association between mean 24-hour temperature and mean 24 to 48-hour temperature, and between mean 24-hour temperature and blood-feeding. It is possible that mean 24 to 48-hour temperature may have exerted some influence on blood-feeding, but in consideration of the lower correlation coefficients and the higher association between this variable and mean 24-hour temperature, this effect would likely be small.

Mean sample period temperature was positively correlated with the proportion of blood-fed for P. mixtum ($p < .05$) and S. venustum/verecundum complex ($p < .01$). Regression analysis (Fig. 20a) indicated that 37% of the variation seen in the proportion of blood-fed S.

venustum/verecundum complex could be explained by mean sample period temperature. Superficially, the proportion of the host-seeking population which successfully blood-fed tended to increase as mean sample period temperature increased.

If changes in the proportion blood-fed are a result of changes of the proportion biting, rather than gorging, then the results presented here are at variance with those of Sutcliffe and McIver (1979). Using an artificial membrane technique, these authors found that as the ambient temperature increased, that is, as the temperature differential between the membrane and the air above it decreased, the percentage of *S. venustum* that would bite decreased. They argued that the temperature differential might not be a stimulus to probe (the first stage of biting), as suggested by other investigators. Instead, they proposed an alternative interpretation suggesting that the temperature differential may act as a very close host-location (seeking) cue that guides landing.

The positive relationship between mean sample period temperature and proportion blood-fed shown in Table 17 suggests that as the temperature differential decreased, the proportion of blood-feds increased, assuming the skin temperature of the bovine bait at any particular location on the body remained relatively constant, i.e., a negative relation existed between the temperature differential and biting. In this case, the temperature differential would not have been acting as a host-location (seeking) cue since the assumed biting increased at a time when the temperature gradient between the surface of the bovine skin and the air above it was decreasing, and any existing cues would have been less perceivable.

It is possible that the relationship between blood-feeding and temperature was actually a relationship between temperature and gorging and not temperature and biting, as assumed in the above discussion. Therefore, the discrepancy between the results of Sutcliffe and McIver (1979) and those presented here may be due to an examination of two different phases of the blood-feeding behaviour. However, this seems highly unlikely because accepting this alternative would imply that temperature influences biting and gorging antagonistically. Such a relationship would reduce the efficiency of blood-feeding behaviour and hamper reproductive success.

A more likely explanation to account for the different results obtained here and those of Sutcliffe and McIver (1979) may be in the techniques used. Sutcliffe and McIver (1979) conducted their experiments in a laboratory and though variation of extrinsic factors and sample error can be greatly reduced in such a setting, black flies are placed in an artificial environment, and under such conditions will behave somewhat differently than in a natural habitat. On the other hand, though the results of the present study were obtained in the field, the effects of extrinsic factors cannot always be removed and the relationship between mean sample period temperature and blood-feeding may have been partially due to confounding variables which actually influenced blood-feeding but were also correlated with mean sample period temperature. Furthermore, Sutcliffe and McIver (1979) used a membrane, whereas in the current study a living host was used which presents many other cues to feeding besides temperature.

D. Davies (1952), conducting field studies, found that temperature had little or no influence on the proportion of S. venustum that would bite. Underhill (1940), in contrast to this, observed that black flies (of an unspecified species) swarmed around turkeys at temperatures of 18 to 35 °C, but maximum blood-feeding took place at 24 to 29 °C. It is evident from the conflicting results and interpretations found in the literature and presented here that more study is needed to elucidate the nature of the relationship between different temperature regimes and various aspects of blood-feeding behaviour.

In examining the relationship between blood-feeding and light, it was found that both P. mixtum ($p < .01$) and S. venustum/verecundum complex ($p < .05$) were negatively correlated with reflected light intensity (Table 17). In the case of P. mixtum, regression analysis (Fig. 19b) showed that 44% of the sample period to sample period variation in the proportion of blood-feds collected could be explained by light intensity. Significant negative correlations between light intensity and mean 24-hour temperature (P. mixtum, $r = -.737$ at $p<.01$; S. venustum/verecundum complex, $r = -.625$ at $p<.01$) were also found. Therefore, similar to the situation with mean 24 to 48-hour temperature, the negative relationship between light and blood-feeding may have been partly due to the confounding association with mean 24-hour temperature and vice versa.

D. Davies (1952) found that if a shaded area of human skin was exposed directly to sunlight, the proportion of S. venustum that bit decreased by 75%. Using an artificial membrane technique, McMahon (1968) found that light influenced the percentage of S. ornatum that would blood-feed, but he was not certain whether light intensity or wave-length was more important. Towards the end of the day, when light intensity was waning, female S. griseicolle, which normally feed on birds, became extremely aggressive and non-selective in the hosts they would bite, which included man (El Bashir et al., 1976). Many species of black flies prefer to bite ungulates on the undersurface (Anderson and Voskuil, 1963; L. Davies, 1957b; Fredeen, 1969, 1977a; Raybould, 1967), and Breyev (1950), seen in Service (1977), showed experimentally that this was a response to reduced illumination. The preference for the undersurface may also be due in part to the greater amount of exposed skin here as compared to most other parts of the body. It is apparent from the above literature that light may influence one or more phases of blood-feeding behaviour, although in the present study it was difficult to separate the effect of light from other factors.

Saturation deficit and wind speed failed to show any relationship to blood-feeding. In the case of wind speed, this is not surprising because a black fly, once on the host and crawling through the hairs in preparation for blood-feeding, would be largely protected from and therefore unaffected by wind.

(ii) Adult size

The results of the t-test showed no significant difference in the size of blood-fed and unfed P. mixtum. This is in contrast to the findings of Mokry (1980) who found that there was a greater tendency towards blood-feeding in the laboratory among larger S. vittatum females compared to smaller ones. What is of particular interest in the present author's findings is that the variation in size in both blood-fed and unfed flies was small, indicating that the size of female P. mixtum attacking cattle was highly uniform. In contrast, Colbo

(1982b) found a marked variation in the size of newly emerged P. mixtum in Newfoundland, even in the same stream over a small geographic area. Given the results of Colbo (1982b), more variation would be expected. Perhaps at the Harding farm a larger variation in size existed within the female population, but only females of a certain size successfully seek a host. Such host-seeking females would most likely be those larger in size, since, as observed by Mokry (1980), smaller females appeared to be less capable of engaging in such activities.

(iii) Time of day and calendar date

It was shown (Tables 18, 19) that the proportion of blood-fed P. mixtum and S. venustum/verecundum complex varied with time both throughout the day and from week to week. Present knowledge of the factors affecting blood-feeding is limited (Mokry, 1980; Sutcliffe and McIver, 1979), and therefore attempting to interpret changes in blood-feeding in relation to these temporal changes would be extremely difficult at best. Nevertheless some of the observed temporal changes in feeding are undoubtedly the result of changing meteorological conditions - for example, the greater overall tendency to feed during the evening may have been a response to the lower light intensity which occurred at this time. More field and laboratory studies, specifically designed to quantitate the various factors which influence blood-feeding, are evidently needed.

C. OTHER BITING FLIES

1. Mosquitoes (Family: Culicidae)

Seven species of mosquitoes were collected in the cattle-baited and CO_2 traps and all have been previously reported in insular Newfoundland (Nielsen and Mokry, 1982; Pickavance et al., 1970; Wood et al., 1979). _Culiseta impatiens_, _Ae. abserratus_, and _Ae. punctor_ were the three most common species, comprising over 90% of the total catch (Table 20). _Aedes abserratus_ and _Ae. punctor_ are considered to be the most common mosquitoes in insular Newfoundland (Mokry, 1983, pers. comm.; Pickavance et al., 1970). _Culiseta impatiens_, which overwinters as an adult (Haufe, 1952; Steward and McWade, 1961), was collected from the bovine bait much earlier than _Ae. punctor_ and _Ae. abserratus_, which overwinter in the egg stage (Wood et al., 1979). _Culiseta impatiens_ is one of the earliest species to seek blood in the spring in mainland Canada (Steward and McWade, 1961; Wood et al., 1979).

Activity of all three species was almost completely restricted to the evening (Table 22), as shown by the cattle-baited trap. The results of the CO_2 trap suggest that *Ae. abserratus* was largely nocturnal. According to Taylor et al. (1979), in the Tantamar Marshes of New Brunswick *Ae. punctor* was most active during the afternoon. Haufe (1952) reported that the activity pattern of this species in Labrador was bimodal, with peak activity occurring at 8:00 and 16:00 hours. Lewis and Bennett (1979b), also working in the Tantamar Marshes, found *Ae. abserratus* to be mainly crepuscular, but also active during the day. *Culiseta impatiens* was found to be active throughout the day in Ontario (Steward and McWade, 1961) and in northern Quebec (Jenkins and Knight, 1950). The host-seeking periodicity of the three species, *Ae. abserratus*, *Ae. punctor* and *Cs. impatiens*, thus appears to vary with geographical location.

The low numbers of *Ae. abserratus* and *Ae. punctor* collected were undoubtedly the result of location, as large populations of these species are known to have existed in the St. John's area in the summer of 1982 (Mokry, 1983, pers. comm.). The owners of the farm on which this study was conducted stated that in certain years, at various locations on the farm, large numbers of mosquitoes would indeed attack cattle. In consideration of this information it would seem presumptuous to make any statement at this time regarding the importance of mosquitoes as pests of livestock in Newfoundland. Further investigation is warranted.

2. Tabanids (Family: Tabanidae)

Eighteen species of tabanids have been previously recorded in insular Newfoundland (Hudson, 1977; Philip, 1962), of which ten were collected in this study (Table 23). The four most common species, C. excitans, C. frigidus, C. furcatus, and H. zonalis, all have been reported to attack cattle elsewhere in North America (Lewis and Bennett, 1977; Lewis and Leprince, 1981; Magnarelli and Anderson, 1980; Shemanchuk, 1978). Little is known about the biology of tabanids in Newfoundland, and therefore it is not certain whether the low numbers collected were due to a normally small population, the location of the trapping site, or the trapping techniques employed. Both Bennett (1983, pers. comm.) and Colbo (1983, pers. comm.) believe that the tabanid population is much reduced in insular Newfoundland than in most areas of mainland Canada.

3. Sand Flies (Family: Ceratopogonidae)

Because of the small size of Culicoides (sand flies), these flies were difficult to see and collect, and consequently, the numbers reported here are certainly much lower than the actual numbers present in both traps. It was shown that populations of Culicoides which attack and blood-feed on cattle do exist in Newfoundland, and further studies should be initiated specifically designed to collect

Culicoides.

The only record of Culicoides from Newfoundland that exists is by Bennett and Coombs (1975), in which Culicoides stilobezzioides Foote and Pratt was collected from a bird-baited trap. It is believed that the collection of C. yukonensis is a new record for insular Newfoundland. Culicoides obsoletus group consists of at least four closely related species in North America (Jamnback and Wirth, 1963), of which at least one, Culicoides sanguisuga (Coquillett), is believed to occur in Newfoundland (unpublished records of Downes and Greiner). Culicoides were most active in the early morning and late evening, which was essentially the same as the findings of other authors (Jones, 1978).

SUMMARY

1. A total of 19,682 female biting flies were collected with the cattle-baited (11,407) and CO_2 (8,275) traps, near Paddy's Pond, St. John's, from May 26 to September 16, 1982. Black flies were the most abundant group comprising 94.1% of the total catch. The remaining families, mosquitoes, sand flies (Culicoides) and tabanids, contributed little to the population, comprising only 5.9% of the total season's catch.

2. Mosquitoes and black flies were the first to appear as blood-seeking females, followed by the sand flies and finally the tabanids. The seasonal succession of adult mammalophilic black flies generally followed the larval or adult succession described by other workers, however, the various species in Newfoundland tend to occur later in the year than in most other places.

3. Black fly activity was most heavily concentrated in June and July, with relatively few flies in the field during the months of May, August and September. Prosimulium mixtum was the predominant species in June and S. venustum/verecundum complex was the major pest in July.

During peak activity of these two simuliids the bovine bait was visibly disturbed and appeared to be under a great deal of stress. Simulium vittatum is a potential pest of cattle, but further studies are needed to ascertain its importance.

4. Preliminary studies suggest that although the host-seeking activity of P. mixtum and S. venustum/verecundum complex might be greatly suppressed by wind speeds, temperatures, saturation deficiences and light intensities outside of certain optimal ranges (referred to as the "meteorological limits of high activity"), these factors do not account for most of the variation observed in the number of flies seeking a host. Further studies are required to elucidate the influence of weather on activity.

5. Prosimulium mixtum was usually most active from mid-morning to late afternoon, with a drop in evening activity. Simulium venustum/verecundum complex showed two peaks of activity, one in the morning and another in the early evening. Limited data also suggests that S. vittatum and St. mutata had similar bimodal patterns of activity. Few black flies were collected during the dark hours.

6. Mean 24-hour temperature appeared to greatly influence the blood-feeding behaviour of *P. mixtum* and *S. venustum*/*verecundum* complex, changes in temperature showing a strong positive correlation with changes in the proportion of blood-fed black flies collected in the cattle-baited trap. The present temperature, mean 24 to 48-hour temperature, and light intensity may also have some influence on blood-feeding behaviour. Further studies are required to clarify the relationship between blood-feeding and weather. The proportion of blood-fed simuliids (*P. mixtum* and *S. venustum*/*verecundum* complex) collected in the cattle-baited trap also varied with time of day and calendar date. No significant difference ($p > .05$) was found between the size of unfed and blood-fed *P. mixtum*.

7. The low number of mosquitoes collected may have been a result of trap location. Due to the small size of the adult *Culicoides* these flies were difficult to see and therefore collect. Consequently the numbers reported here are certainly much lower than the actual numbers present in both traps. Little is known about the biology of tabanids in insular Newfoundland and therefore it is not known if the low numbers collected in the present study were due to a pauperate fauna, the location of the trapping site or the trapping techniques

employed.

8. On the basis of one trapping season, it appears that the cattle-baited trap is an effective method for the study of host-seeking activity and blood-feeding behaviour of at least black flies under field conditions. Information obtained in this trap, correlated with the various parameters of animal productivity, could be used to establish economic and disease vector thresholds which are at present lacking. This trap deserves further consideration.

9. The CO_2 trap accurately reflected changes in the host-seeking activity of P. mixtum and S. venustum/verecundum complex towards the bovine bait. As such this trap warrants further investigation as a means of quantifying the diurnal and seasonal host-seeking activity of biting flies towards cattle.

TABLE 1

SCHEDULE OF STANDARD SUNSET TIMES WITH THE EQUIVALENT LOCAL CLOCK TIMES UNDER WHICH THE CATTLE-BAITED TRAP WAS OPERATED.

Sample times	Standard sunset time (SST)[1]	Approximate local time[3]	
		Weeks 1-11 (May 23-August 7)	Weeks 12-14 (August 8-August 28)
Morning sample period			
1st	12:00[2]	9:00	8:15
2nd	12:30	9:30	8:45
3rd	13:00	10:00	9:15
4th	13:30	10:30	9:45
Afternoon sample period			
1st	17:00	14:00	13:15
2nd	17:30	14:30	13:45
3rd	18:00	15:00	14:15
4th	18:30	15:30	14:45
Evening sample period			
1st	22:30	19:30	18:45
2nd	23:00	20:00	19:15
3rd	23:30	20:30	19:45
4th	24:00 or 0:00	21:00	20:15

1 Refers to the number of hours after a reference sunset.

2 All times given refer to the start of each ten-minute sample time.

3 Appendix A gives the exact local clock time of each weekly reference sunset.

TABLE 2

NUMBER OF BLACK FLIES COLLECTED IN THE CATTLE-BAITED TRAP WITH AND WITHOUT THE BOVINE BAIT

Date	No. collected with bovine bait[1]	No. collected without bovine bait[2]
July 4		
Trial 1	40	5
Trial 2	25	1
July 7		
Trial 1	7	0
Trial 2	7	1
July 8		
Trial 1	29	1
Trial 2	18	0
Total	126	8
Mean No./Trial	21(±13.0)	1.3(±1.86)

1 Black flies collected: 97 S. venustum/verecundum complex, 28 P. mixtum, 1 St. mutata

2 Black flies collected: 4 S. venustum/verecundum complex, 4 P. mixtum

TABLE 3

CONTINGENCY TABLE COMPARING THE FREQUENCY WITH WHICH BLACK FLIES WERE COLLECTED IN THE CATTLE-BAITED AND CO_2 TRAPS, FROM JUNE 13 TO AUGUST 16, 1982. THE OBSERVED FREQUENCY IS GIVEN WITH EXPECTED FREQUENCY IN PARENTHESES.

	S. venustum/verecundum complex	*P. mixtum*	Other species[1]	
Cattle-baited trap	2,197 (2,219.0)	626 (605.1)	132 (130.8)	2,955
CO_2 trap	975 (953.0)	239 (259.9)	55 (56.2)	1,269
	3,172	865	187	4,224

Chi square = 3.16, not significant at $p > .05$, with df = 2

[1] Other species include *St. mutata*, *S. vittatum* and *S. decorum*.

TABLE 4

COMPARISONS OF THE DAILY NUMBER OF BLACK FLIES COLLECTED IN THE CATTLE-BAITED AND CO_2 TRAPS, FROM JUNE 13 TO AUGUST 16, 1982[1]

Date		*P. mixtum*		*S. venustum/verecundum* complex		*St. mutata*	
		No. in cattle-baited trap	No. in CO_2 trap	No. in cattle-baited trap	No. in CO_2 trap	No. in cattle-baited trap	No. in CO_2 trap
June	13	133	88	4	2	2	11
	14	168	84	8	4	3	28
	29	148	36	209	64	6	3
July	6	36	7	194	96	12	2
	8	113	19	658	280	34	3
	13	4	1	99	44	1	0
	20	21	3	537	312	2	0
	21	3	1	206	75	0	0
	30	0	0	0	2	--	--
	31	---	--	6	7	--	--
August	6	---	--	30	2	--	--
	8	---	--	1	7	--	--
	9	---	--	15	12	--	--
	16	---	--	230	68	--	--
Correlation coefficient (r)		$r = .855^{**}$ (9)[2]		$r = .971^{**}$ (14)		$r = -.134$ (8)	

** Significant at $p<.01$ with df = n-2

1 The total number of black flies collected in the cattle-baited trap on each complete sample day during the sample times 12:30, 13:30, 17:30, 18:30, 22:30, and 23:30 hours (SST) were correlated with the corresponding total catch in the CO_2 trap during the sample hours 12:00-13:00, 13:00-14:00, 17:00-18:00, 18:00-19:00, 22:00-23:00 and 23:00-24:00 hours (SST).

2 Number of complete sample days correlated.

TABLE 5

CUMULATIVE CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF *P. MIXTUM* COLLECTED AT VARIOUS TIMES OF THE DAY IN THE CATTLE-BAITED AND CO_2 TRAPS FROM JUNE 7 TO JULY 20, 1982[1]

Variables	Correlation coefficients (*r*)		
	June 7-June 29	June 7-July 6	June 7-July 20
No. in morning catch in cattle-baited trap vs. no. in CO_2 trap[2]	.733* (8)[3]	.824** (12)	.848** (18)
No. in afternoon catch in cattle-baited trap vs. no. in CO_2 trap	.579* (13)	.640** (19)	.747** (25)
No. in evening catch in cattle-baited trap vs. no. in CO_2 trap	.957** (12)	.944** (16)	.919** (20)

* Significant at $p<.05$, ** significant at $p<.01$, with df = n-2

1 The number of *P. mixtum* collected in the cattle-baited trap during the morning (12:30, 13:30 hours SST), afternoon (17:30, 18:30), and evening (22:30, 23:30) sample times were correlated with the equivalent morning (12:00-13:00, 13:00-14:00 hours SST), afternoon (17:00-18:00, 18:00-19:00) and evening (22:00-23:00, 23:00-24:00) hourly catches in the CO_2 trap.

2 Morning correlations were started from June 13.

3 The number of observations correlated.

TABLE 6

CUMULATIVE CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF S. VENUSTUM/VERECUNDUM COMPLEX COLLECTED AT VARIOUS TIMES OF THE DAY IN THE CATTLE-BAITED AND CO_2 TRAPS FROM JUNE 18 TO AUGUST 25, 1982.[1]

Variables	Correlation coefficients (r)		
	June 18-July 8	June 18-July 21	June 18-August 25
No. in morning catch in cattle-baited trap vs. no. in CO_2 trap[2]	.944** (12)[3]	.769** (18)	.642** (26)
No. in afternoon catch in cattle-baited trap vs. no. in CO_2 trap	.610* (15)	.643** (20)	.662** (28)
No. in evening catch in cattle-baited trap vs. no. in CO_2 trap	.887** (10)	.780** (16)	.777** (22)

* Significant at $p<.05$, ** significant at $p<.01$, with $df = n-2$

1 The number of S. venustum/verecundum complex collected in the cattle-baited trap during the morning (12:30, 13:30 hours SST), afternoon (17:30, 18:30), and evening (22:30, 23:30) sample times were correlated with the equivalent morning (12:00-13:00, 13:00-14:00 hours SST), afternoon (17:00-18:00, 18:00-19:00) and evening (22:00-23:00, 23:00-24:00) hourly catches in the CO_2 trap.

2 Morning correlations were June 18-August 16 only.

3 Number of observations correlated.

TABLE 7

TOTAL NUMBER OF BLACK FLIES COLLECTED IN THE CATTLE-BAITED TRAP, NEAR PADDY'S POND, ST. JOHN'S, FROM 12:00 TO 24:00 HOURS (SST), MAY 26 TO AUGUST 25, 1982.

Species present	Total catch		Mammalophilic catch	
	No.	%	No.	%
C. ornithophilia	11	.10	---	---
Eusimulium spp.	10	.09	---	---
P. mixtum	3,395	31.59	3,395	31.65
S. decorum	24	.22	24	.22
S. venustum/verecundum complex	6,849	63.73	6,849	63.85
S. vittatum	241	2.24	241	2.25
St. mutata	217	2.02	217	2.02
Totals	10,747	99.99%	19,726[1]	99.99%

1 This number is equal to 99.80% of the total catch.

TABLE 8.

TOTAL NUMBER OF BLACK FLIES COLLECTED IN THE CO_2 TRAP, NEAR PADDY'S POND, ST. JOHN'S, FROM JUNE 6 TO SEPTEMBER 16, 1982.

Species present	12:00 to 24:00 hours (SST)				24:00 to 12:00 hours (SST)			
	Total catch		Mammalophilic catch		Total catch		Mammalophilic catch	
	No.	%	No.	%	No.	%	No.	%
C. ornithophilia	4	.07	---	---	2	.10	---	---
Eusimulium spp.	56	.98	---	---	21	1.02	---	---
P. mixtum	1,941	33.93	1,941	34.29	108	5.26	108	5.32
S. decorum	9	.16	9	.16	14	.68	14	.69
S. venustum/verecundum complex	3,350	58.57	3,350	59.19	1,809	88.11	1,809	89.11
S. vittatum	45	.79	45	.80	17	.83	17	.84
St. mutata	315	5.51	315	5.57	82	4.00	82	4.04
Totals	5,720	100.01%	5,660[1]	100.01%	2,053	100.00%	2,030[2]	100.00%

1 This number is equal to 98.95% of the total catch.

2 This number is equal to 98.88% of the total catch.

TABLE 9

SAMPLE TIMES IN WHICH APPROXIMATELY 75% OF THE WEEKLY CATCH OF *P. MIXTUM* WAS COLLECTED IN THE CATTLE-BAITED TRAP DURING WEEKS FOUR, SIX, AND SEVEN.

Week[1]	Total no. of sample times/week	No. of sample times with approx. 75% of weekly catch	Total no. of flies collected/week	No. of flies with approx. 75% of weekly catch
Week 4	43	14	1,743	1,302 (74.7%)[2]
Week 6	37	8	800	575 (71.9%)
Week 7	40	13	461	345 (74.8%)
Totals	120	35	3,004	2,222 (74.0%)

1. The dates of each week are given in Appendix A.

2. Actual percent of weekly catch.

TABLE 10

POOLED RANGE OF EACH METEOROLOGICAL CONDITION UNDER WHICH APPROXIMATELY 75% AND 100% OF THE WEEKLY CATCH OF P. MIXTUM WAS COLLECTED IN THE CATTLE-BAITED TRAP DURING WEEKS FOUR, SIX, AND SEVEN[1]

Percent of weekly catch	Ambient temperature °C	Saturation deficit mm Hg.	Wind speed km/h	Reflected light intensity lux
75%[2]	11-22	0-12.6	0-9.5	147-15,500
100%	4.5-29	0-20	0-13	2-22,000

1 The dates of each week are given in Appendix A.

2 The boundaries of each pooled range (for the 75% catch) may be considered as the meteorological limits of high activity such that both high and low activity occurred within the confines of these limits, but only low activity was observed outside these limits.

TABLE 11

CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF HOST-SEEKING *P. MIXTUM* COLLECTED IN THE CATTLE-BAITED TRAP AND VARIOUS METEOROLOGICAL CONDITIONS.

Variables	Correlation coefficients (r)		
	Week 4[1]	Week 6	Week 7
Activity vs. temperature			
all sample times	.303* (43)[3]	.254 (37)	-.186 (40)
sample times with remaining conditions within meteorological limits of high activity[2]	.304 (34)	.399 (24)	-.193 (29)
Activity vs. saturation deficit:			
all sample times	-.081 (43)	-.028 (37)	-.251 (40)
sample times with remaining conditions within meteorological limits of high activity	-.356 (29)	-.358 (20)	-.081 (30)
Activity vs. wind speed:			
all sample times	-.016 (43)	-.214 (37)	.098 (40)
sample times with remaining conditions within meteorological limits of high activity	-.428* (29)	-.557** (24)	-.083 (30)
Activity vs. reflected light intensity:			
all sample times	-.077 (43)	.178 (37)	-.204 (40)
sample times with remaining conditions within meteorological limits of high activity	-.407* (35)	.125 (24)	-.020 (33)

* Significant at $p<.05$, ** significant at $p<.01$, with df = n-2

1 The dates of each week are given in Appendix A.

2 Meteorological limits of high activity are given in Table 10.

3 Number of sample times correlated.

TABLE 12

SAMPLE TIMES IN WHICH APPROXIMATELY 75% OF THE WEEKLY CATCH OF S. VENUSTUM/VERECUNDUM COMPLEX WAS COLLECTED IN THE CATTLE-BAITED TRAP DURING WEEKS SIX, SEVEN AND NINE.

Week[1]	Total no. of sample times/week	No. of sample times with approx. 75% of weekly catch	Total no. of flies collected/week	No. of flies with approx. 75% of weekly catch
Week 6	37	7	721	526 (73.0%)[3]
Week 7	40	10	2,098	1,568 (74.7%)
Week 9[2]	36	7	3,058	2,190 (71.6%)
Totals	113	24	5,877	4,284 (72.9%)

1 The dates of each week are given in Appendix A.

2 July 26 was included in Week 9 due to the low number of sample times (n = 24) taken during this week.

3 Actual percent of total catch.

TABLE 13

POOLED RANGE OF EACH METEOROLOGICAL CONDITION UNDER WHICH APPROXIMATELY 75% AND 100% OF THE WEEKLY CATCH OF S. VENUSTUM/VERECUNDUM COMPLEX WAS COLLECTED IN THE CATTLE-BAITED TRAP DURING WEEKS SIX, SEVEN, AND NINE[1]

Percent of weekly catch	Ambient temperature °C	Saturation deficit mm/Hg.	Wind speed km/h	Reflected light intensity lux
75%[2]	11-22	0-9.8	0-8.0	127-15,500
100%	4.5-29	0-20	0-13	2-17,500

1 The dates of each week are given in Appendix A. July 26 was included in week 9 due to the low number of sample times (n = 24) taken during this week.

2 The boundaries of each pooled range (for the 75% catch) may be considered as the meteorological limits of high activity such that both high and low activity occurred within the confines of these limits, but only low activity was observed outside these limits.

TABLE 14

CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF HOST-SEEKING S. VENUSTUM/VERECUNDUM COMPLEX COLLECTED IN THE CATTLE-BAITED TRAP AND VARIOUS METEOROLOGICAL CONDITIONS.

Variables	Correlation coefficients (r)					
	Week 6[1]		Week 7		Week 9	
Activity vs. temperature:						
all sample times	.036	(37)[3]	-.081	(40)	-.240	(36)
sample times with remaining conditions within meteorological limits of high activity[2]	.115	(18)	.486*	(20)	-.379	(25)
Activity vs. saturation deficit:						
all sample times	-.069	(37)	-.368*	(40)	-.281	(36)
sample times with remaining conditions within meteorological limits of high activity	-.010	(15)	-.304	(23)	-.164	(18)
Activity vs. wind speed:						
all sample times	-.334*	(37)	-.534**	(40)	-.172	(36)
sample times with remaining conditions within meteorological limits of high activity	-.741**	(21)	-.549**	(24)	.122	(18)
Activity vs. reflected light intensity:						
all sample times	.270	(37)	-.457**	(40)	-.331*	(36)
sample times with remaining conditions within meteorological limits of high activity	.402	(16)	-.294	(24)	-.015	(24)

* Significant at $p<.05$, ** significant at $p<.01$, with df = n-2

1 The dates of each week are given in Appendix A.

2 Meteorological limits of high activity are given in Table 13.

3 Number of sample times correlated.

TABLE 15

NUMBER OF ST. MUTATA AND S. VITTATUM COLLECTED AT VARIOUS TIMES OF THE DAY IN THE CATTLE-BAITED TRAP.

Species	No. of sample periods	No. of flies	Percent of total catch
St. mutata			
morning sample period[1]	11	83	56.1%
afternoon sample period	11	4	2.7%
evening sample period	11	61	41.2%
Totals		148	100.0%
S. vittatum			
morning sample period	18	84	42.0%
afternoon sample period	18	37	18.5%
evening sample period	18	79	39.5%
Totals		200	100.0%

1 Only complete sample days were considered to ensure an equal sample size among sample periods for each species considered.

TABLE 16

NUMBER AND PROPORTION OF BLOOD-FED BLACK FLIES COLLECTED IN THE CATTLE-BAITED TRAP FROM MAY 26 TO AUGUST 25, 1982. THE 95% CONFIDENCE INTERVALS ARE GIVEN WITH PROPORTIONS.

Species	Number blood-fed	Number collected	Proportion blood-fed
P. mixtum	1,181	3,395	.348±.02
S. venustum/verecundum complex	4,756	6,849	.694±.01
S. vittatum	57	241	.237±.05
St. mutata	12	217	.056±.03

TABLE 17

CORRELATION COEFFICIENTS BETWEEN THE PROPORTION OF BLOOD-FED P. MIXTUM AND S. VENUSTUM/VERECUNDUM COMPLEX COLLECTED IN THE CATTLE-BAITED TRAP (PER SAMPLE PERIOD) AND VARIOUS METEOROLOGICAL CONDITIONS.

Variables correlated	Correlation coefficients (r)	
	P. mixtum	S. venustum/verecundum complex
Proportion blood-fed in each sample period vs[1]		
mean sample period temperature	.541*	.634**
mean 24-hour temperature	.852**	.693**
mean 24 to 48-hour temperature	.569*	.447*
mean sample period saturation deficit	.096	-.128
mean sample period wind speed	-.287	-.268
mean sample period reflected light intensity	-.691**	-.438*
Total no. of complete sample periods correlated	16	23
Total no. of black flies	2,679	6,[illegible]07

* Significant at $p<.05$, ** significant at $p<.01$, with $df = n-2$

[1] Only complete sample periods with 30 or more of either P. mixtum or S. venustum/verecundum complex were considered.

TABLE 18

PROPORTION OF BLOOD-FED *P. MIXTUM* COLLECTED IN THE CATTLE-BAITED TRAP, TABULATED BY TIME OF DAY (SAMPLE PERIOD) AND CALENDAR DATE (WEEK). 95% CONFIDENCE INTERVALS ARE GIVEN WITH THE NUMBER OF FLIES COLLECTED IN PARENTHESES.

Time (sample period)	Calendar date (week)[1]						
	Week 3[2]	Week 4	Week 6	Week 7	Week 8	Week 9	Totals
morning	-----	.25±.04 (533)	.34±.07 (198)	.48±.07 (214)	-----	.27±.14 (41)	.32±.03 (986)
afternoon	.27±.05 (287)	.28±.03 (824)	.36±.04 (536)	.42±.10 (91)	-----	-----	.31±.02 (1,738)
evening	-----	.47±.05 (386)	.42±.12 (66)	.64±.07 (159)	-----	-----	.51±.04 (611)
Totals		.31±.02 (1,743)	.36±.03 (800)	.52±.05 (464)			

1 No samples were collected during Week 5.

2 The dates of each week are given in Appendix A.

TABLE 19

THE PROPORTION OF BLOOD-FED S. VENUSTUM/VERECUNDUM COMPLEX COLLECTED IN THE CATTLE-BAITED TRAP, TABULATED BY TIME OF DAY (SAMPLE PERIOD) AND CALENDAR DATE (WEEK). THE 95% CONFIDENCE INTERVALS ARE GIVEN WITH THE NUMBER OF FLIES COLLECTED IN PARENTHESES.

Calendar date (week)[1]	Time (sample period)			Totals
	Morning	Afternoon	Evening	
Week 4[2]	---	.24±.12 (50)	---	---
Week 6	.43±.05 (408)	.54±.06 (256)	.58±.13 (57)	.48±.04 (721)
Week 7	.59±.03 (880)	.50±.06 (238)	.81±.02 (980)	.68±.02 (2,098)
Week 8	.81±.09 (77)	.37±.17 (30)	.75±.08 (114)	.72±.06 (221)
Week 9	.81±.03 (554)	.89±.05 (167)	.80±.02 (1,384)	.81±.02 (2,105)
Week 10	.78±.03 (847)	.74±.09 (88)	---	---
Week 11	.64±.08 (135)	.42±.12 (69)	---	---
Week 12	---	---	---	---
Week 13	.40±.09 (45)	.86±.08 (78)	.73±.06 (182)	.71±.05 (305)
Week 14	---	---	.66±.10 (91)	---
Totals	.67±.02 (2,946)	.60±.03 (976)	.79±.02 (2,808)	

1 No samples were collected during Week 5.

2 The dates of each week are given in Appendix A.

TABLE 20

TOTAL NUMBER OF MOSQUITOES COLLECTED IN THE CATTLE-BAITED (12:00 TO 24:00 HOURS SST) AND CO_2 (12:00 TO 12:00 HOURS SST) TRAPS, NEAR PADDY'S POND, ST. JOHN'S.[1]

Species	Cattle-baited trap			CO_2 trap		
	No. collected	Date first collected	Date last collected	No. collected	Date first collected	Date last collected
Ae. abserratus	113	July 1	August 9	80	June 17	August 25
Ae. canadensis	1	July 26	July 26	4	July 21	August 13
Ae. cantator[2]	0	---	---	3	August 5	August 9
Ae. decticus[2]	1	August 6	August 6	0	---	---
Ae. hexodontus[2]	1	July 6	July 6	0	---	---
Ae. punctor	82	July 4	August 25	22	July 15	August 15
Cs. impatiens[3]	165	May 31	August 8	8	June 17	August 8
Totals	363			117		

[1] The cattle-baited and CO_2 traps were operated on select days from May 26 to August 25 and June 6 to September 16, 1982, respectively.

[2] Identification not confirmed.

[3] Several *Cs. impatiens* were active before systematic trapping was instituted.

TABLE 21

NUMBER AND PROPORTION OF BLOOD-FED MOSQUITOES COLLECTED IN THE CATTLE-BAITED TRAP FROM MAY 31 TO AUGUST 25, 1982. THE 95% CONFIDENCE INTERVALS ARE GIVEN WITH PROPORTIONS.

Species	Number blood-fed	Number collected	Proportion blood-fed
Ae. abserratus	81	113	.72±.08
Ae. punctor	56	82	.68±.10
Cs. impatiens	43	165	.26±.07

TABLE 22

NUMBER OF AE. ABSERRATUS, AE. PUNCTOR, AND CS. IMPATIENS COLLECTED AT VARIOUS TIMES OF THE DAY IN THE CATTLE-BAITED TRAP.

Species	No. of sample periods	No. of flies	Percent of total catch
Ae. abserratus			
morning sample period[1]	11	7	7.4%
afternoon sample period	11	1	1.1%
evening sample period	11	86	91.5%
Totals		94	100.0%
Ae. punctor			
morning sample period	10	3	4.2%
afternoon sample period	10	0	0.0%
evening sample period	10	69	95.8%
Totals		72	100.0%
Cs. impatiens			
morning sample period	15	6	5.0%
afternoon sample period	15	1	0.8%
evening sample period	15	112	94.1%
Totals		119	99.9%

1 Only complete sample days were considered to ensure an equal sample size among sample periods for each species considered.

TABLE 23

TOTAL NUMBER OF TABANIDS COLLECTED IN THE CATTLE-BAITED TRAP NEAR PADDY'S POND, ST. JOHN'S, FROM 12:00 TO 24:00 HOURS (SST), JULY 6 TO AUGUST 17, 1982. NUMBER OF BLOOD-FED FLIES IS GIVEN IN PARENTHESES.[1]

Species	No. collected	Date first collected	Date last collected
C. excitans	33 (21)	July 13	August 17
C. frigidus	29 (2)	July 13	August 17
C. furcatus	28 (10)	July 20	August 17
C. mitis	1 (0)	July 21	July 21
C. sordidus	3 (0)	July 20	August 9
C. zinzalus	1 (1)	July 31	July 31
H. frontalis	1 (0)	July 31	July 31
H. lurida	1 (0)	July 6	July 6
H. minuscula	1 (0)	August 6	August 6
H. zonalis	8 (3)	July 13	August 6
Total	106 (37)		

1 The cattle-baited and CO_2 traps were operated on select days from May 26 to August 25 and June 6 to September 16, 1982, respectively.

TABLE 24

A COMPARISON BETWEEN THE SPECIES OF ADULT BLACK FLIES TAKEN IN THE PRESENT STUDY AND LARVAL BLACK FLIES COLLECTED BY LEWIS AND BENNETT (1974) IN THE VICINITY OF PADDY'S POND, ST. JOHN'S, NEWFOUNDLAND[1]

Larval species (Lewis and Bennett, 1974)	Adult species (present study, 1982)
P. mixtum/fuscum complex[2]	*P. mixtum*
S. tuberosum	*S. decorum*
S. verecundum	*S. venustum/verecundum* complex
S. venustum	*S. vittatum*
St. mutata	*St. mutata*

1 Ornithophilic species have been excluded from the comparison.

2 *P. mixtum/fuscum* complex is now thought to include only *P. mixtum*.

FIG. 1 Study Site.

bn = barn
cbt = cattle-baited trap
CO_2 = Trueman-McIver segregating CO_2 trap (not visible)
ws = field weather station

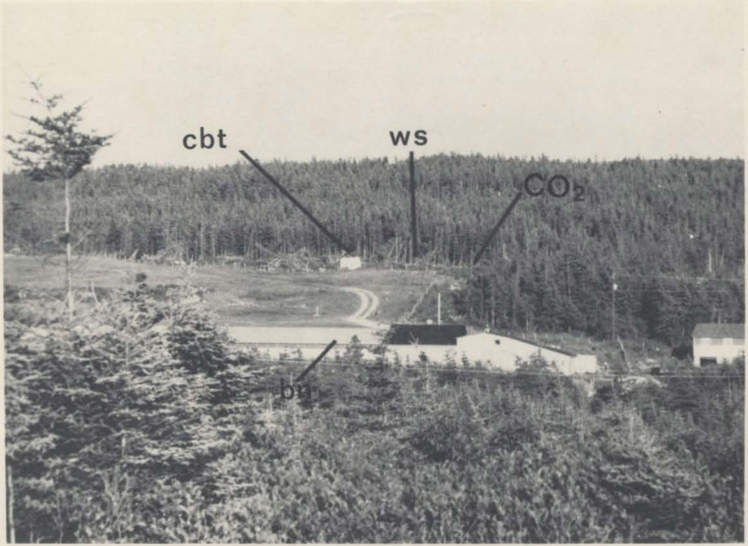

cbt
ws
CO_2
bg

FIG. 2 Cattle-baited trap (continued next page)

(a) cattle-baited trap with collapsible tent in down position

(b) metal frame showing rectangular base and hoops

(c) diagram of rectangular base indicating dimensions

(d) close up view of one corner section of the rectangular base

cp = corner piece
ct = collapsible tent
ecc = electrical conduit connector
hs = hoop socket

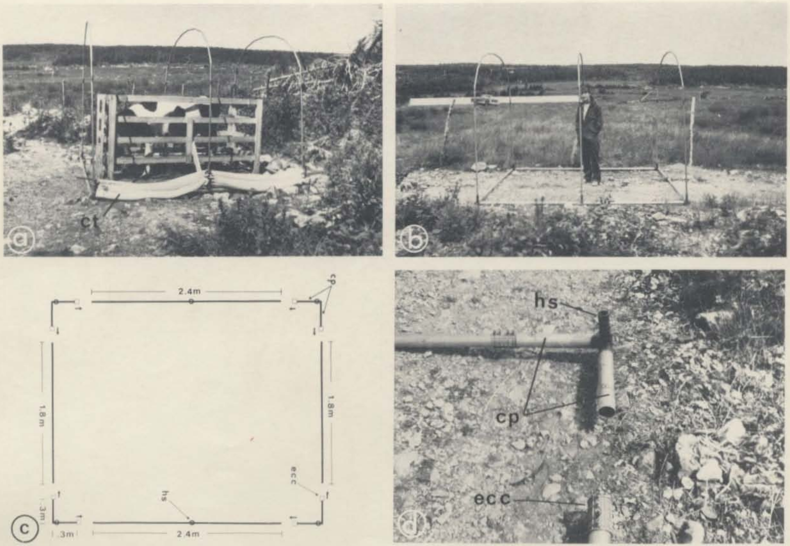

a
ct
b
c
2.4m
1.8m
.3m
cp
ecc
hs
d
hs
cp
ecc

FIG. 2 (continued) Cattle-baited trap.

(e) cattle-baited trap with collapsible tent in up position

(f) attachment of collapsible tent to metal frame

(g) back view of collapsible tent showing entrance

(h) operation of cattle-baited trap

cf = canvas flap
cs = canvas strip
h = hoop
rg = metal ring and attached brass eye

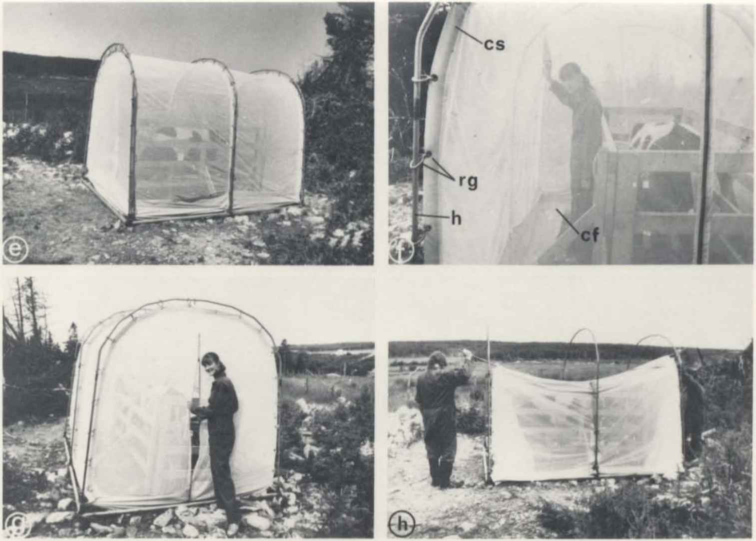

e
cs
rg
h
cf
f
g
h

FIG. 3 Modified hand vacuum used as a field aspirator.

cb = collecting bag


cb

FIG. 4 Trueman-McIver segregating CO_2 trap.

(a) front view of trap

(b) front view of trap showing segregating mechanism

CO_2 = CO_2 gas cylinder
fl = flow line (connecting gas cylinder to flow meter)
fm = flow meter
fn = fan
sm = segregating mechanism


fm
a
fm
fl
sm
CO2
b

FIG. 5 Seasonal variation in the daily mean number of female mammalophilic black flies collected in the cattle-baited trap, near Paddy's Pond, St. John's, from 12:00 to 24:00 hours (SST), May 26 to August 16, 1982. Dates left blank are days on which sampling was incomplete or not done. Days on which sampling was conducted but no black flies were collected are indicated by zeros.

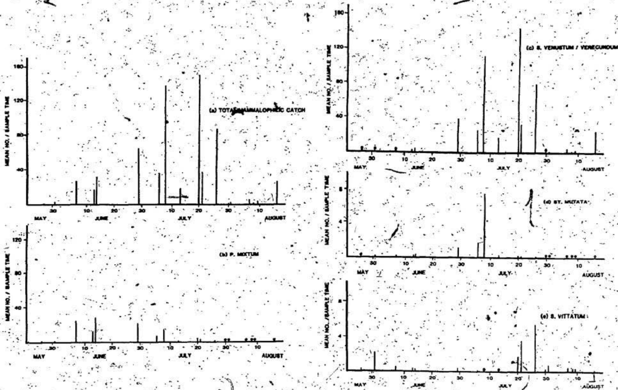

(a) TOTAL MAMMALOPHILIC CATCH
(b) P. MIXTUM
(c) S. VENUSTUM / VERECUNDUM
(d) ST. MUTATA
(e) S. VITTATUM
MEAN NO. / SAMPLE TIME
MAY
JUNE
JULY
AUGUST

FIG. 6 Seasonal variation in the daily mean number of female mammalophilic black flies collected in the CO_2 trap, near Paddy's Pond, St. John's, from 12:00 to 24:00 hours (SST), June 6 to September 16, 1982. Dates left blank are days on which sampling was not done. Days on which sampling was conducted but no black flies were collected are indicated by zeros.

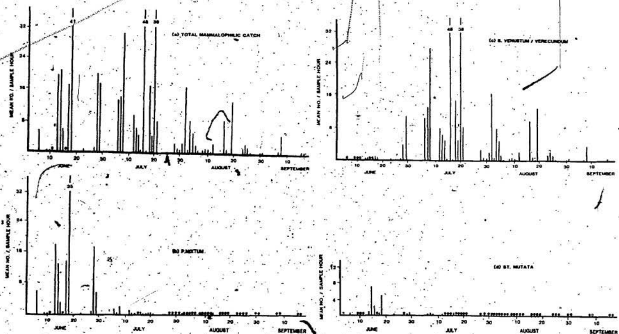

(a) TOTAL MAMMALOPHILIC CATCH
MEAN NO. / SAMPLE HOUR
32
24
16
8
41
48
38
10
20
30
JUNE
JULY
AUGUST
SEPTEMBER
(b) P.MIXTUM
35
(c) S. VENUSTUM / VERECUNDUM
(d) ST. MUTATA
12
4

FIG. 7 Seasonal occurrence and abundance of mammalophilic black flies collected in the cattle-baited and CO_2 traps, near Paddy's Pond, St. John's, from 12:00 to 24:00 hours (SST). The cattle-baited and CO_2 traps were operated on select days from May 26 to August 25 and June 6 to September 16, 1982, respectively. The total number of each species (or species complex) collected over the entire trapping season is indicated at the end of each bar. The date on which 50% of the total season's catch was cumulatively collected for each species (species complex) is indicated.

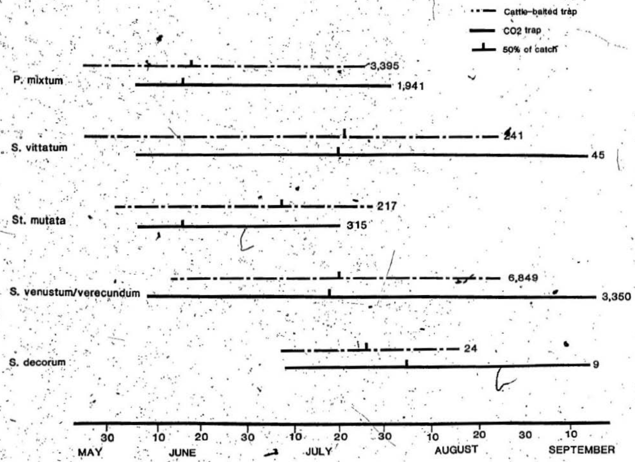
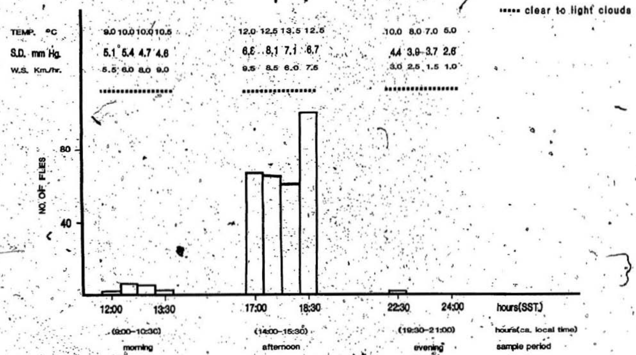

Cattle-baited trap
CO2 trap
50% of catch
P. mixtum
3,395
1,941
S. vittatum
241
45
St. mutata
217
315
S. venustum/verecundum
6,849
3,350
S. decorum
24
9
30
10
20
30
10
20
30
10
20
30
10
MAY
JUNE
JULY
AUGUST
SEPTEMBER

FIG. 8 Diurnal activity of P. mixtum on June 7, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

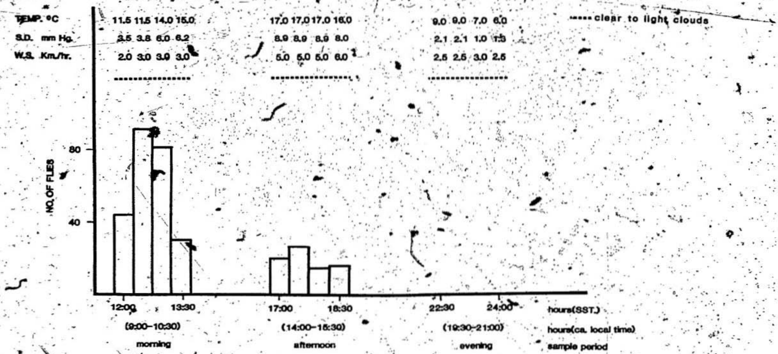
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg
W.S. Km/hr.
9.0 10.0 10.0 10.5
5.1 5.4 4.7 4.6
5.5 6.0 8.0 9.0
12.0 12.5 13.5 12.5
6.8 8.1 7.1 6.7
9.5 8.5 6.0 7.5
10.0 8.0 7.0 5.0
4.4 3.9 3.7 2.6
3.0 2.5 1.5 1.0
clear to light clouds
NO. OF FLIES
80
40
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST)
(9:00–10:30)
(14:00–15:30)
(19:30–21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 9 Diurnal activity of *P. mixtum* on June 14, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

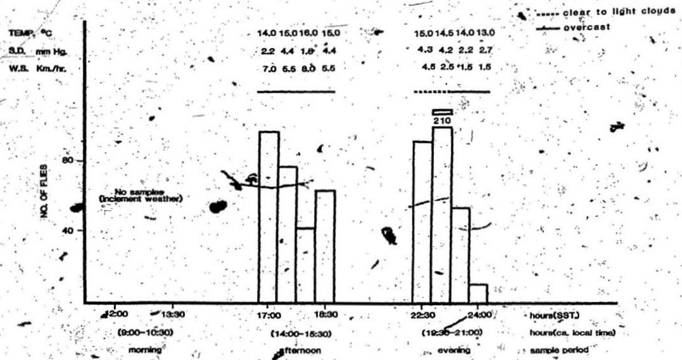
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
11.5 11.5 14.0 15.0
3.5 3.8 6.0 6.2
2.0 3.0 3.9 3.0
17.0 17.0 17.0 16.0
8.9 8.9 8.9 8.0
5.0 5.0 5.0 6.0
9.0 9.0 7.0 6.0
2.1 2.1 1.0 1.3
2.5 2.5 3.0 2.5
----- clear to light clouds
NO. OF FLIES
80
40
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00–10:30)
(14:00–15:30)
(19:30–21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 10 Diurnal activity of P. mixtum on June 17, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

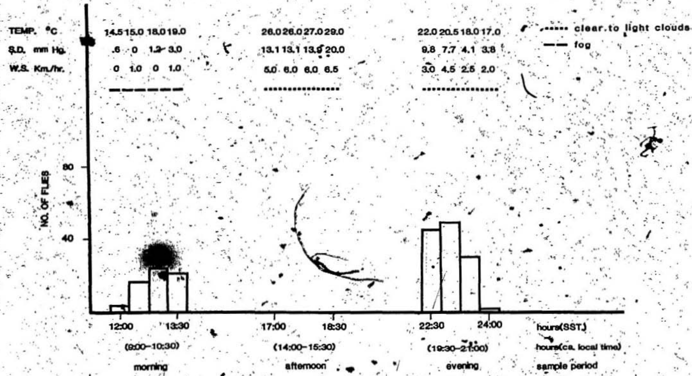
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
14.0 15.0 16.0 15.0
2.2 4.4 1.8 4.4
7.0 5.5 8.0 5.5
15.0 14.5 14.0 13.0
4.3 4.2 2.2 2.7
4.5 2.5 1.5 1.5
clear to light clouds
overcast
210
NO. OF FLIES
80
40
No samples
(inclement weather)
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00-10:30)
(14:00-15:30)
(19:30-21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

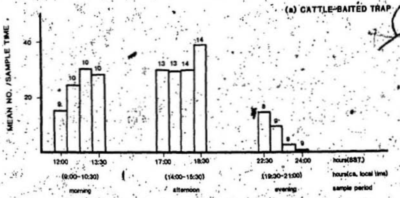
FIG. 11 Diurnal activity of _P. mixtum_ on July 8, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
14.5 15.0 18.0 19.0
.6 0 1.2 3.0
0 1.0 0 1.0
26.0 26.0 27.0 29.0
13.1 13.1 13.9 20.0
5.0 6.0 6.0 6.5
22.0 20.5 18.0 17.0
9.8 7.7 4.1 3.8
3.0 4.5 2.5 2.0
clear to light clouds
fog
NO. OF FLIES
80
40
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00–10:30)
(14:00–15:30)
(19:30–21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 12 Generalized pattern of diurnal activity of *P. mixtum* as determined by the cattle-baited and CO_2 traps. Each graph is based on the mean number of black flies collected per sample time (cattle-baited trap) or hour (CO_2 trap) from June 7 to July 8, 1982. The number of samples taken is given above each bar. SST refers to the number of hours after a reference sunset.


(a) CATTLE-BAITED TRAP
MEAN NO. / SAMPLE TIME
hours(SST)
hours(ca. local time)
sample period
(9:00-10:30)
morning
(14:00-15:30)
afternoon
(19:30-21:00)
evening

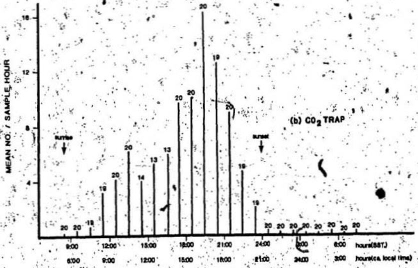
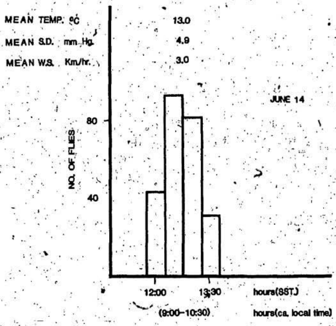

(b) CO_2 TRAP
MEAN NO. / SAMPLE HOUR
sunrise
sunset
hours(SST)
hours(ca. local time)

FIG. 13 The influence of wind on the number of _P. mixtum_ collected in the cattle-baited trap on the mornings of June 13 and June 14. SST refers to the number of hours after a reference sunset.

S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed


MEAN TEMP. °C
13.0
MEAN S.D. mm Hg.
4.9
MEAN W.S. Km/hr.
3.0
JUNE 14
NO. OF FLIES
80
40
12:00
13:30
hours(SST.)
(9:00-10:30)
hours(ca. local time)

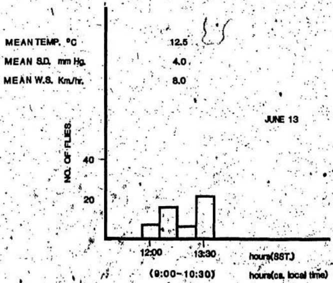
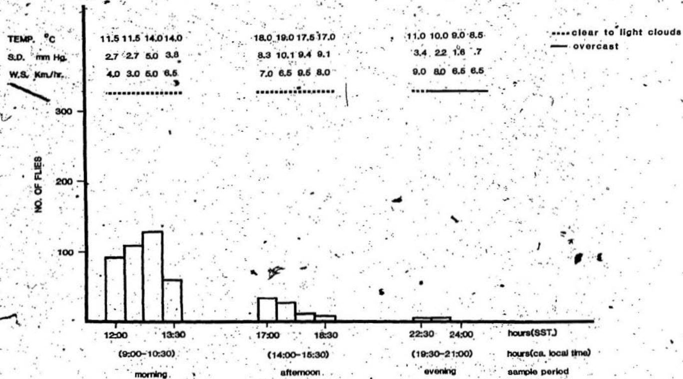

MEAN TEMP. °C
12.5
MEAN S.D. mm Hg.
4.0
MEAN W.S. Km/hr.
8.0
JUNE 13
NO. OF FLIES
40
20
12:00
13:30
hours(SST.)
(9:00-10:30)
hours(ca. local time)

FIG. 14 Diurnal activity of S. venustum/verecundum complex on June 29, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

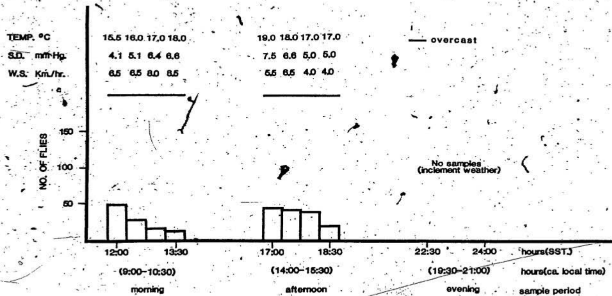
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
11.5 11.5 14.0 14.0
2.7 2.7 5.0 3.8
4.0 3.0 5.0 6.5
18.0 19.0 17.5 17.0
8.3 10.1 9.4 9.1
7.0 6.5 9.5 8.0
11.0 10.0 9.0 8.5
3.4 2.2 1.6 .7
9.0 8.0 6.5 6.5
clear to light clouds
overcast
NO. OF FLIES
300
200
100
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00–10:30)
(14:00–15:30)
(19:30–21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 15 Diurnal activity of S. venustum/verecundum complex on July 7, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

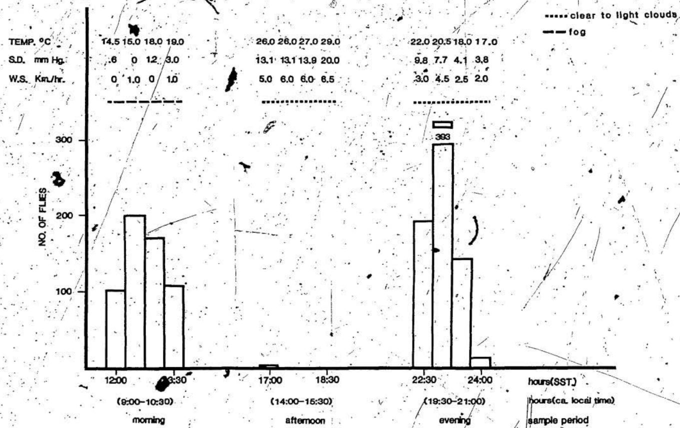
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
15.5 16.0 17.0 18.0
4.1 5.1 6.4 6.6
6.5 6.5 8.0 8.5
19.0 18.0 17.0 17.0
7.5 6.6 5.0 5.0
5.5 6.5 4.0 4.0
overcast
NO. OF FLIES
150
100
50
No samples
(inclement weather)
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00–10:30)
(14:00–15:30)
(19:30–21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 16 Diurnal activity of S. venustum/verecundum complex on July 8, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed, and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

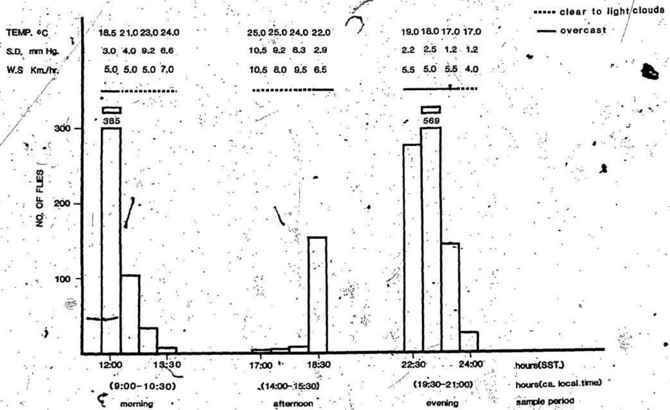
S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



clear to light clouds
fog
TEMP. °C
S.D. mm Hg.
W.S. Km./hr.
14.5 15.0 18.0 19.0
.6 0 1.2 3.0
0 1.0 0 1.0
26.0 26.0 27.0 29.0
13.1 13.1 13.9 20.0
5.0 6.0 6.0 6.5
22.0 20.5 18.0 17.0
9.8 7.7 4.1 3.8
3.0 4.5 2.5 2.0
393
NO. OF FLIES
300
200
100
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00-10:30)
(14:00-15:30)
(19:30-21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 17 Diurnal activity of S. venustum/verecundum complex on July 20, 1982, as determined by the cattle-baited trap. Ambient temperature, saturation deficit, wind speed and cloud cover are given for each sample time. SST (standard sunset time) refers to the number of hours after a reference sunset.

S.D. = saturation deficit
TEMP. = temperature
W.S. = wind speed



clear to light clouds
overcast
TEMP. °C
S.D. mm Hg.
W.S Km/hr.
18.5 21.0 23.0 24.0
3.0 4.0 9.2 6.6
5.0 5.0 5.0 7.0
25.0 25.0 24.0 22.0
10.5 9.2 8.3 2.9
10.5 8.0 9.5 6.5
19.0 18.0 17.0 17.0
2.2 2.5 1.2 1.2
5.5 5.0 5.5 4.0
385
569
NO. OF FLIES
300
200
100
12:00
13:30
17:00
18:30
22:30
24:00
hours(SST.)
(9:00-10:30)
(14:00-15:30)
(19:30-21:00)
hours(ca. local time)
morning
afternoon
evening
sample period

FIG. 18 Generalized pattern of diurnal activity of <u>S. venustum/verecundum</u> complex as determined by the cattle-baited and CO_2 traps. Each graph is based on the mean number of black flies collected per sample time (cattle-baited trap; June 28 to July 31) or hour (CO_2 trap; June 28 to August 4). The number of samples taken is given above each bar. SST refers to the number of hours after a reference sunset.

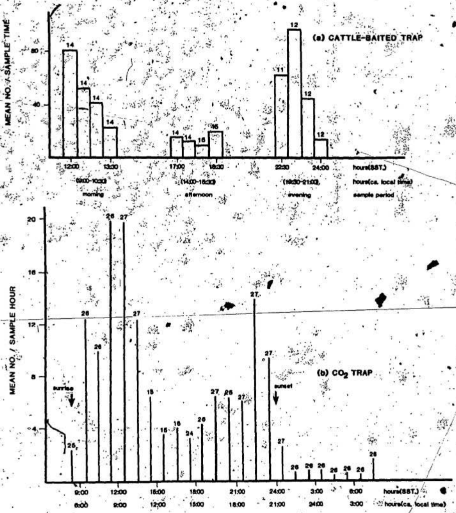
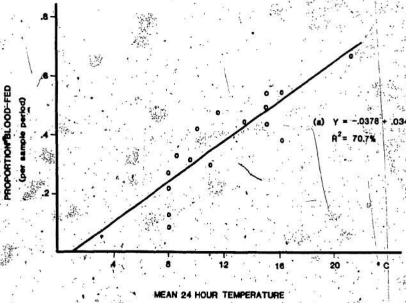

(a) CATTLE-BAITED TRAP
MEAN NO. / SAMPLE TIME
hours(SST.)
hours(ca. local time)
sample period
(9:00-10:30)
morning
(14:00-15:30)
afternoon
(19:30-21:00)
evening
(b) CO_2 TRAP
MEAN NO. / SAMPLE HOUR
sunrise
sunset
hours(SST.)
hours(ca. local time)

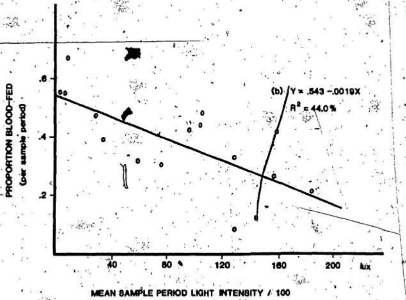
FIG. 19 Regression analysis of the proportion of blood-fed *P. mixtum* collected in the cattle-baited trap (per sample period) on:

(a) mean 24-hour temperature

(b) mean sample period light intensity/100



.8
.6
.4
.2
PROPORTION BLOOD-FED
(per sample period)
(a) Y = -.0378 + .0344X
R^2 = 70.7%
4
8
12
16
20
°C
MEAN 24 HOUR TEMPERATURE

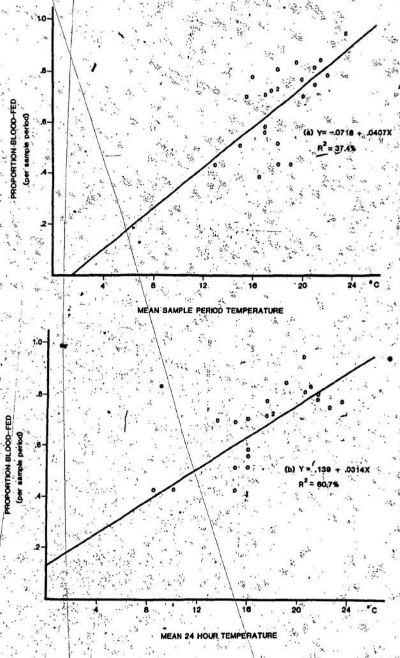


.6
.4
.2
PROPORTION BLOOD-FED
(per sample period)
(b) Y = .543 -.0019X
R^2 = 44.0%
40
80
120
160
200
lux
MEAN SAMPLE PERIOD LIGHT INTENSITY / 100

FIG. 20 Regression analysis of the proportion of blood-fed *S. venustum/verecundum* complex collected in the cattle-baited trap (per sample period) on:

(a) mean sample period temperature

(b) mean 24-hour temperature


PROPORTION BLOOD-FED
(per sample period)
MEAN SAMPLE PERIOD TEMPERATURE
°C
(a) Y= -.0718 + .0407X
R² = 37.4%
PROPORTION BLOOD-FED
(per sample period)
MEAN 24 HOUR TEMPERATURE
°C
(b) Y = .139 + .0314X
R² = 60.7%

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APPENDIX A

The date and local clock time of each reference sunset used in standard sunset time (SST) under which both the cattle-baited and CO_2 traps were operated during the late spring to late summer of 1982.

Week		Date of Reference Sunset (Sunday)	Local Time of Reference Sunset *
1	May 23-May 29	May 23	20:42
2	May 30-June 5	May 30	20:50
3	June 6-June 12	June 6	20:56
4	June 13-June 19	June 13	21:00
5	June 20-June 26	June 20	21:05
6	June 27-July 3	June 27	21:06
7	July 4-July 10	July 4	21:04
8	July 11-July 17	July 11	21:02
9	July 18-July 24	July 18	20:55
10	July 25-July 31	July 25	20:46
11	Aug. 1-Aug. 7	Aug. 1	20:38
12	Aug. 8-Aug. 14	Aug. 8	20:27
13	Aug. 15-Aug. 21	Aug. 15	20:15
14	Aug. 22-Aug. 28	Aug. 22	20:02
15	Aug. 29-Sept. 4	Aug. 29	19:49
16	Sept. 5-Sept. 11	Sept. 5	19:36
17	Sept. 12-Sept. 18	Sept. 12	19:20

* local clock times of sunset were obtained from the St. John's weather office.

APPENDIX B

Regression analysis of the proportion of blood-fed *P. mixtum* collected in the cattle-baited trap (per sample period) on mean 24-hour temperature (an average of the maximum and minimum temperatures observed over the previous 24 hours with time zero designated as the start of the sample period).

```
THE REGRESSION EQUATION IS
Y = -0.0378 +0.0344 X

where, Y = proportion blood-fed (per sample period)
       X = mean 24-hour temperature
```

	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
Y Intercept	-0.03777	0.07155	-0.53
Slope	0.034353	0.005633	6.10

```
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 0.08538
WITH (16 - 2) = 14 DEGREES OF FREEDOM

R-SQUARED = 72.7 PERCENT
R-SQUARED = 70.7 PERCENT, ADJUSTED FOR D.F.
```

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS = SS/DF	F
Regression	1	0.271127	0.271127	37.12
Residual	14	0.102047	0.007289	
Total	15	0.373175		

ROW	X VALUE	Y VALUE	PRED. Y VALUE	ST.DEV. PRED. Y	ST.RES.
1	8.0	0.2700	0.2370	0.0316	0.42
2	8.0	0.1300	0.2370	0.0316	-1.35
3	8.0	0.0800	0.2370	0.0316	-1.98
4	8.0	0.2200	0.2370	0.0316	-0.21
5	9.5	0.3200	0.2886	0.0260	0.39
6	11.5	0.4800	0.3573	0.0216	1.49
7	11.0	0.3000	0.3401	0.0223	-0.49
8	8.5	0.3300	0.2542	0.0295	0.95
9	10.0	0.4300	0.3058	0.0245	1.52
10	13.5	0.4300	0.4260	0.0227	0.05
11	15.0	0.5500	0.4775	0.0268	0.89
12	15.0	0.4800	0.4775	0.0268	0.03
13	15.0	0.4400	0.4775	0.0268	-0.46
14	16.0	0.5500	0.5119	0.0305	0.48
15	16.0	0.3800	0.5119	0.0305	-1.65
16	21.0	0.6700	0.6836	0.0544	-0.21

APPENDIX C

Regression analysis of the proportion of blood-fed *P. mixtum* collected in the cattle-baited trap (per sample period) on mean sample period reflected light intensity/100.

```
THE REGRESSION EQUATION IS
Y = 0.543 -0.0019 X

where, Y = proportion blood-fed (per sample period)
       X = mean sample period reflected light intensity/100
```

	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
Y Intercept	0.54259	0.05451	9.95
Slope	-0.0018513	0.0005178	-3.58

```
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 0.1180
WITH (16 - 2) = 14 DEGREES OF FREEDOM

R-SQUARED = 47.7 PERCENT
R-SQUARED = 44.0 PERCENT, ADJUSTED FOR D.F.
```

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS = SS/DF	F
Regression	1	0.17810	0.17810	12.79
Residual	14	0.19507	0.01393	
Total	15	0.37317		

ROW	X VALUE	Y VALUE	PRED. Y VALUE	ST.DEV. PRED. Y	ST.RES.
1	148	0.2700	0.2695	0.0425	0.00
2	143	0.1300	0.2788	0.0407	-1.34
3	125	0.0800	0.3112	0.0350	-2.05
4	185	0.2200	0.2001	0.0580	0.19
5	60	0.3200	0.4320	0.0331	-0.99
6	28	0.4800	0.4916	0.0432	-0.11
7	77	0.3000	0.4005	0.0301	-0.88
8	130	0.3300	0.3019	0.0365	0.25
9	158	0.4300	0.2510	0.0463	1.65
10	98	0.4300	0.3621	0.0299	0.59
11	5	0.5500	0.5332	0.0523	0.16
12	108	0.4800	0.3426	0.0312	1.21
13	105	0.4400	0.3482	0.0307	0.81
14	7	0.5500	0.5296	0.0515	0.19
15	33	0.3800	0.4813	0.0412	-0.92
16	9	0.6700	0.52[illegible]4	0.0507	1.35

APPENDIX D

Regression analysis of the proportion of blood-fed S. venustum/verecundum complex collected in the cattle-baited trap (per sample period) on mean sample period temperature.

THE REGRESSION EQUATION IS
Y = -0.0718 +0.0407 X

where, Y = proportion blood-fed (per sample period)
X = mean sample period temperature

	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
Y Intercept	-0.0718	0.2004	-0.36
Slope	0.04069	0.01083	3.76

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 0.1257
WITH (23 - 2) = 21 DEGREES OF FREEDOM

R-SQUARED = 40.2 PERCENT
R-SQUARED = 37.4 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS = SS/DF	F
Regression	1	0.22306	0.22306	14[illegible]2
Residual	21	0.33172	0.01580	
Total	22	0.55478		

ROW	X VALUE	Y VALUE	PRED. Y VALUE	ST.DEV. PRED. Y	ST.RES.
1	13.0	0.4300	0.4572	0.0636	-0.25
2	18.0	0.4300	0.6606	0.0265	-1.88
3	20.0	0.7000	0.7420	0.0317	-0.35
4	15.0	0.5200	0.5386	0.0447	-0.16
5	19.0	0.4300	0.7013	0.0271	-2.21
6	17.0	0.5600	0.6199	0.0300	-0.49
7	15.5	0.7000	0.5589	0.0405	1.19
8	17.0	0.7100	0.6199	0.0300	0.74
9	18.0	0.5200	0.6606	0.0265	-1.14
10	17.0	0.5800	0.6199	0.0300	-0.33
11	19.5	0.8400	0.7217	0.0290	0.97
12	22.0	0.7900	0.8234	0.0474	-0.29
13	21.0	0.7500	0.7827	0.0389	-0.27
14	21.0	0.8200	0.7827	0.0389	0.31
15	23.5	0.9500	0.8844	0.0616	0.60
16	18.0	0.8100	0.6606	0.0265	1.22
17	20.0	0.7700	0.7420	0.0317	0.23
18	16.0	0.7800	0.5792	0.0365	1.67
19	17.5	0.7300	0.6403	0.0278	0.73
20	16.5	0.3900	0.5996	0.0330	-1.73
21	21.5	0.8500	0.8030	0.0430	0.40
22	18.0	0.7300	0.6606	0.0265	0.56
23	18.0	0.7300	0.6606	0.0265	0.56

APPENDIX E

Regression analysis of the proportion of blood-fed S. venustum/verecundum complex collected in the cattle-baited trap (per sample period) on mean 24-hour temperature (an average of the maximum and minimum temperatures observed over the previous 24 hours with time zero designated as the start of the sample period).

THE REGRESSION EQUATION IS
Y = 0.139 +0.0314 X

where, Y = the proportion blood-fed (per sample period)
X = mean 24-hour temperature

	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
Y Intercept	0.13873	0.09695	1.43
Slope	0.031371	0.005421	5.79

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 0.09373
WITH (22 - 2) = 20 DEGREES OF FREEDOM

R-SQUARED = 62.6 PERCENT
R-SQUARED = 60.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS = SS/DF	F
Regression	1	0.294262	0.294262	33.49
Residuals	20	0.175724	0.008786	
Total	21	0.469986		

ROW	X VALUE	Y VALUE	PRED. Y VALUE	ST.DEV. PRED. Y	ST.RES. *
1	8.5	0.4300	0.4054	0.0527	0.32
2	10.0	0.4300	0.4524	0.0453	-0.27
3	13.5	0.7000	0.5622	0.0295	1.55
4	15.0	0.5200	0.6093	0.0241	-0.99
5	15.0	0.4300	0.6093	0.0241	-1.98
6	16.0	0.5600	0.6407	0.0216	-0.88
7	16.0	0.7000	0.6407	0.0216	0.65
8	17.0	0.7100	0.6720	0.0202	0.41
9	17.0	0.5200	0.6720	0.0202	-1.66
10	16.0	0.5800	0.6407	0.0216	-0.67
11	21.0	0.8400	0.7975	0.0276	0.47
12	21.5	0.7900	0.8132	0.0295	-0.26
13	22.5	0.7500	0.8446	0.0337	-1.08
14	20.5	0.8200	0.7818	0.0258	0.42
15	20.5	0.9500	0.7818	0.0258	1.87
16	21.5	0.8100	0.8132	0.0295	-0.04
17	23.5	0.7700	0.8760	0.0382	-1.24
18	17.5	0.7800	0.6877	0.0200	1.01
19	17.5	0.7300	0.6877	0.0200	0.46
20	19.0	0.8500	0.7348	0.0216	1.26
21	18.0	0.7300	0.7034	0.0202	0.29
22	18.0	0.7300	0.7034	0.0202	0.29

* one X value was removed from the regression analysis due to a high standard residual