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ARBOVIRUSES AND HUMAN HEALTH IN CANADA

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FOREWORD

This monograph was prepared by Dr. D.M. McLean, Faculty of Medicine, Division of Medical Microbiology, University of British Columbia, Vancouver, B.C., at the request of the Biological Subcommittee of the National Research Council's Associate Committee on Scientific Criteria for Environmental Quality. The manuscript was critically reviewed and approved for publication by the Subcommittees appropriate to the subject and the Associate Committee.

ARBOVIRUSES AND HUMAN HEALTH IN CANADA

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INTRODUCTION

Arthropod-borne viruses (arboviruses) constitute a recurrent hazard to human well-being throughout Canada during the warmer months of each year, at times of high prevalence of two categories of blood-sucking arthropods - culicine and aedine mosquitoes and ixodid ticks. Despite the low incidence of clinically manifest illnesses, principally encephalitis, which are due to arbovirus infections, the severity of symptoms attracts widespread public attention. Control of the spread of arbovirus infections has been promoted by knowledge of dose/effect relationships between arboviruses and (i) their arthropod vectors on the one hand; and (ii) human and other vertebrate reservoirs on the other hand. Data applicable to the Canadian environment relating to the spread of arboviruses by mosquitoes and ticks (paragraph 4.1.3 of ACSCEQ Report No. 1) have been compiled in the present report.

The human illness which results from arbovirus infections contracted within Canada usually involves the central nervous system. Within North America, the four arboviruses associated regularly with encephalitis or aseptic meningitis are EASTERN EQUINE ENCEPHALOMYELITIS (EEE), WESTERN EQUINE ENCEPHALOMYELITIS (WEE), ST. LOUIS ENCEPHALITIS (SLE) and CALIFORNIA ENCEPHALITIS (CE) (McGowan *et al.* 1973). Occasional cases of encephalitis have developed following infection with POWASSAN (POW) and VENEZUELAN EQUINE ENCEPHALOMYELITIS (VEE) viruses. One North American arbovirus, COLORADO TICK FEVER (CTF) virus, usually evokes severe fever without symptoms referable to the central nervous system. Finally, no illness has been attributed to infections in Canada with arboviruses of the BUNYAMWERA group, or to TURLOCK and FLANDERS-HART PARK viruses. Within adjacent tropical areas of the Caribbean

and Central and South America and the Pacific Islands and Southeast Asia, however, additional arboviruses pathogenic for man are endemic. These include: dengue, which may induce high fever accompanied by maculopapular rash plus severe aches within the back and limbs; yellow fever, which may induce jaundice plus 'black vomit' through induction of mid-zonal necrosis of the liver; and several other agents which may induce undifferentiated fevers.

"Arboviruses are viruses which are maintained in nature principally, or to an important extent, through biological transmission between susceptible vertebrate hosts by hematophagous arthropods; they multiply and produce viremia in the vertebrates, multiply in the tissues of arthropods, and are passed on to new vertebrates by the bites of arthropods after a period of extrinsic incubation" (WHO 1967). Currently, 359 arbovirus prototype strains have been catalogued (Berge 1975). All share certain biological properties such as: ability to replicate in brains of suckling mice with production of fatal encephalitis; loss of infectivity following treatment with sodium deoxycholate or diethyl ether, which demonstrates the presence of an outer coat on the virus particle; and the presence of ribonucleic acid as the only form of nucleic acid (McLean 1968). Diameters of these enveloped virus particles range from 20 to 100 nanometres (nm). Although most serotypes exhibit cubic symmetry (TOGAVIRUSES), with a particle size of 20 to 50 nm, a substantial number exhibit helical symmetry (BUNYAVIRUSES) with a particle size of 80 to 100 nm, whilst others show a bullet-shaped internal structure (RHABDOVIRUSES) in electron micrographs (Pereira and Andrewes 1972). On the basis of hemagglutination inhibition and complement fixation tests, the arboviruses are subdivided into approximately 40 serological groups (Berge 1975). Within each serological group, individual arbovirus serotypes are identified by mouse neutralization, plaque reduction neutralization, or immunodiffusion tests.

ARBOVIRUSES

PREVALENCE OF ARBOVIRUSES IN CANADA

Prevalence of one or more serotypes of arbovirus has been established in Canada within all six Provinces and two Territories west of the St. Lawrence River (Fig. 1), by the isolation of virus from wild-caught unengorged mosquitoes or ticks on the one hand, or from blood or tissues of naturally infected vertebrates on the other hand, or from both arthropods and vertebrates (Table 1). To date, arbovirus foci have not been detected in the four Atlantic Provinces, but limited serological surveys suggest their presence. Among these arboviruses, only two (POW and WEE) have induced clinical illness in human residents of Canada, and subclinical infections have been caused by two additional serotypes (CE and CTF).

HUMAN INFECTIONS

WESTERN EQUINE ENCEPHALOMYELITIS (WEE) virus has caused both widespread outbreaks and sporadic cases of acute encephalitis amongst human residents of the Prairie Provinces during many summers since 1941. In Manitoba, between 1941 and 1949, the case fatality rate ranged from 0.7% to 41%, with 15% of 509 cases reported in 1941 terminating fatally (Adamson *et al.* 1950). In Saskatchewan during 1965, among 490 patients hospitalized with acute encephalitis, WEE infection was confirmed in 72 of whom 8 (11%) died (Rozdilsky *et al.* 1968). In 1971, for the first time, serologically confirmed infections with WEE virus were recorded in three residents of the Thompson-Okanagan region of British Columbia (Kettyls *et al.* 1972). Subclinical infections, as determined by antibody production in selected population groups without overt encephalitis, involved 0.3% of British Columbia residents (*ibid*) and 9% of Alberta inhabitants (Iversen *et al.* 1971). During various epidemics, the subclinical infection rate in Manitoba ranged from 3 to 19% (Bowman 1947).

CALIFORNIA ENCEPHALITIS (CE) virus, SNOWSHOE HARE (SSH) subtype, has induced subclinical infections in 2.5% of British Columbia residents (Kettyls *et al.* 1972) and in 30% of members of a farming community in northern Alberta (Iversen *et al.* 1971), but no cases of

Fig.- 1 Arbovirus prevalence in Canadian vegetation zones.

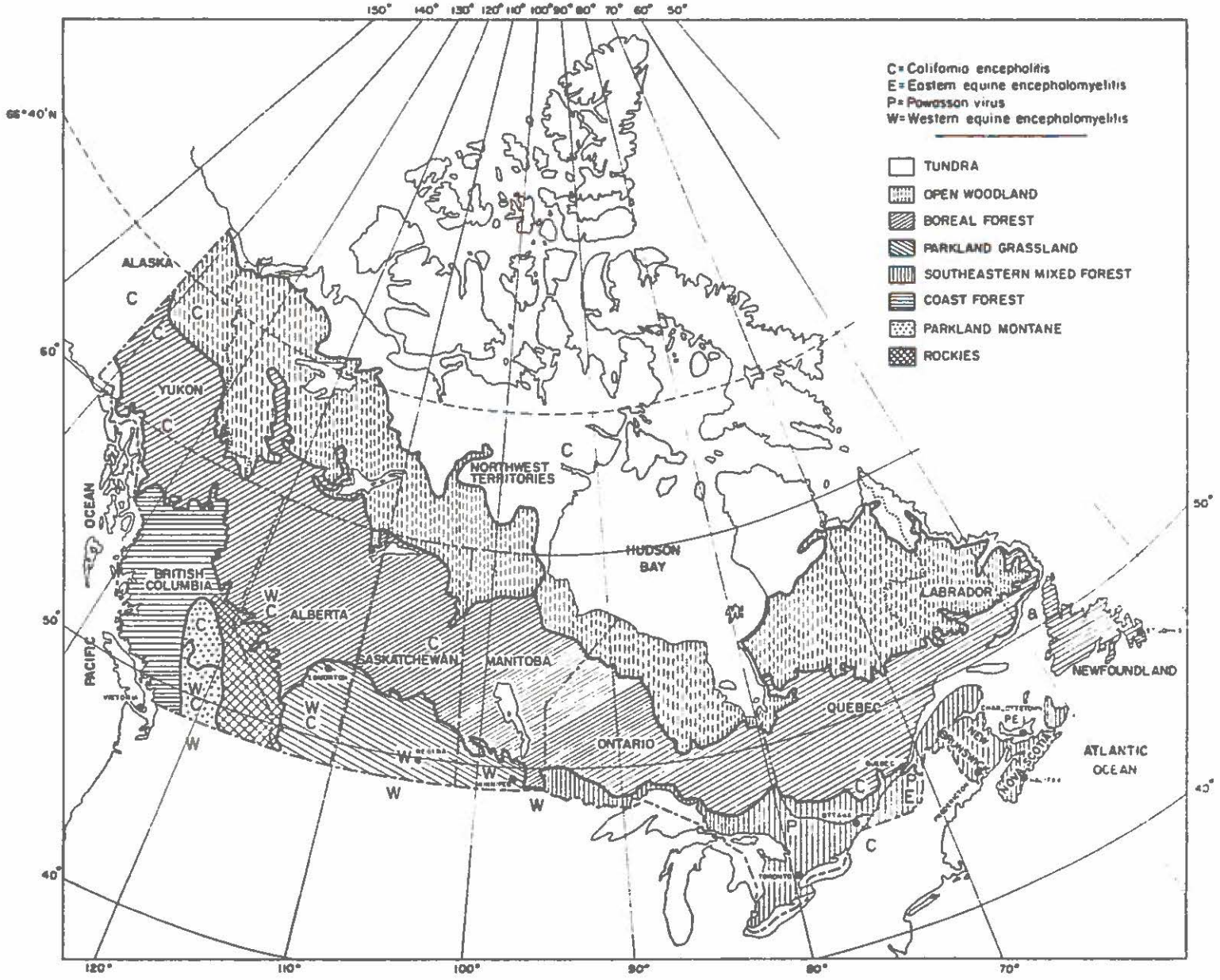

Table 1. Prevalence rates of arbovirus infections in Canadian provinces.

Province or Territory	Arbovirus serotype	Virus isolation rates			Antibody incidence	
		Vertebrate	Mosquito	Tick	Human	Vertebrate
British Columbia	California encephalitis 1969-1970		*Aedes canadensis* 1:1300 (a)†		subclinical 48:1936, 2.5% (c)	*Lepus americanus* 20:31, 64.5% (b)
						Marmota flaviventis 15:252, 6.0% (b)
						Citellus columbianus 1:146, 0.7% (b)
	1973		*Aedes fitchii* 1:8 (d)			
	Western equine encephalomyelitis	equine 2:60 (c)			clinical 3 subclinical 6:1936, 0.6% (c)	
	Colorado tick fever 1965-1966			*Dermacentor andersoni* 8:670 (e)	subclinical 2:1936, 0.1% (c)	
Yukon Territory	California encephalitis 1971-1974		*Aedes canadensis* 1:496 (f,g)			*Lepus americanus* 430:1076, 40% (f)
			Aedes cinereus 1:1179 (f)			*Citellus undulatus* 266:3610, 7% (f)
			Aedes communis 1:1765 (f)			
			Culiseta inornata 1:1778 (f)			

Table 1. (Cont'd)

Province or Territory	Arbovirus serotype	Virus isolation rates			Antibody incidence	
		Vertebrate	Mosquito	Tick	Human	Vertebrate
Alberta	California encephalitis 1964-1968	*Lepus americanus* 1 (j)	*Aedes communis* 1:2000 (h)		subclinical 51:160, 32% (c)	*Lepus americanus* 111:216, 52% (i)
		sentinel rabbits 3:36 (j)	*Aedes stimulans* 1:3032 (h)			sentinel rabbit 3:14, 21% (i)
	Bunyamwera group 1965		Mixed species 1:3500 approx. (k)			
	Silverwater 1965	*Lepus americanus* 2 (j)		*Haemaphysalis leporis-palustris* 15 (j)		*Lepus americanus* 0-68% (j)
	Turlock 1965		*Culiseta inornata* 1:3500 approx. (k)			
	Western equine* encephalomyelitis 1965		*Culex tarsalis* 1:3500 approx. (k)		subclinical 20:180, 11% (i)	*Lepus americanus* 44:232, 19% (i)
Saskatchewan	California encephalitis 1972		*Aedes cataphylla* 1:313 (1)			
			Aedes excrucians 1:201 (1)			
			Aedes fitchii 1:3072 (1)			
			Aedes punctor 1:238 (1)			

Table 1. (Cont'd)

Province or Territory	Arbovirus serotype	Virus isolation rates			Antibody incidence	
		Vertebrate	Mosquito	Tick	Human	Vertebrate
	Western equine* encephalomyelitis 1963-1965	birds 12:480 (n)	*Aedes campestris* 1:988 (m)		clinical 3 1963 (only) (n)	
		horses 47:279 (n)	*Aedes dorsalis* 1:766 (m)			
		(1963 only)	*Aedes flavescens* 1:3852 (m)			
			Aedes spencerii 1:2088 (m)			
			Aedes vexans 1:1477 (m)			
			Culex tarsalis 1:180 (m)			
			Culiseta inornata 1:2810 (m)			
	Cache Valley 1971		*Culiseta inornata* 1:4490 (o)			
	Flanders-Hart Park 1967		*Culex tarsalis* (p) *Aedes flavescens* (p)			
	St. Louis encephalitis 1971		*Culex tarsalis* 1:1004 (o)			

Table 1. (Cont'd)

Province or Territory	Arbovirus serotype	Virus isolation rates			Antibody incidence	
		Vertebrate	Mosquito	Tick	Human	Vertebrate
Manitoba	Western equine* encephalomyelitis 1941-1947	human fatality 8-41% (q)	*Culex tarsalis* (q)		subclinical 3-19% (q)	
Ontario	California encephalitis 1963, 1965	sentinel rabbits 5:9 (r)				sentinel rabbits 20:29, 69% (r)
						Lepus americanus 9:107, 8% (s)
	Powassan* 1958	human 1 (t)			subclinical 6:180, 3% (u)	
	1962			*Ixodes marxi* 1:14 pools (w)		
	1964-1966	*Marmota monax* 1:497 (v)		*Ixodes cookei* 1:15 pools (v)		*Marmota monax* 437:993, 44% (t)
						Tamiasciurus hudsonius 20:109, 18% (v)
	Silverwater 1960			*Haemaphysalis leporis-palustris* 1:24 (x)		*Lepus americanus* 19:211, 9% (x)
	1962			*Haemaphysalis leporis-palustris* 1:21 (w)		
	1963			*Haemaphysalis leporis-palustris* 1:57 pools (v)		*Lepus americanus* 21:107, 20% (s)

Table 1. Cont'd)

Province or Territory	Arbovirus serotype	Virus isolation rates: Vertebrate	Mosquito	Tick	Human	Antibody incidence: Vertebrate
Quebec	Eastern equine encephalomyelitis 1972	equine 5 (z)				equine 5:29, 17% (y)
	Powassan 1972				clinical 1 (z)	
Northwest Territories	California encephalitis 1973		*Aedes hexodontus* 4:4757 (aa)			*Lepus americanus* 8:29, 27% (bb)

* These viruses have been isolated from brains of fatal human cases in the stated Province.

† Legend to references.

(a) McLean *et al.* 1970
(b) McLean *et al.* 1971
(c) Kettyls *et al.* 1972
(d) McLean *et al.* 1974
(e) Hall *et al.* 1968b
(f) McLean *et al.* 1975a
(g) McLean *et al.* 1972
(h) Iversen *et al.* 1969
(i) Iversen *et al.* 1971
(j) Yuill *et al.* 1969
(k) Hall *et al.* 1968b
(l) Iversen *et al.* 1973
(m) McLintock *et al.* 1970
(n) Burton *et al.* 1966
(o) Burton *et al.* 1973
(p) Hall *et al.* 1969
(q) Adamson *et al.* 1950
(r) McKiel *et al.* 1966
(s) McLean *et al.* 1964
(t) McLean and Donohue 1959
(u) McLean *et al.* 1960
(v) McLean *et al.* 1967
(w) McLean *et al.* 1963
(x) McLean *et al.* 1961
(y) Bellavance *et al.* 1973
(z) Rossier *et al.* 1974
(aa) Wagner *et al.* 1975
(bb) Gaunt *et al.* 1974

encephalitis due to CE virus have been reported to date in Canada.

Clinical cases of encephalitis due to POWASSAN (POW) virus occurred in a child resident of Ontario in 1958, who subsequently died (McLean and Donohue 1959), and in a Quebec pediatric patient during 1972 who made a slow recovery (Rossier *et al.* 1974). In Ontario, 3% of human residents developed POW antibody in the absence of encephalitis (McLean *et al.* 1960).

COLORADO TICK FEVER (CTF) virus has shown a subclinical infection rate of 0.1% in British Columbia residents (Kettyls *et al.* 1972), but no virologically-confirmed clinical cases of fever due to this agent have yet been documented in Canada.

ST. LOUIS ENCEPHALITIS (SLE) virus has not yet been associated with clinical or subclinical infection in residents of Canada,[a] despite its continuing prevalence as a cause of encephalitis in human residents of southeastern, midwestern and western USA and its recent isolation from mosquitoes in Saskatchewan (Burton *et al.* 1973). Similarly, EASTERN EQUINE ENCEPHALOMYELITIS (EEE) virus has not yet been associated with human illness in Canada.

NON-HUMAN VERTEBRATES

Infections of non-human vertebrates with WEE virus occurred in British Columbia during 1971 when brains of two of 60 horses which were kept in the Thompson-Okanagan region (51°N), yielded WEE virus (Kettyls *et al.* 1972). In Alberta, 44 of 232 snowshoe hares collected at 54°N during 1965 had antibody (Iversen *et al.* 1971). In Saskatchewan during the summer of 1963, 47 of 279 horses with encephalitis died, and WEE virus was isolated from blood or tissues of 12 of 480 nestling wild birds of 20 species, principally those which frequent sloughs (Burton *et al.* 1966).

In the eastern townships of Quebec, during the summer of 1972, serological evidence of EEE virus infection was detected in five horses which developed encephalitis among 29 tested, and the brain of one fatal case yielded EEE virus (Bellavance *et al.* 1973).

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[a] See Addendum on page 30.

ARBOVIRUSES

CALIFORNIA ENCEPHALITIS virus infections have been demonstrated serologically in 20 of 31 snowshoe hares and 15 of 252 marmots (*Marmota flaviventris*) collected in British Columbia during 1970 near Penticton (49½°N, 120°W) (McLean *et al.* 1971). In 1971, between Williams Lake (52°N) and Prince George (54°N), 39 of 78 snowshoe hares (*Lepus americanus*) and 1 of 35 Columbian ground squirrels (*Citellus columbianus*) showed CE neutralizing antibodies (McLean *et al.* 1972). In the Yukon Territory, between latitudes 61 and 66°N, 430 of 1076 *L. americanus* and 266 of 3610 Arctic ground squirrels (*Citellus undulatus*) showed CE neutralizing antibodies between the summers of 1971 and 1974 (McLean *et al.* 1975a). Near Rochester, Alberta (54°N, 113°W), between 1964 and 1968, CE virus (snowshoe hare subtype) was isolated from the blood of one *L. americanus* plus 3 of 63 sentinel rabbits. CE antibodies were found in 111 of 216 wild-caught *L. americanus* and antibody conversions in 3 of 14 sentinel domestic rabbits (Yuill *et al.* 1969). Near Ottawa, Ontario (45°N, 76°W), during 1963 and 1965, CE virus was isolated from the blood of 5 of 9 sentinel rabbits, and another 20 of 29 sentinel rabbits showed CE antibody conversions (McKiel *et al.* 1966). In 1963, near North Bay, Ontario, (46°N, 79°W), sera from 9 of 107 *L. americanus* showed CE antibody (McLean *et al.* 1964).

POWASSAN virus was isolated from blood of 2 of 993 groundhogs (*Marmota monax*) collected near North Bay, Ontario, between 1964 and 1966, and POW neutralizing antibody was detected in 437 of 993 *M. monax* plus 20 of 109 red squirrels (*Tamiasciurus hudsonicus*) at the same location (McLean *et al.* 1967).

SILVERWATER (SIL) virus, which has not yet been incriminated as a human pathogen, was isolated from the blood of two *L. americanus* collected near Rochester, Alberta during 1965, and 0 to 68% *L. americanus* collected during each summer between 1964 and 1968 had antibody (Yuill *et al.* 1969). Near North Bay, Ontario, in 1963, sera from 21 of 107 *L. americanus* showed SIL complement fixing antibody (McLean *et al.* 1964), whilst on Manitoulin Island (46°N, 83°W), 19 of 211 *L. americanus* sera contained SIL antibody during the summers of 1960 and 1961 (McLean *et al.* 1961).

D.M. McLEAN

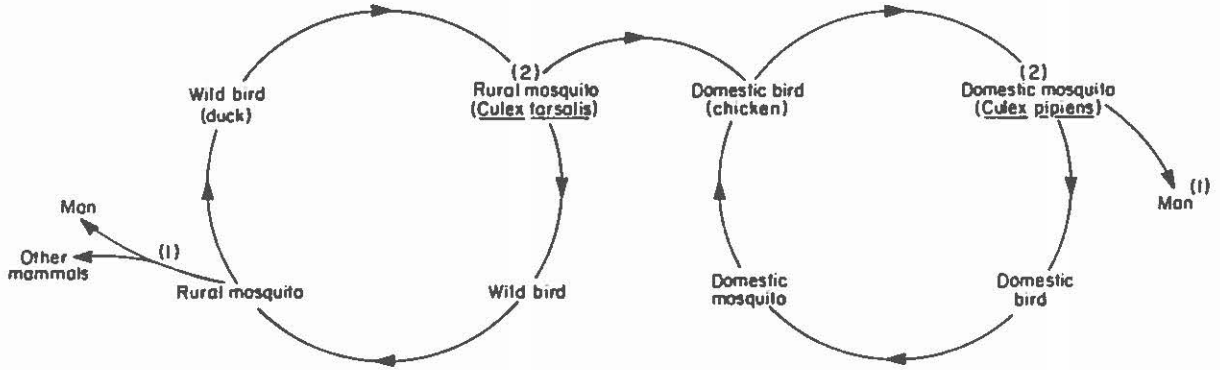
ARTHROPODS

(i) MOSQUITO VECTORS

The principal mosquito vector of WEE virus in the Prairie Provinces during successive summers has been *Culex tarsalis* (Fig. 2). In Saskatchewan, during 1963-1965, the minimum field infection rate (MFIR = number of pools of wild-caught mosquitoes which yielded virus, divided by the total number of wild-caught mosquitoes processed in pools for virus isolation) for *Culex tarsalis* was 1:180 (McLintock *et al.* 1970). This was substantially lower than the MFIR for five *Aedes* species which ranged from 1:766 for *A. dorsalis* to 1:3852 for *A. flavescens* and 1:2810 for *Culiseta inornata* (*ibid.*) (Fig. 3). The high MFIR for *Culex tarsalis*, the repeated virus isolations during successive summers, the readiness with which it feeds on both wild and domestic birds despite ingestion of earlier blood meals, its readiness to bite man, and the isolation of virus from wild-caught mosquitoes as early as 22 June until 15 August, both before and during the occurrence of human and horse cases of encephalitis, provide adequate criteria in support of its role as the principal natural vector species. *Culex tarsalis* was found as far north as 53°N (Burton and McLintock 1970), which was the northern limit of prevalence of cases of encephalitis. Although virus was isolated from *Culiseta inornata* less frequently, this species yielded virus between 20 and 24 September, which was the latest time of year at which virus-infected mosquitoes were collected. Both *Culex tarsalis* and *Culiseta inornata* overwinter as adults, thus providing a means by which mosquitoes infected during late summer may maintain virus until extensive activity of vertebrates and arthropods commences the following spring. There is no field or laboratory evidence of transovarial transfer of WEE to date. Low MFIR in *Aedes* mosquitoes, together with the relative infrequency with which they imbibe more than one vertebrate blood meal, render the role of these five species as natural vectors unlikely.

In Alberta and Manitoba, *Culex tarsalis* has been incriminated repeatedly as the principal vector of WEE virus. No details are available regarding WEE vectors in British Columbia.

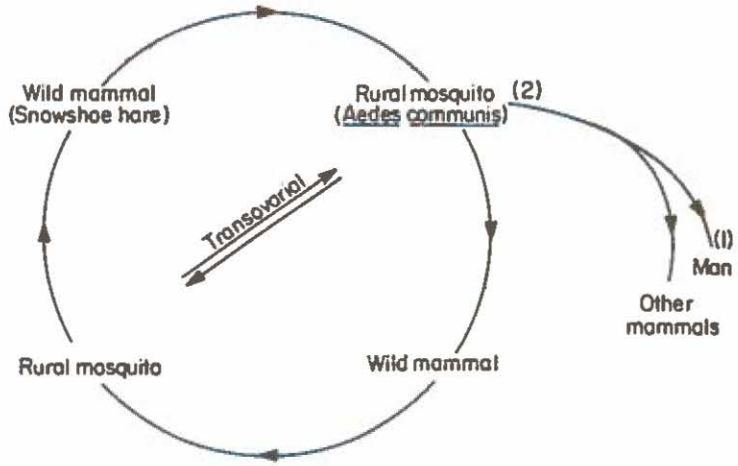
Figure 2



Bird-mosquito cycle
(e g. western equine encephalitis)

No evidence of transovarial transfer
Transmission of infection to man may be prevented by:
(1) repellants and protective clothing
(2) mosquito abatement (larval and adult)

Figure 3



Mammal-mosquito cycle
(e.g. California encephalitis)

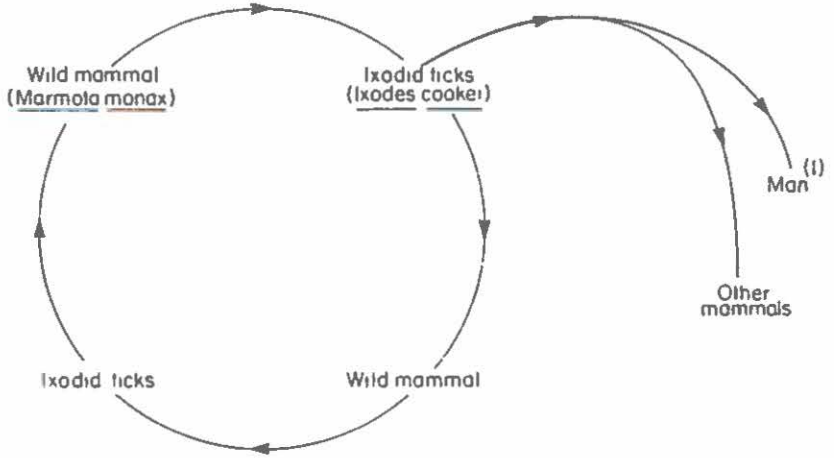
Transovarial transfer is indicated. Birds are insusceptible hosts
Transmission of infection to man may be prevented by:
(1) repellants and protective clothing
(2) mosquito abatement (larval and adult)

ARBOVIRUSES

The principal mosquito vectors of CE virus in the boreal forest regions of British Columbia (McLean *et al.* 1974), Alberta (Iversen *et al.* 1969), Saskatchewan (Iversen *et al.* 1973), the Yukon (McLean *et al.* 1975a) and the Northwest Territories (Wagner *et al.* 1975), comprise several species of *Aedes* and *Culiseta*. These mosquitoes also serve as vectors in irrigated farmlands of southcentral British Columbia (McLean *et al.* 1970) and southeastern Alberta (Morgante and Semanchuk 1967). *Aedes canadensis* and *A. communis* have shown the highest MFIR, and repeated isolations during successive summers point towards these species as principal vectors, although seven other *Aedes* species caught in nature have yielded virus (Rozdilsky *et al.* 1968) (Fig. 3). Virus replication has been demonstrated in salivary glands of *A. canadensis*, *cinereus*, *communis* and *hexodontus* following intrathoracic injection and incubation at 21° and 13°C (McLean *et al.* 1975a); *A. cinereus* transmitted virus by biting suckling mice 15 days after intrathoracic injection following incubation at 13°C (McLean *et al.* 1974). The isolation of CE virus from *Aedes* larvae collected at Kusawa Lake (61°N, 136°W), Yukon Territory, on 16 May 1974 before the springtime emergence of adult mosquitoes at that location (McLean *et al.* 1975a), strongly suggests that this agent has overwintered by transovarial transmission. *Culiseta inornata* showed MFIR comparable to those for *Aedes* mosquitoes in the Yukon. This species has transmitted CE virus 15 days after intrathoracic injection following incubation at 28°C (McLean *et al.* 1974); infectivity has been demonstrated in salivary glands of mosquitoes held continuously for 138 days at 0°C and from day 77 to day 194 at -1°C, following intrathoracic injection (McLean *et al.* 1975b). In the Yukon, *Culiseta inornata* emerges during early May, along with some *Aedes* species, and has been collected until mid-June, thus permitting ample opportunity for one or more blood meals from vertebrates. Daytime temperatures of 10 to 15°C would be sufficient to permit prompt viral replication in mosquito salivary glands, following which the virus could overwinter within the adult mosquitoes.

BUNYAMWERA GROUP viruses (CACHE VALLEY) have been isolated from *Aedes* mosquitoes of mixed species collected in central Alberta near Coronation (52°N, 111°W) during August 1965 (Hall *et al.* 1968a), when the MFIR was

Figure 4



Mammal-tick cycle
(e.g. Powassan virus)

No evidence of transovarial transfer
Transmission of infection to man may be prevented by:
(i) repellants and protective clothing

approximately 1:3500, and from *Culiseta inornata* collected near Weyburn, Saskatchewan (50°N, 105°W) during July 1971 (Burton *et al.* 1973). Both of these BUNYAMWERA GROUP isolates in Canada were achieved from mosquitoes at prairie locations where horses have contracted encephalitis due to WEE virus repeatedly during summer, but to date there is no evidence that encephalitis due to these viruses has affected human residents and horses. To date, these are the only two isolations of BUNYAMWERA GROUP viruses from mosquitoes in Canada but another BUNYAMWERA GROUP agent, NORTHWAY (NOR) virus, was isolated in June 1970 from *A. hexodontus* mosquitoes near Northway, Alaska (63°N, 142°W) (Calisher *et al.* 1974), where CE virus was also isolated from mosquitoes (Ritter and Feltz 1974). This is 150 miles southwest of Dawson City (64°N, 139°W), Y.T., where CE virus has been isolated from mosquitoes (McLean *et al.* 1975a).

TURLOCK virus was recovered from *Culiseta inornata* mosquitoes collected near Coronation, Alberta (52°N, 111°W) during August 1965 (Hall *et al.* 1968a). Both TURLOCK and mosquito-borne arboviruses of the FLANDERS-HART PARK group have also been recovered on several occasions from mosquitoes collected in southeastern Saskatchewan (J. McLintock, personal communication).

(ii) TICK VECTORS

COLORADO TICK FEVER virus has been recovered from 8 of 22 tick pools comprising 670 *Dermacentor andersoni* ticks which were collected in forested mountain terrain in southeastern British Columbia mainly near Salmo (49°N, 118°W) during the spring of 1965 and 1966 (Hall *et al.* 1968b). These comprise the northernmost isolations of CTF virus from *D. andersoni* in locations adjacent to their principal areas of prevalence in the States of Washington, Idaho and Montana.

Tick vectors of POWASSAN virus have been identified only in Ontario near North Bay (46°N) where 18 of 273 pools of *Ixodes cookei* collected between 1964 and 1966 (McLean *et al.* 1964) and 1 of 14 pools of *I. marxi* collected in 1962 (McLean and Larke 1963) (containing 1 to 9 ticks per pool) have yielded virus. These ticks feed

principally on marmots and squirrels respectively, but both species will bite man. Although *D. andersoni* ticks collected in southcentral British Columbia have not yielded POW virus, laboratory-infected larval and nymphal ticks have transferred virus transstadially, and hamsters and mice have been infected by bites of infected ticks (Chernesky and McLean 1969).

SILVERWATER virus was first recovered from 2 of 49 pools of *Haemaphysalis leporis-palustris* (HLP) ticks collected on Manitoulin Island, Ontario (46°N, 83°W) during the summer of 1960 (McLean *et al.* 1961). Near North Bay, Ontario (46°N, 79°W), this agent was recovered from a pool of HLP ticks collected during July 1962 among 24 pools tested between July 1959 and October 1962 (McLean and Larke 1963). During May 1963, one HLP tick pool collected in the same region yielded SIL virus, among 57 tick pools tested during the summer of 1963 (McLean *et al.* 1964). Subsequently, SIL virus was isolated from 15 pools of HLP ticks collected from snowshoe hares near Rochester, Alberta (54°N, 113°W) during the spring and summer of 1962 to 1965 (Yuill *et al.* 1969).

(iii) VEGETATION AND TERRAIN

Mosquito-borne arboviruses are distributed widely throughout the grassland and boreal forest regions west of the Great Lakes. In grassland regions of the Prairie Provinces, *Culex tarsalis* is an abundant summertime mosquito species. The increasing use of irrigation in agriculture promotes the buildup of mosquito populations, especially *Culex tarsalis*. This facilitates the natural transmission of several arboviruses, but favors particularly the prevalence of WEE virus (McLintock *et al.* 1970). The northern limit of distribution of *C. tarsalis* is 53°N in Saskatchewan (Burton and McLintock 1970), which corresponds both with the northerly extent of documented WEE infection in man and mosquitoes, and the northernmost fringe of prairie grassland. In the boreal forest, however, both near St. Walburg and in Prince Albert National Park (53°N), *Aedes* mosquitoes and *Culiseta inornata* predominate. These species are associated particularly with the transmission of CE virus, and during the summer of 1972, eight CE isolates were achieved from four *Aedes* species (Iversen *et al.*

1973). In Alberta, *Culex tarsalis* which was collected at the northern limit of grassland near Stettler (52°N) has yielded WEE virus (Hall *et al.* 1968a). In the boreal forest near Rochester (54°N), however, the mosquito population was composed predominantly of *Culiseta inornata* and several *Aedes* species, which have repeatedly yielded arboviruses of the CE group (Iversen *et al.* 1969).

In mountain forest regions of British Columbia, especially in the Okanagan and Shushwap valleys where fruit is grown extensively, large populations of *Aedes* mosquitoes have built up during early summer of each year. Extensive mosquito abatement procedures which relied upon DDT and organophosphates, until banned during the summer of 1971, reduced mosquito populations to negligible numbers by mid-July, thus eliminating opportunities for natural transmission of arboviruses. Prevalence of CE virus was first established positively in the south Okanagan region during June 1969 by the isolation of CE virus from wild-caught *A. canadensis* (McLean *et al.* 1970). During the summer of 1971, recovery of WEE virus from the brain of a horse which developed encephalitis near Salmon Arm, plus diagnostically significant WEE antibody increments in three human residents of, or visitors to, the Shushwap and Okanagan valleys who developed encephalitis (Kettyls *et al.* 1972), confirmed the long-suspected prevalence of this arbovirus in southeastern British Columbia.

In montane and subalpine forest regions of central British Columbia, the endemic prevalence of CE virus was firmly established in July 1973 by the isolation of CE virus from *A. fitchii* mosquitoes collected near Williams Lake (52°N) (McLean *et al.* 1974). Serological evidence of infection of small rodents has revealed infection with this agent from this point northward into boreal forest regions of northeastern British Columbia and the Yukon Territory (McLean *et al.* 1971, 1975a).

The boreal forest covers virtually all of the Yukon Territory south of the Arctic Circle. Repeated isolations of CE virus from *Aedes* mosquitoes and *Culiseta inornata* in or adjacent to forest habitats between 60 and 66°N during the summers of 1971 through 1974 (McLean *et al.* 1975a) suggest its endemic prevalence throughout the entire boreal forest region of the Yukon.

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In the tundra region of the Northwest Territories near Rankin Inlet (63°N, 92°W), the prevalence of CE virus was clearly demonstrated in July 1973 by its isolation from *A. hexodontus* mosquitoes (Wagner *et al.* 1975), a species typical of boreal forest and tundra regions.

Although the boreal forest extends eastward to the province of Newfoundland and Labrador, insufficient studies have been undertaken east of Saskatchewan to determine whether or not arboviruses are prevalent in this vegetation zone.

In southeastern mixed forest regions of Ontario, endemic foci of mosquito-borne CE virus activity have been identified at three locations at latitudes 45 to 46°N: Monitoulin Island (McLean *et al.* 1961), North Bay (McLean *et al.* 1964) and near Ottawa (McKiel *et al.* 1966). In each location, *Aedes* comprises the dominant mosquito genus within the mosquito population. Although to date no isolations of CE virus have been achieved in this vegetation zone east of Ottawa, another mosquito-borne agent, EEE virus, was identified for the first time in September 1972 as the etiological agent in an epizootic of encephalitis which affected horses in the eastern townships of Quebec (Bellavance *et al.* 1973).

In the southeastern mixed forest zone, foci of activity of two tick-borne arboviruses have also been identified. POWASSAN virus has been isolated from a human patient, pools both of *Ixodes cookei* and *Ixodes marxi* ticks and the blood of groundhogs (*Marmota monax*), near North Bay (McLean and Donohue 1959; McLean *et al.* 1967; McLean and Larke 1963). Serological evidence of infection of a human patient was detected southeast of Montreal (Rossier *et al.* 1974). SILVERWATER virus foci were identified by virus isolation from *Haemaphysalis leporis-palustris* ticks collected on Manitoulin Island (McLean *et al.* 1961) and near North Bay (McLean *et al.* 1964).

ARBOVIRUSES

GAPS IN KNOWLEDGE

1. Although the prevalence of mosquito-borne CE virus has been establish clearly in the boreal forest zone of the Yukon Territory, British Columbia, Alberta, and Saskatchewan, an urgent need is to determine and map its prevalence throughout the open woodland vegetation zone along the Mackenzie Valley, immediately east of the border between the Yukon and the Northwest Territories. This need has become imminent through the immediate prospect of location of several thousand workers in primitive rural campsites during construction of the proposed Mackenzie Valley pipeline, highway, and other services. Under these circumstances, a substantial human population will become exposed simultaneously to mosquito bites throughout May, June, and July of each year. Whilst the possibility of development of encephalitis in man following bites by infective mosquitoes is estimated at 1:200 to 1:500, two to five cases could be expected among every 1000 persons located in an endemic focus.

An equally urgent requirement is to define the prevalence of CE virus in open woodland and tundra regions near Inuvik and other coastal settlements on the Arctic Ocean on account of: (i) extensive oil drilling operations in Arctic Ocean coastal districts, and (ii) the isolation of CE virus along the Arctic seacoast at Beaufort Lagoon, Alaska, about 200 miles west of Inuvik.

2. Although CE virus was recovered from mosquitoes collected on the tundra near Rankin Inlet, N.W.T., there is a complete absence of information regarding possible arbovirus prevalence throughout tundra and transitional zones of the eastern Arctic.

3. Arbovirus prevalence has not yet been established in boreal forest and southeastern mixed forest zones of Quebec, Newfoundland and Labrador, Nova Scotia, New Brunswick, and Prince Edward Island. Preliminary serological evidence has suggested the prevalence of CE virus in Nova Scotia.

4. Intensive field investigations are required in the eastern townships of Quebec to determine quantitative host-vector relationships in foci of activity of mosquito-borne EEE and tick-borne POW viruses.

5. Quantitative relationships must be determined between the incidence of infection in mosquito larvae, adult mosquitoes and animal reservoirs for CE virus in the Yukon Territory. With the decline of incidence of usual wild vertebrate hosts during 1975, it is essential to investigate whether transovarial transfer of this virus will alone ensure a sufficiently high proportion of infected mosquitoes in successive summers to maintain foci of natural infection without fresh introduction of virus into the mosquito populations by imbibing viremic blood of infected vertebrates before ovulation each summer. In Wisconsin, the serologically related CE group agent, LA CROSSE virus, has infected about 5% of emergent *A. triseriatus* adults derived from parent mosquitoes which imbibed infective blood 9 months earlier (Watts *et al.* 1974).

6. Despite some 30 years of intensive investigation of the prevalence of WEE virus in mosquitoes, vertebrate reservoirs and human inhabitants of prairie portions of Saskatchewan, including the provision of good laboratory diagnostic facilities for clinical infections in man, new epidemiological investigations are required whenever new tracts of prairie are converted from dry-farming to irrigation.

7. The influence of temperatures approaching 0°C on the replication of CE, NOR, WEE and EEE virus in natural vector species such as wild-caught *Aedes* spp. and *Culiseta* spp. from various vegetation zones in Canada has only commenced to be investigated for CE and NOR viruses, and no data exist for WEE and EEE viruses. Such knowledge may improve our ability to predict outbreaks of mosquito-borne diseases and to prevent them.

ARBOVIRUSES

SUMMARY

Quantitative data have been assembled on the prevalence of five mosquito-borne arboviruses in Canada, including two ALPHAVIRUSES, EASTERN (EEE) and WESTERN (WEE) EQUINE ENCEPHALOMYELITIS, one FLAVIVIRUS, ST. LOUIS ENCEPHALITIS (SLE), and two BUNYAVIRUSES, the SNOWSHOE HARE (SSH) subtype of CALIFORNIA ENCEPHALITIS (CE), and a CACHE VALLEY-like agent. All of these, with the possible exception of the CACHE VALLEY agent, have induced encephalitis in man. Data have also been assembled for two human pathogenic tick-borne arboviruses, a FLAVIVIRUS, POWASSAN (POW), and an ungrouped agent, COLORADO TICK FEVER (CTF). Minimum field infection rates of arboviruses in mosquitoes, plus virus isolation rates and/or antibody prevalence rates in humans and mammalian or avian reservoirs, have been tabulated. Correlations have been developed between foci of arbovirus activity and the several vegetation zones of Canada. Gaps in knowledge of the potential hazards of arboviruses under Canadian conditions of climate, vegetation zones, and human settlement, have been identified; in particular: (i) there are vast regions where evidence of arbovirus activity has not yet been sought; and (ii) little is known about the effects of atmospheric temperature and transovarial transfer rates on the maintenance and spread of arboviruses in regions of demonstrated arbovirus endemicity.

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ADDENDUM

HUMAN INFECTIONS WITH SLE AND WEE VIRUSES DURING THE SUMMER OF 1975

During the summer of 1975, clinically-manifest human infections with SLE virus were encountered for the first time in Canada. By 6 October, 44 of 191 human residents of southwestern Ontario who developed meningoencephalitis had serological evidence of SLE infection (Canada Diseases Weekly Report 1: 92, 1975).

In Manitoba, 4 human residents who developed encephalitis during August 1975 had laboratory evidence of WEE virus infection. Horses were also affected, sentinel chickens showed rising WEE antibody titers, and WEE virus was isolated from *Culex tarsalis* mosquitoes following a substantial population build-up. Following commencement of extensive mosquito abatement programs in Winnipeg and environs on 15 August, the *C. tarsalis* population declined, and no further human cases of WEE infection were reported in the area. In Saskatchewan, although no human cases of WEE virus infection have been reported, several horse deaths have been attributed to this virus, and WEE virus has been isolated from *C. tarsalis* (Canada Diseases Weekly Report 1: 89, 1975).

In the United States up to 30 September 1975, a total of 541 laboratory-confirmed cases of SLE virus infection had been reported from 19 States and the District of Columbia, with the highest incidence reported in Illinois, Indiana, Ohio and Mississippi (Morbidity and Mortality Weekly Report 24: 339, 1975). To 2 September, 82 human cases of encephalitis had been reported in Minnesota and North Dakota, and 9 had serological evidence of current WEE virus infection (*ibid.* 24: 295, 1975). Thus, throughout the Mississippi River drainage basin extending northwards into southwestern Ontario, SLE virus prevalence has been high during the summer of 1975, whilst in the Red River basin extending northwards into the prairie portion of Manitoba, WEE virus has been widely prevalent.

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