BIOLOGY OF THE WESTERN BLACK-LEGGED TICK, *IXODES PACIFICUS*, **(COOLEY AND KOHLS, 1943)**: A POTENTIAL VECTOR OF LYME DISEASE IN SOUTH COASTAL BRITISH COLUMBIA.

by

Carl S. Arnason

B.Sc., University of Lethbridge, 1988

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF PEST MANAGEMENT
in the Department
of
Biological Sciences

SIMON FRASER UNIVERSITY
NOVEMBER 1992

APPROVAL

Name: **CARL STEFAN ARNASON**

Degree: **Master of Pest Management**

Title of Thesis:

BIOLOGY OF THE WESTERN BLACK-LEGGED TICK, *IXODES PACIFICUS*
(COOLEY AND KOHLS, 1943): A POTENTIAL VECTOR OF LYME DISEASE IN
SOUTH COASTAL BRITISH COLUMBIA

Examining Committee:

Chair: Dr. R.C. Ydenberg, Associate Professor

Dr. P. Belton, Associate Professor, Senior Supervisor,
Department of Biological Sciences, SFU

Dr. A.S. Harestad, Associate Professor,
Department of Biological Sciences, SFU

Mr. H.G. Philip, Regional Entomologist,
B.C. Ministry of Agriculture, Fisheries and Food,
Kelowna, B.C.
Public Examiner

Date Approved 1992 11 16

Title of Thesis/Project/Extended Essay

Biology of the western black-legged tick, Ixodes pacificus, (Cooley and Kohls, 1943): A Potential vector of Lyme Disease in South COASTAL British Columbia.

Author:

(signature)

CARL S. ARNASON

(name)

NOVEMBER 19 / 1992

(date)

Abstract

The western black-legged tick, *Ixodes pacificus* (Cooley and Kohls, 1943), is a known vector of the Lyme disease spirochete, ***Borrelia burgdorferi***, in California. Very little is known of the biology of this tick in British Columbia and nothing of its ability to vector the spirochete. This research investigates the distribution of subadult, (larval and nymphal), and adult stadia of the tick and the host preference of the subadult stadia. Field surveys for adult *Ixodes pacificus* were conducted during March and April of 1990, and the first eight months of 1991. Adults were collected by brushing the vegetation with a square of cloth and fieldsites classified by British Columbia Ministry of Forests standards into a biogeoclimatic zone and ecosystem. The hosts selected by subadults were determined by trapping small mammal hosts and hand collecting northern alligator lizards from West Vancouver and Nanoose Bay fieldsites during 1991.

No adults were collected in 1990. Two hundred and fourteen male and 202 female adult ticks were collected from four fieldsites during January through July 1991, with peak numbers occurring in the month of May. The preferred habitat for all stadia of *Ixodes pacificus* was the xeric ecosystem of the Coastal Douglas Fir Zone. Significantly more nymphs and larvae per host were found on lizards than on deer mice. Deer mice were the commonest of eight species of small mammal host (264/323), and significantly more larvae than nymphs were collected from them in most months.

None of the 189 adult ticks submitted to the B.C. Ministry of Health was positive for Lyme disease, although deer mice, evidently the reservoir for the disease in California, are common hosts of the immature stages of the tick in British Columbia. It seems likely that because there are so few cases of the disease confirmed in the province, the causal spirochete is not yet present.

Acknowledgements

I would like to thank Dr. S. Bannerjee of the British Columbia Center for Disease Control for culturing tick isolates. I would also like to thank Mrs. D. Kindree of the Vancouver B.C. Lyme Borreliosis Society for her assistance in locating tick "hotspots". Finally, I would like to especially thank Mr. John Gregson, without whose earlier work this study would not have been possible.

This work was partially funded by a contract with the B.C. Ministry of Health. All mammal and reptile species were collected under B.C. Ministry of Environment permit # CO43883.

Table of Contents

Page

List of Tables **Page**

List of Figures   Page

Introduction

The Canadian Medical Association Journal (Anon., 1991) reports that 11 cases of Lyme disease were identified in British Columbia during 1989 - 1990. These cases, combined with another 84 cases reported in Ontario and Manitoba, were the first accounts of the appearance of this disease in Canada. Lyme disease, which has reached epidemic proportions in the United States during the last 10 years, had caused widespread unease in Canada mostly because of lack of knowledge of its presence in nature and the biology of its tick vectors.

Reports of Lyme disease have spread rapidly across the United States since it was discovered there in 1977. In 1989, some 7400 new cases were reported (Anon., 1990). A western focus for this disease has been identified in California, where the vector tick was identified as *Ixodes pacificus*. Studies by Gregson (1935) of the ticks of British Columbia indicated that *Ixodes pacificus* was a prevalent tick species in south coastal British Columbia. Although this tick was notorious for inflicting painful bites on man, because it had never been associated with the transmission of any zoonosis to man or livestock there is only rudimentary information about its distribution and life cycle in British Columbia.

In California, the cycling and occurrence of Lyme disease has led to a discovery of the importance of the tick's life cycle and host selection in this zoonosis. However, there are still some questions about how closely the life cycle of *Ixodes pacificus* at the northern end of its range corresponds with that in California. Specifically, the availability of hosts for immature stages of the tick may be very different in British Columbia.

The Ixodida

All ticks are members of the subclass Acari and the order Parasitiformes. Previously classified as the order Metastigmata and the suborder Ixodides, acarological systematics now place ticks in the suborder Ixodida with a single superfamily, the Ixodoidea (Krantz, 1978). Ticks, with approximately 800 species described worldwide, have the interstadial heteromorphy (hexapod larva, octopod nymph, octopod adult) typical of other Acari (Krantz, 1978). Adults of this group resemble other arachnids in that they have six pairs of appendages, including a pair of chelicerae, a pair of sensory palps, and four pairs of legs. They differ from other arachnids by the development of a discrete head structure, the capitulum, a necessity as they are the only suborder that are entirely ectoparasitic. A hypostome armed with retrorse teeth is a part of the capitulum, and is used to anchor the tick to its host (Krantz, 1978). Larval ticks are, like other acarines, hexapod. Three families belong to this suborder: the Argasidae, the Ixodidae, and the Nuttalliellidae.

The Argasidae or soft ticks are a relatively small group of 140 species in five genera (Krantz, 1978). Soft ticks are identified by a ventral capitulum entirely hidden from the top, and the absence of an evident scutum. Argasids mostly inhabit nests, caves, or burrows (Cooley and Kohls, 1945). These ticks feed rapidly, from 2 minutes to 2 hours, often on a single host (Krantz, 1978). Argasid ticks are often found in arid tropical or semitropical regions, and have adapted to long-term survival in the absence of their hosts. Some argasid species are known to live without food for up to ten years (Balashov, 1972).

The Ixodidae or hard ticks are identified by the scutum on the dorsal side through all life stages, and the anterior capitulum which is visible from above. The hard ticks number approximately 650 species that fall into 13 genera (Krantz, 1978). Ixodids are generally three host ticks, attaching to a different host for each active life stages: larva, single nymph, and adult. A smaller number of ixodids are one or two host ticks.

Nymphal hard ticks closely resemble adult females in that they both have an abbreviated podonotal scutum which allows for idiosomal expansion during feeding (Krantz, 1978). Adult male ixodids have a scutum over their dorsal surface, resulting in a inability to engorge while feeding. Ixodida attach to hosts by piercing the skin with the chelicerae, and anchoring to the site by inserting the hypostome into the wound (Arthur, 1957). Ixodid males feed slowly and in small amounts. For many nest and burrow inhabiting species, males have not been recovered from the host and may either not feed or feed parasitically from engorged females (Krantz, 1978). Ixodid females feed slowly, often requiring a few days to a week in order to engorge. Gender dimorphism usually does not appear until transition from the nymph to adult stadia has occurred.

The Nuttalliellidae are known by a single, geographically isolated species, *Nuttalliella namaqua*, with characteristics of both soft and hard ticks (Krantz, 1978). This tick is found in south and south-west Africa and may be a parasite of either small mammals or birds.

Ticks vectoring Lyme disease are members of the genus *Ixodes*, and the family Ixodidae. These ticks, the hard ticks, have had a long association with humans. Although in all cases, man serves only as a incidental host for such ticks, our knowledge of their existence goes back a long time. Egyptian papyri, dated 1550 B.C., relate the occurrence of a disease associated with tick bite, a "tick fever" (Obenchain and Galun, 1982). Homer mentioned the occurrence of ticks on Ulysses' dog in 850 B.C., and Greek and Roman scholars mentioned the difficulties caused by ticks to livestock (Hoogstraal, 1970). In both of these cases, the tick species was probably *Ixodes ricinus*, the European vector of Lyme disease and the nominal species of the several that can vector *Borrelia* and *Babesia* pathogens, the *Ixodes ricinus* complex.

The role of hard ticks in vectoring disease to man and his livestock was not known until 1893 when the cattle tick *Boophilus microplus* was implicated in the transmission of Texas cattle fever (Arthur, 1961). Since that seminal discovery, hard ticks have been implicated in the transmission of disease-causing protozoa, rickettsias, and spirochetes. Diseases vectored by ticks that infect man are almost exclusively zoonotic infections. The World Health Organization defines zoonoses as "those diseases and infections which are naturally transmitted between vertebrate animals and man" (WHO, 1967). In the case of Lyme disease, it has recently become apparent that this is a classical zoonosis, in which the spirochete cycles between wild hosts (eg. small mammals) with only incidental involvement of humans.

Lyme Disease

First described in 1977, Lyme disease was recognized because of an unusual clustering of children around the town of Lyme, Connecticut with symptoms similar to those of juvenile rheumatoid arthritis (Steere *et al.*, 1977). Epidemiological studies linked the symptom of erythema migrans, a spreading circular rash, with the bite of some type of arthropod vector, and also linked the North American syndrome with an already recognized complex of conditions known in Europe. These studies determined that the bites of certain species of ixodid ticks were always associated with those symptoms.

The condition first recognized in Europe, erythema migrans or erythema chronicum migrans, was described in 1909 and was initially linked to a tick bite (Afzelius, 1921). It was described in both Sweden and Austria and it was later recognized that other conditions could be associated with the appearance of erythema migrans. A chronic skin condition, acrodermatitis chronica atrophicans, developed after the disappearance of erythema migrans (Steere, 1989). Bannwarth, in the 1940's, described a condition called tick-borne meningopolyneuritis which followed the appearance of erythema migrans. In 1948, Lennhoff described spirochete like structures in skin sections of erythema migrans lesions. As a result, antibiotics were first prescribed for treatment of this problem (Steere, 1989).

That a single type of spirochete was the cause of these disparate conditions was finally determined after the 1982 discovery of *Borrelia burgdorferi* in the midgut diverticula of *Ixodes dammini* ticks in the United States (Burgdorfer *et al.*, 1982). Spirochetes of the same type were later found in European patients who had erythema migrans and Bannwarth's syndrome. Although certain regional differences exist among the spirochetes, the syndrome is now considered to be closely similar or even identical across its North American and European range (Steere, 1989).

Pathogenesis

Lyme disease generally occurs in progressive stages, beginning with localized erythema migrans. Disseminated infection occurs within days or weeks, and intermittent symptoms arise from weeks to months after infection. Persistent infection arises about a year after the onset of the disease, although patients may not display symptoms for all stages (Ashbrink and Hovmark, 1988).

Localized Erythema Migrans

After its transmission by tick bite, *B. burgdorferi* spreads locally through the skin of 60 to 80 percent of those infected. This spread results in erythema migrans, the localized red swelling in a fairly consistent bull's eye pattern centered at the location of the tick bite. Frequently at this stage, the spirochete causes little or no heightened immune response (Steere, 1989). Even if left untreated, the erythema migrans lesions generally disappear in 3 to 4 weeks, although some may persist and others may recur.

Disseminated Infection

From the skin, spirochetes will enter the blood and lymph circulatory systems and spread throughout the body. This may occur in days or weeks. The spirochete probably spreads to most major organs of the body, before it gradually becomes restricted to the reservoir sites. Typically, this stage of the disease is most associated with symptoms occurring in the skin, the nervous system and the musculoskeletal system (Steere *et al.*, 1983).

The most pronounced symptom of this stage is the migratory musculoskeletal pain which induces chronic malaise or fatigue in many patients (Steere *et al.*, 1983). The pain is usually centered in joints, muscle, bone, tendons and bursae. These pains are usually intermittent, lasting for hours or days only to disappear and then occur at a different location. For reasons not yet understood, the development of these migrating pains and the attendant fatigue syndrome is most commonly associated with the North American strain of *B. burgdorferi* (Steere, 1989).

After a few weeks of spread throughout the circulatory system, the spirochetes sequester themselves in a few immunocompromised reservoir sites (Steere, 1989). Once this has occurred, many patients suffer neurological involvement including facial palsy and meningitis (Pachner and Steere, 1985). In a few cases demyelination of nerve segments occurs as a result of infection (Duray and Steere, 1988).

A few patients suffer cardiovascular distress once the disease has begun. This period lasts only for a few weeks but has in a few cases resulted in fatality (Marcus *et al.*, 1985). As well, about 60% of North American patients develop brief attacks of a asymmetric, oligoarticular arthritis, most often in the knee (Steere, 1989).

Persistent Infection

After one to two years of infection, longer episodes of arthritis begin to occur (Steere, 1989). These episodes may last for months, and in some cases, the condition may become chronic in which the joint undergoes continual inflammation for over a year (Steere *et al.*, 1987). In some cases, the spirochetes have been recovered from cultures of the joint fluid (Schmidli *et al.*, 1988). Severe cases of this condition have been known to cause destruction of the bone and cartilage of the involved sites. In rare cases, permanent damage and disability may occur (Steere *et al.*, 1987). As the condition ages in patients from year to year, the number who suffer recurrent arthritis decreases. As well, the occurrence of Lyme arthritis is far less common in Europe than in North America, although the manifestation of the condition is the same (Steere, 1989).

In Europe, the most common latent symptom of infection by *B. burgdorferi* is the development of the skin condition acrodermatitis chronica atrophicans (Ashbrink and Hovmark, 1988). This persistent skin lesion may last for years or possibly decades, resulting eventually in the atrophy of the skin.

Causal Agent

Borrelia burgdorferi is a member of the eubacterial phylum of the spirochetes (Barbour and Hayes, 1986). Structural investigation of *B. burgdorferi* has shown that it has the characteristic structure of a protoplasmic cylinder surrounded by a cell membrane. Flagella extrude from this membrane and coil around the spirochete. Around all of this is a secondary membrane or sheath which has only a loose association with the structures it covers. Spirochetes of *B. burgdorferi* are 20 to 30 μm long and 0.2 to 0.3 μm wide (Burgdorfer *et al.*, 1982, Hovind-Hougen *et al.*, 1986). They have 7 to 11 flagella, and have a less coiled appearance than other members of the genus (Barbour and Hayes, 1986).

This species has been cultured in Barbour-Stoenner-Kelly (BSK) II media at 33 °C (Barbour, 1984). The borrelia grow slowly, dividing only once every 12 to 24 hours (Barbour, 1984). Primary isolates can easily be obtained from infected ticks, but successful culturing of the spirochete from infected patients is rare (Steere *et al.*, 1983). Once cultured, *B. burgdorferi* loses its pathogenicity after about 15 passes (Schwan *et al.*, 1988).

Comparison of isolates from North America and Europe show great variation between the populations. European isolates show a greater variation in morphology and protein composition (Steere, 1989). Experimental inoculation of hamsters with a strain of *B. burgdorferi* from New England conferred immunological protection against other eastern North American isolates, but not against West Coast or European strains (Johnson *et al.*, 1985). Steere (1989) suggests that this diversity may well explain the different clinical symptoms observed in different geographical regions. Although there are several different strains or races of this spirochete, a universal classification system has not been agreed upon.

Burgdorfer *et al.* (1983) suggested four possible routes for infection by an ixodid tick. Ticks could salivate the infecting organism into a bite wound, or regurgitate stomach contents into the wound. As well, ticks frequently defecate onto the host while feeding, and are often crushed near the wound by grooming hosts. Ribiero *et al.* (1987) found that in unfed adult *I. dammini* infected with *B. burgdorferi*, the spirochetes were mainly in the midgut. Once these ticks attached to their host, the spirochetes penetrated the midgut epithelium and quickly spread throughout the tick's hemolymph. This often occurred within 1 day of attachment. After three days, Ribiero *et al.*, (1987) found spirochetes in the saliva. Zung *et al.* (1989) demonstrated that *B. burgdorferi* penetrated the salivary glands from the hemolymph as a part of its generalized spread throughout the tick. They claimed that only those spirochetes that entered the salivary gland could later enter the new host.

Tick Vectors of Lyme Disease

The discovery of *Borrelia burgdorferi* in the midgut diverticula of the hard tick *Ixodes dammini* was only the second known case of a member of the Ixodidae being associated as vector of a spirochete (Burgdorfer *et al.*,1989). It now appears that this spirochete can be vectored by several species of the *Ixodes ricinus* complex. This complex is a group of morphologically similar yet geographically distinct ixodid species widely distributed across the northern temperate regions of the world. The three member species that are definite vectors of this disease to humans are: *Ixodes ricinus* in Europe, *Ixodes dammini* in north-east and north-central North America, and *Ixodes pacificus* on the Pacific Coast of North America (Fig. 1).

Europe

In the 1909 description of erythema chronicum migrans by Afzelius (1921), the condition only developed after a tick bite. It now appears that this tick was *Ixodes ricinus*, commonly called the castor bean or sheep tick. Early investigators focussed on the possibility that during biting, this tick transmitted toxins, viruses, or rickettsiae. In 1948, Lemmhoff suggested that *Ixodes ricinus* may be a carrier of spirochetes which could induce the erythema condition (Burgdorfer, 1984). This was not followed up, and live spirochetes of *B. burgdorferi* were not discovered in the midgut of *I. ricinus* until 1982 (Lane *et al.*, 1991).

Ixodes ricinus is the commonest tick in Europe. It is widely distributed, from Ireland in the west to the Eurasian plains in Northern Iran, from southern Scandinavia to the Mediterranean Coast of Europe (Lane *et al.*, 1991). Occasional collections of *I. ricinus* have also occurred in North Africa, where they are apparently carried by migrating birds. The ideal biotype for this tick has been described as deciduous forest with dense undergrowth and damp soil.

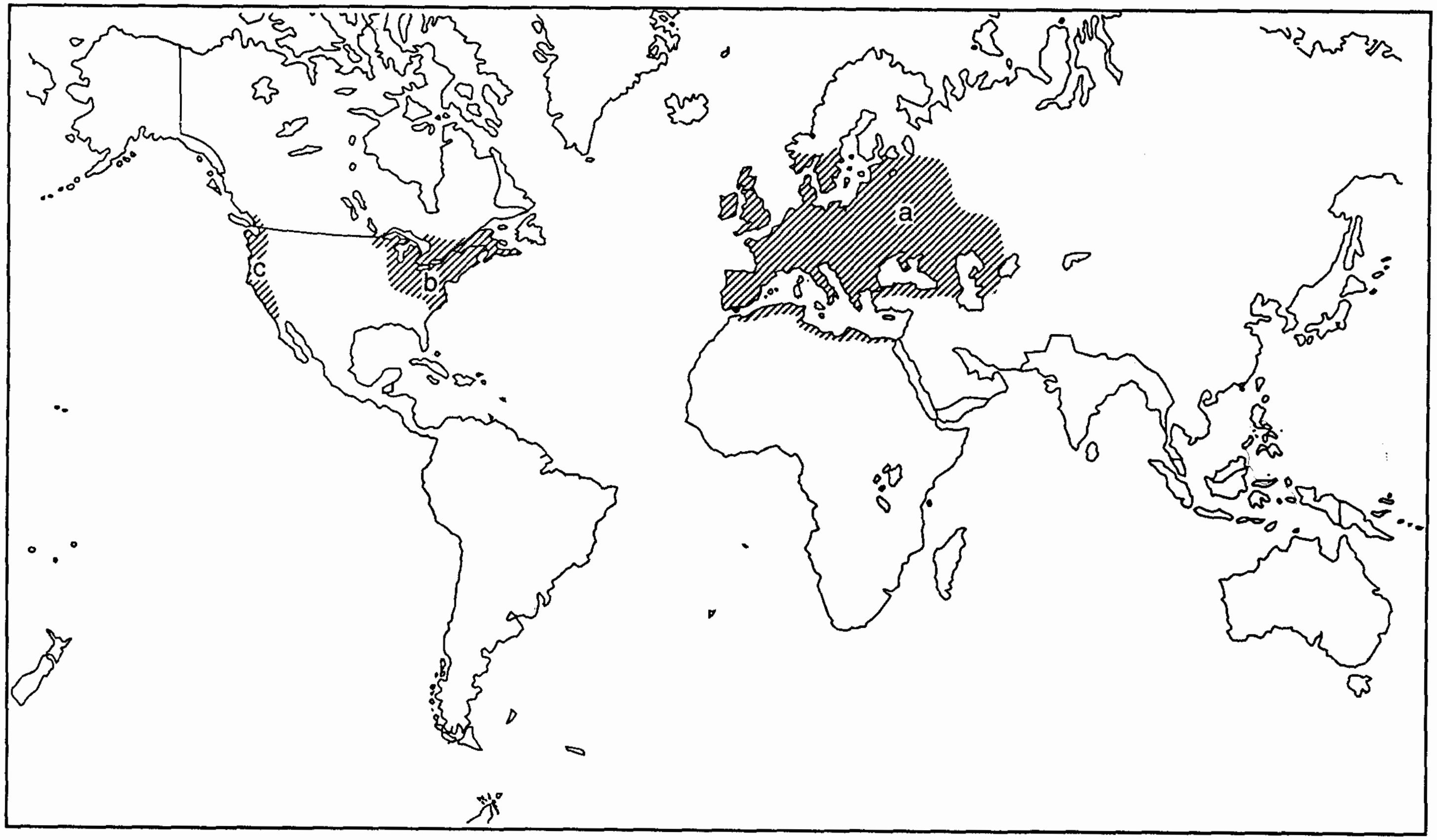

Figure 1. Known distribution of the member species for the *Ixodes ricinus*-species complex:(a) *Ixodes ricinus*, (b) *Ixodes dammini*, (c) *Ixodes pacificus* .

Ixodes ricinus is an indiscriminate feeder; attacking birds, reptiles, and both small and large mammals (Lane *et al.*, 1991). Small rodent species, particularly *Apodemus* spp. and *Clethrionomys* spp., are important hosts for immature stages of *I. ricinus*. In areas where lizards are abundant, they are heavily parasitized. The adult stage of *Ixodes ricinus* attacks large mammals, the preferred hosts.

Ixodes ricinus does not have a coherent seasonality to its life stages. All stages of the tick occur together throughout most of the season, beginning in March or April and disappearing by November. Adult and nymphal activity starts about one month before larval activity. The activity of all stages is minimal during mid-summer. Bimodal activity patterns are therefore expressed in south-central Europe while north-central Europe may show continuous activity (Matuschka and Spielman, 1986).

Eastern North America

The Lyme disease vector in eastern North America is *Ixodes dammini* (Spielman *et al.*,1979). It was in this tick that Burgdorfer discovered the causal spirochete of the Lyme disease syndrome, *Borrelia burgdorferi* (Burgdorfer *et al.*,1982). The geographical range of *I. dammini* appears to be expanding. It has been collected along the eastern seaboard of the United States from Maine to Georgia, and inwards to Minnesota (Lane *et al.*, 1991). Because of its facility at vectoring the Lyme disease spirochete, much is known about this tick.

Ixodes dammini was not described as a distinct species until 1979 (Spielman *et al.*, 1979). Prior to this, it had been collected and misidentified as *Ixodes scapularis*, the southern deer tick. Tick collections in the 1920's on a sparsely populated island near Cape Cod, Massachusetts yielded an apparently isolated population of *I. dammini*. These specimens were identified as *I. scapularis* even though the collection site was many hundreds of miles north of the defined range for this species (Matuschka and Spielman, 1986).

The rapid spread of *I. dammini* throughout its modern range has to be attributed to changing land use patterns and the resultant repopulation of these areas by deer. Before the arrival of European colonists, deer were abundant throughout New England (Matuschka and Spielman, 1986). Within 100 years these populations had been severely reduced. They were kept low by intensive agriculture until the early 1900's. With the decline of this land for agricultural use and its return to a state of semi-wild parkland, deer began to reemerge as a part of the region's fauna. From the 1930's onward, deer populations dispersed from their few refuges until they had regained most of their former range. With the spread of the deer, *Ixodes dammini* also began to appear in areas from which it had not been recorded. It is suggested by some that the spread of *Ixodes dammini*, as evinced by the numbers of new collection records reported, is just a reoccupation of its former range (Matuschka and Spielman, 1986).

Spielman *et al.* (1985) described the seasonal activity of *Ixodes dammini*. Over a period of two years there are three trophic stadia: larval, nymphal, and adult, each feeding only once on blood. Larvae are abundant from July to September. Nymphs are abundant earlier in the year, peaking in numbers during May and June. Adults quest during the late fall, early winter, and the following spring. These ticks mate on their host. Once the female has mated and engorged, she detaches from the host, falls to the ground, and lays her eggs in the surface detritus. Males will remain on the host searching for another mate.

Immature stages of *Ixodes dammini* feed on a broad range of mammalian and avian hosts. Thirty-one mammalian and 49 avian species have been recorded as hosts of either larval or nymphal stages (Anderson, 1988). Thirteen species of medium and large sized mammals have been recorded as hosts of *I. dammini* adults (Lane *et al.*, 1991).

Most studies have focussed on the importance of two mammalian hosts of *I. dammini* in the epizootiology of Lyme disease. The white-footed mouse, *Peromyscus leucopus*, is the host most frequently parasitized by immatures of *I. dammini* (Lane *et al.*, 1991). White-tailed deer, *Odocoileus virginianus*, may carry infestations of adult *I. dammini* of up to 500 per deer (Lane *et al.*, 1991). On experimental test sites where deer populations have been removed, the populations of *I. dammini* immatures have been severely impacted (Wilson *et al.*, 1988).

Western North America

The western black-legged tick, *Ixodes pacificus*, is the only confirmed vector of Lyme disease in western North America. Discovery of *B. burgdorferi* in this tick occurred in 1982 (Burgdorfer *et al.*, 1985). Subsequent tick/spirochete surveys have found a low prevalence of infected ticks. In a 1982-1984 survey of northern California and southern Oregon, the highest prevalence of infected ticks was found in south-western Oregon at a rate of 2.1% infected per the sample population (Burgdorfer *et al.*, 1985).

Ixodes pacificus was initially identified in 1908 as the species *Ixodes californicus* then revised in 1911 to *Ixodes ricinus* var. *californicus* (Cooley and Kohls, 1945). The classification was again revised in 1943 when it was decided that *I. pacificus* was not a subspecies of *I. ricinus* (Cooley and Kohls, 1943). The initial description of the range of *I. pacificus* in British Columbia occurred in 1934 (Gregson, 1935). Subsequent studies have now produced a geographical range for this species that covers the Pacific Coast of North America from the south coast of British Columbia to southern California (Fig. 2) and inland to isolated populations in southern Utah and Nevada (Arthur and Snow, 1968).

Females of *I. pacificus* are easily identified by their red-brown bodies, black capitulum, black legs, and long hypostome. They are small ticks, averaging 2.6 mm in length (Furman and Loomis, 1984). The males are usually uniformly black although sometimes brown, and are about half the size of the females. It is a three host tick, the subadults attacking small mammals and lizards with the adults feeding on large mammals. Adults are commonly collected from late winter to early summer. Subadults emerge from mid-spring to mid-summer.

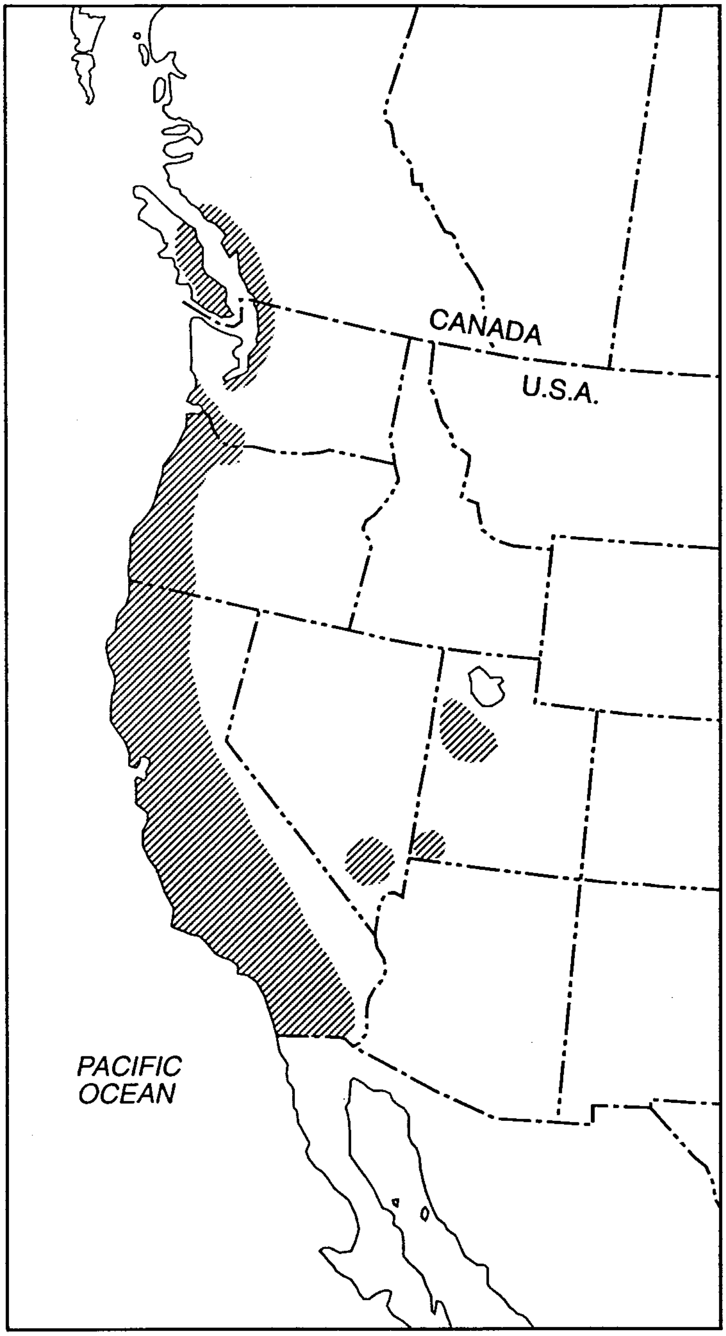

Figure 2. Distribution of the western black-legged tick, *Ixodes pacificus*, in western North America.(Derived from Cooley and Kohls, 1945; Gregson, 1956; Arthur and Snow, 1968; and Furman and Loomis, 1984).

Vector Capacity and Host Reservoir Competence

Vector capacity is a term defining all vector related variables affecting the stability of pathogen transmission (Spielman *et al.*, 1984). Stability of transmission to a pathogen means the consistent ability of the disease organism to pass between hosts and continue the cycle of infection. These factors include the ability to maintain and increase a proliferating population of spirochetes in the vector, the lifestyle that causes a high number of potential reservoir hosts to be infected, and the ability of the vector to efficiently acquire spirochetes and transmit them to and from reservoir hosts.

The best researched vector capacity for Lyme disease is that of *Ixodes dammini*. Adults of *I. dammini* have been shown to transmit spirochetes to laboratory rabbits (*Oryctolagus cuniculus*). Studies have also shown that *I. dammini* nymphs can effectively transmit *B. burgdorferi* to both white-footed mice and hamsters (*Mesocricetus auratus*) (Lane *et al.*, 1991). These tests show that better than 66% of infected nymphs can successfully transmit *B. burgdorferi*. The ability of infected nymphs to transmit the pathogen is related directly to the duration of their attachment to the host (Piesman *et al.*, 1987).

Research into the natural infection rates of ticks in enzootic areas has shown that approximately 50% of the adult *I. dammini* examined from such areas carry spirochetes (Lane *et al.*, 1991). Because ixodid ticks require a blood meal before they moult to both the nymph and adult stage, an adult has had two chances to acquire the infection. In highly enzootic areas up to 100% of the adult ticks may be infected (Burgdorfer, 1984). Transovarial transmission , the process of larval infection from an infected adult female through the egg, does occur but only to a very limited extent. Mangarelli *et al.* (1987) report that only 44 out of 2,297 larvae (approximately 2%) acquired the infection transovarially.

Ixodes pacificus adults were first found to contain spirochetes that morphologically and immunologically resembled *B. burgdorferi* in a survey in 1982 (Burgdorfer *et al.*, 1985). The 2-year survey yielded 1,687 ticks of which 25 (1.5%) contained spirochetes. A spirochete isolated from one infected tick was nearly identical in antibody reaction and whole cell lysate protein profile to isolates from the eastern United States. Burgdorfer *et al.* (1985) also noted that 8 (32%) of the 25 infected ticks had generalized infections where spirochetes had disseminated from the midgut to other tissues. Lane *et al.* (1991) report that up to 46% of infected *Ixodes pacificus* may have disseminated infections. Work on the other two confirmed vector species, *I. ricinus* and *I. dammini*, indicates that only a small percentage of unfed adults (less than 5%) develop generalized infections (Lane *et al.*, 1991).

This apparent difference in *Ixodes pacificus* may have implications for the epidemiology and epizootiology of the disease in the Pacific Coast region. Lane *et al.* (1991) suggest that unfed females with generalized infections may transmit this disease more easily to progeny by transovarial transmission. Lane and Burgdorfer (1987) found that one of these field collected females with spirochetal infection produced a F1 generation that were all infected. The infections were maintained transtadially, from larva to nymph to adult, and in 4 of 5 cases, up to 97% of the F2 generation acquired infections transovarially. Secondly, ticks with disseminated infections may transmit the pathogenic organism very rapidly to their host since the infection would already be established in the salivary glands (Lane *et al.*, 1991.

Ixodes pacificus can acquire pathogenic spirochetes from infected hosts in the laboratory. Burgdorfer (1984) found that up to 17.5% of nymphs that acquired infections as larvae had maintained the infection. As of June 1992, no detailed studies on the vector competence of *Ixodes pacificus* have been published.

Tick-spirochete surveys in Europe have yielded rates of infection for *I. ricinus* between 4 and 40% (Stanek *et al.*, 1988; Stiernstedt, 1985). *Ixodes ricinus* is present in all stages during the season, with nymphal ticks starting to feed 4 weeks before larvae (Lane *et al.*, 1991). Spirochetes appear to be limited mainly to the midgut; with less than 5% of unfed wild caught larvae maintaining spirochetes as evidence of transovarial transmission (Aeschlimann *et al.*, 1986).

In Europe, recent studies indicate that *Ixodes hexagonus* may vector the spirochete. Since it commonly feeds on hedgehogs (Insectivora) and Mustelidae (Carnivora), but only rarely on humans, it is not considered a factor in human disease (Lane *et al.*, 1991). In North America, three other tick species are found naturally infected by *B. burgdorferi* (Piesman and Sinsky, 1988). *Dermacentor variabilis* and *Amblyomma americanum* acquired spirochetal infection but did not maintain it. *Ixodes scapularis* acquired and maintained infection transtadially and transmitted the infection to hamsters in the laboratory. Field collections of *I. scapularis* have not revealed any specimens that contain the spirochete.

For the disease to cycle successfully, hosts that maintain the spirochetal infection must figure prominently in the life cycle of the tick. This is termed host reservoir potential. In eastern North America, *Ixodes dammini* subadults feed predominantly on white-footed mice. In one study in Connecticut, 86% of the collected white-footed mice carried spirochetes (Anderson *et al.*, 1985). Furthermore, these mice appeared to be highly infective to *I. dammini* because most larvae removed from naturally infected white-footed mice contained the spirochete (Donahue *et al.*, 1987).

No published records were found for the infection rates in *Apodemus* spp. and *Clethrionomys* spp., the small mammal hosts of *I. ricinus* subadults in Europe. Lane *et al.* (1991) mention that these species can easily acquire the *B. burgdorferi* spirochetes and maintain the infection through their lifetime.

Lane and Loye (1989) have determined that the western fence lizard (*Sceloporus occidentalis*) is the most important host for *I. pacificus* subadults in California. Gregson (1934) reported that in British Columbia, subadults of this tick could be found on the northern alligator lizard (*Gerrhonotus coeruleus principis*). Lane (1990a) found that lizards are apparently refractory to infection by *B. burgdorferi* spirochetes. *Ixodes pacificus* subadults have also been collected from small mammals and birds. The most important small mammal hosts in California are deer mice, *Peromyscus maniculatus*, and piñon mice, *Peromyscus truei*, (Lane, 1990b). Surveys for spirochetemia in these small mammals have yielded seropositivity but spirochetes have yet to be cultured, and because other *Borrelia* spp. are present, results must be interpreted cautiously (Lane *et al.*, 1991).

Objective

The western black-legged tick, *Ixodes pacificus*, is a known vector of the Lyme disease spirochete, *Borrellia burgdorferi*, in its California range on the Pacific Coast of North America. Recently, cases of what is apparently Lyme disease have been diagnosed in the south coastal region of British Columbia. These cases are few in number and the diagnoses incomplete, and the place where infection occurred is in most cases unknown. *Ixodes pacificus* is present in south coastal British Columbia, with very high numbers occurring in some areas.

The objective of my project was to determine the range and biology of *I. pacificus* in British Columbia. The tick's range was studied in relation to the ranges of its hosts and if it is restricted to particular biogeoclimatic zones. The hosts of *I. pacificus* subadults were particularly important. The potential of a host to harbour a disease organism (reservoir potential) may determine whether or not *I. pacificus* in south coastal British Columbia can vector *B. burgdorferi*.

Along with field collections, a review of earlier records for *I. pacificus* was conducted to determine if there has been changes in geographical or host range. Since little information exists as to the biology of *I. pacificus* in its northern range, aspects of the ticks behavior in the field were noted. These include questing, seasonality, climate, humidity, and vegetation used.

Methods and Materials

Adult Field Surveys

Preliminary field surveys were conducted during March and April of 1990 at Northwest Bay and the Nanoose Peninsula, Vancouver Island, B.C. More intensive field surveys were conducted from January to August of 1991 at the Nanoose Bay site on Vancouver Island, and at a site near Cypress Creek in West Vancouver, B.C. Small surveys were also conducted at a series of selected sites on Vancouver Island, the Gulf Islands, and the Lower Mainland (Fig. 3).

Field surveys to collect questing adults consisted of single person "walk throughs" in which the collector would walk through a field site brushing the vegetation with a flag. Because of the uneven terrain, I determined that straight line transects were impractical. Relative densities of the tick population were therefore calculated as number of ticks collected per hour of search time. Ticks were collected using forceps from both the flag and the researcher. The flags used were 1.3 m wooden dowels to which a piece of white cotton flannel (45 cm x 28 cm) was secured at one end. The flag was swept around possible questing sites, with care being taken to contact all sides and the top of the possible questing substrates. All ticks collected were placed in labelled 1.5 oz. jars with snap-top lids. The jars contained pieces of torn salal (*Gaultheria shallon*) leaves to maintain high humidity within the jar. During one collection survey the height above the ground was measured for all of the substrates from which ticks were collected.

At Simon Fraser University, the collected ticks were identified to species, and their sex and lifestage determined. Two keys, Gregson (1956) and Furman and Loomis (1984), were used to confirm identification. All specimens were then stored at 4 °C in jars containing salal leaves. A sample of the collected adults was forwarded to the British Columbia Center for Disease Control where they were cultured and examined for spirochetes.

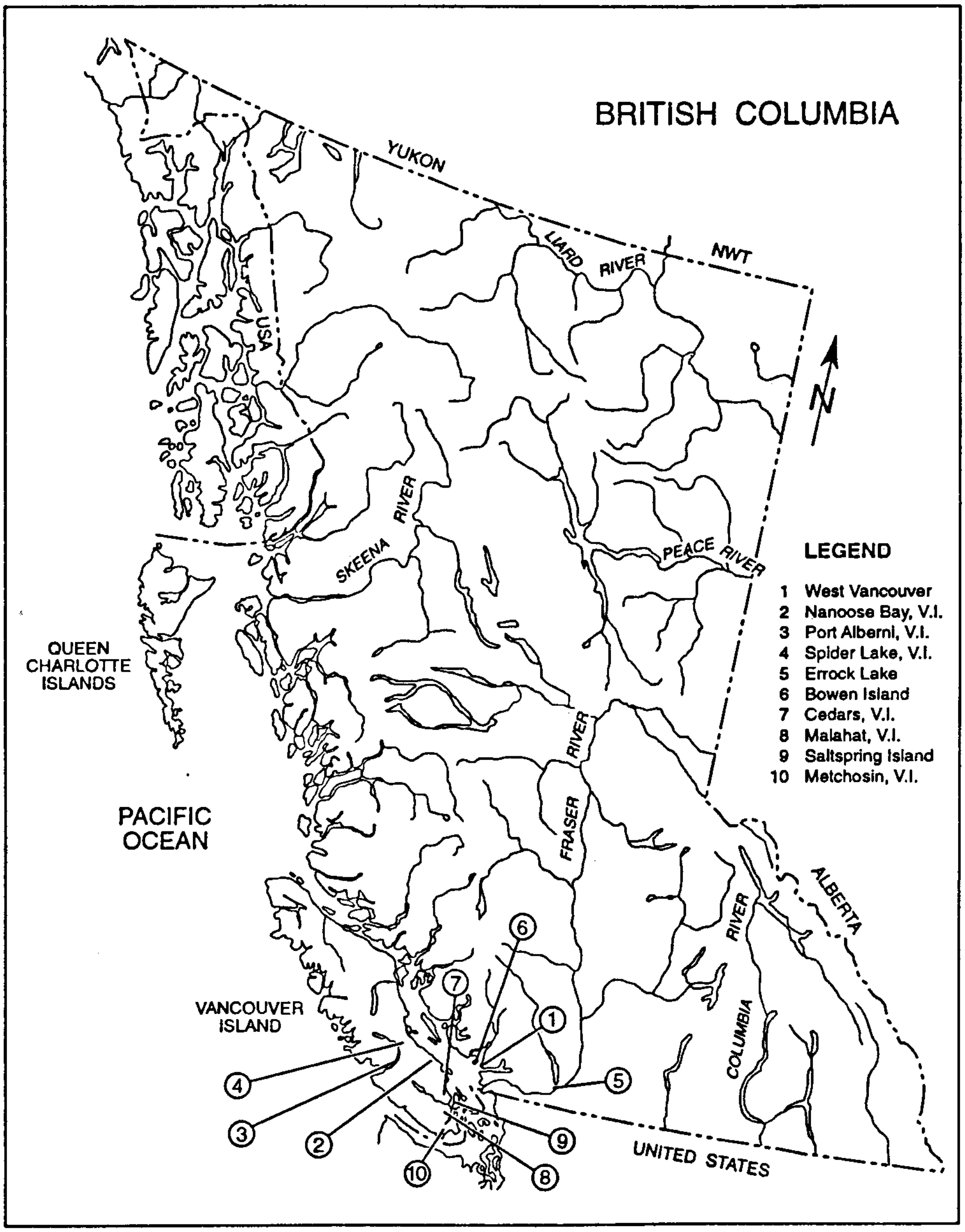

Figure 3. Southern coastal British Columbia field sites of the 1991 survey for questing adults of *Ixodes pacificus*.

Description of Field Sites .

All field sites were assigned to biogeoclimatic zones using indicator species of vegetation as outlined in the Forestry Handbook for British Columbia (1984). A review of previous collection records for *Ixodes pacificus* indicated that two biogeoclimatic zones, the Coastal Douglas Fir Zone and Coastal Western Hemlock Zone, included the localities of most records in the province of British Columbia. Because the majority of human habitation and human encroachment into suitable tick habitat occurs in the Coastal Douglas Fir Zone, all of the field sites that were surveyed in detail are within this zone.

There are two subzones in the Coastal Douglas Fir (CDF) Zone. The dry CDF subzone is a single representative unit, but the wet CDF subzone has four ecosystems depending on soil type and soil moisture, and identified by indicator species of vegetation. To identify and possibly predict the habitat of *Ixodes pacificus* in south coastal British Columbia, the zone and ecosystem in which all adult ticks and trapped small mammals were collected was noted. The zones and ecosystems were identified as follows:

1. Dry CDF subzone- identified by Douglas fir (*Pseudotsuga menziesii*), arbutus (*Arbutus menziesii*), shore pine (*Pinus contorta*), and Garry oak (*Quercus garryana*). In dry sites, Douglas fir is replaced entirely by arbutus and shore pine.

2. Wet CDF Mesic ecosystem - Douglas fir overstory, with well developed shrub layer dominated by salal, and red huckleberry (*Vaccinium parviflorum*).

3. Wet CDF Xeric ecosystem - tree layer dominated by mixed Douglas fir and shore pine. Shrub-layer consists of salal, hairy manzanita (*Arctostaphylos columbiana*), and red huckleberry.

4. Wet CDF Hygric ecosystem - tree layer of Douglas fir and western red cedar (*Thuja plicata*). Herb layer of foamflower (*Tiarella trifoliata*) and sword fern (*Polystichum munitum*).

5. Wet CDF Subhygric ecosystem - tree layer of western red cedar and red alder (*Alnus rubra*). Herb layer consists of skunk cabbage (*Lysichiton americanum*) and slough sedge (*Carex obnupta*).

Survey of Subadult *Ixodes pacificus* Hosts

A. Small Mammals

Small mammals were trapped in the fall of 1990 and the spring-summer of 1991 using 50 Sherman live traps 3" x 3.5" x 9" (Sherman Trap Co., Tallahassee, Florida). Traps were placed in two transect lines with 25 traps each 10 m separating each trap. Traps were placed in the morning of the initial day, left overnight and collected the next morning. Each pair of transects set for one night represents an effort of 50 trap-nights.

All small mammals collected were removed from the traps and lightly anesthetized using fluothane or chloroform. When groggy, the small mammals were identified by external features, sexed, and checked for immature ticks. All immature ticks were removed using #7 biological forceps and placed in labelled vials containing 70% ethanol. The site of attachment to the host was noted for all immature ticks. After the survey for immature ticks, the small mammals were allowed to recover from the anaesthetic and released. Surveys of the plant indicator species were used to determine the type of biogeoclimatic subzone and ecosystem. All small mammals collected within one ecosystem were considered to be a part of the potential host population. The sample rate of parasitism for each host population was calculated as the mean ± SD and a 95% confidence interval. Potential host population sample parasitism rates from each ecosystem were compared as ranked groups using the Newman-Keuls Multiple Comparison. Significantly different populations were interpreted as a higher relative population density of subadult ticks, and thus indicated a preference for one ecosystem. Populations not significantly different were considered to be homogeneous populations with no preference for a particular ecosystem.

B. Northern Alligator Lizard

Northern alligator lizards were hand collected from field survey sites. The time of the initial appearance of lizards at the field sites was noted, as was the habitat type. Each lizard was inspected for the presence of immature ticks and its body and tail length measured. All immature ticks were removed with #7 biological forceps and preserved in labelled vials with 70% ethanol. The immature ticks were identified using Gregson's (1956) key to *Ixodes* subadults. A sample rate of parasitism for lizards was calculated as a mean ± SD with a 95% C.I.. Comparison of the sample rates of parasitism for northern alligator lizards and the most likely small mammal host species were conducted using non-parametric statistical tests to determine which species is the preferred host of subadult *Ixodes pacificus*.

Results

Collection of Adult *Ixodes pacificus*

The ten field sites visited on Vancouver Island, the Gulf Islands, and the Lower Mainland are shown in Figure 3. Four of the ten field sites visited yielded questing adults of *Ixodes pacificus* (Table 1). A total of 416 adults was collected in the 1991 field surveys. The most heavily infested area surveyed was Site 1 in West Vancouver, yielding a collection rate mean and SD of 20.7 ± 4.6 ticks/hour (95% C.I. 16.4-25.0) during May 1991. I surveyed the West Vancouver fieldsite from January 1991 to August 1991 and found significant differences in the adult questing population in relation to gender and emergence (Table 2). Significantly higher numbers of adult males were questing immediately after the population emergence which occured in February. The questing male population did not alter significantly from February through May ($P > 0.05$). The female questing population increased significantly from February to March and from April to May where it peaked with a mean ± SD of 13.1 ± 2.7 females/hour. No significant difference in numbers of questing males and females existed in March and April ($P > 0.05$), but signifcantly higher numbers of females than males were questing in May of 1991 ($P < 0.05$).

Nine of the 10 field sites were in the Coastal Douglas Fir Zone. The Port Alberni field site was classified as being in the Coastal Western Hemlock Zone. Questing adult populations were collected primarily in small areas of either Dry CDF subzone or Wet CDF xeric ecosystem. In West Vancouver (Site 1), 279 (74%) of the 376 adult *I. pacificus* collected were from the Wet CDF xeric ecosystem. At Nanoose Bay (Site 2), 10 (83%) of the 12 adult *I. pacificus* collected were from the Wet CDF xeric ecosystem. At the Metchosin survey site, 15 (100%) of the *I. pacificus* collected were found in the Dry CDF subzone.

On 9 May, 1991, a field survey at West Vancouver was conducted in which the plants used by questing adults were identified to species and their heights measured. A total of 87 adult

Table 1. Total collections of questing adult *Ixodes pacificus* and months collection sites were surveyed.

Location	Total	Males	Females	Month[1]
West Vancouver	383	191	192	Jan., Feb., Mar., Apr., May, June, July
Nanoose Bay, V.I.	12	6	6	Feb., Mar., Apr., May, June
Port Alberni, V.I.	0	0	0	Apr., May
Spider Lake, V.I.	0	0	0	Apr., May
Erroch Lake	6	5	1	Feb.
Bowen Island	0	0	0	Mar.
Cedars, V.I.	0	0	0	Mar., Apr., May
Saltspring Island	0	0	0	May
Malahat, V.I.	0	0	0	Apr., May
Metchosin, V.I.	15	12	3	Apr.
Total	416	214	202	

[1] months in which surveys were conducted at that site in 1991.

Table 2. Total collections of questing adult *Ixodes pacificus*/hour at West Vancouver from January-August 1991.

Month	N^1	Adults	.....95% C.I.	Males	95% C.I.	Females	95% C.I.	.P^2
January	8	0.0±0.0	—	0.0±0.0	—	0.0±0.0	—	-
February	7	8.0±1.9	6.2-9.8	5.4±1.6	3.9-6.9	2.6±0.8	1.8-3.3	<0.05
March	6	11.5±2.3	9.0-14.0	5.7±1.6	3.9-7.4	5.8±1.3	4.4-7.2	>0.05
April	6	14.8±2.1	12.5-17.1	7.0±2.4	4.4-9.5	7.8±1.0	6.8-8.8	>0.05
May	7	20.7±4.6	16.4-25.0	7.6±2.3	5.4-9.7	13.1±2.7	10.6-15.7	<0.05
June	3	5.3±3.1	-2.3-12.9	1.7±1.5	-2.1-5.5	3.7±2.1	-1.5-8.8	>0.05
July	4	0.3±0.5	-0.5-1.0	0.0±0.0	—	0.3±0.5	—	-
August	5	0.0±0.0	—	0.0±0.0	—	0.0±0.0	—	-

N^1 = number of person hours per survey

P^2 = statistical significance between numbers of questing male and female *I. pacificus*/person hour using Student's t test.

ticks were collected. Fifty-four ticks (62%) were collected from salal, 19 (22%) were collected from scoulier willow (*Salix scoulerina*), and 8 (9%) were collected from dwarf wild rose (*Rosa gymnocarpa*). The remaining 7% were collected from the standing straw of *Festuca myuros* and *Festuca pacifica*. The average height of the salal used as a questing substrate was 33 cm. On the willow, all questing ticks were collected under 61 cm above the ground although tree height often exceeded 183 cm.

Collections of Subadult *Ixodes pacificus*/*Ixodes* spp.

Trapping of small mammal hosts and field collections of northern alligator lizard were conducted over a five month period from April through August 1991. During that period 323 small mammals were live trapped over 1350 trap-nights , identified to species, and checked for ticks. A total of 727 subadult ixodid ticks was collected, mounted on slides, and identified.

A. Site 1 (West Vancouver)

During 600 trap-nights a total of 207 small mammals were trapped of which 78.7% were deer mice. Five hundred and fifty-six subadult ixodid ticks were removed from these animals. Three hundred and forty seven (62.4%) of these subadult ticks were identified as *Ixodes pacificus*. *Ixodes angustus* comprised another 23.2% of the subadult ticks removed. *Ixodes soricis* collected from shrews (*Sorex* sp.) made up the remainder of the *Ixodes* subadults collected with the exception of 1 larval *Ixodes spinipalpas*. The most common ixodid species collected over the 5 month trapping period are shown in Table 3. *Ixodes pacificus* subadults were present from April through October 1991. The rate of parasitism on small mammal populations by subadults ranged from 64.5% to 69% and were relatively constant over the five month sampling period.

Table 3. Monthly trap results and collection of immature ixodid species from small mammals at West Vancouver (Site 1) by month during April-August, 1991.

Month	N	%[1] *I.p.*	*Ixodes pacificus*	*Ixodes soricis*	*Ixodes angustus*	Other *Ixodes* sp.
April	31	64.5	41	2	7	1
May	60	65.0	143	20	52	0
June	37	67.0	64	20	9	0
July	49	69.0	75	21	40	0
August	30	66.0	24	16	21	0
Total	207		347	79	129	1

N = number of small mammals caught during 600 trap-nights.

[1] number of small mammals parasitised by at least 1 *I. pacificus* subadult.

Small mammal trapping over the five month sampling period indicated that at least 8 small mammal species may act as either primary or occasional hosts of larval and nymphal *Ixodes pacificus* (Table 4). Comparison of the total numbers of deer mice collected, and the number of *Ixodes pacificus* collected indicate that *P. maniculatus* is the primary small mammal host for *Ixodes pacificus* at Site 1.

Surveys of habitats of the trapped small mammals indicates that the Wet CDF - xeric ecosystem, with a maximum mean ± SD of 5.23 ± 4.82 subadult *Ixodes pacificus*/small mammal (ANOVA, $n=17$) for May 1991, was the favored habitat of immature *Ixodes pacificus* (Table 5). Comparison of the *I. pacificus* subadults/small mammal parasitism rate from the three Wet CDF ecosystems surveyed per month are shown in Table 5. Small mammals in the xeric ecosystem had significantly higher rates of parasitism by subadult *I. pacificus* than did those populations in the other two ecosystems (Newman-Keuls Multiple Comparison, $\mathbf{P} < 0.05$). There was no significant difference between the mesic and hygric ecosystems (Newman-Keuls Multiple Comparison, $\mathbf{P} > 0.05$), with both ecosystems having statistically homogeneous populations. This trend held for all five months of the field survey. Results also indicate that the peak questing period for both stadia of *I. pacificus* subadults was from late May to the beginning of July (Table 5).

Parasitism of deer mice by the two different stadia at the West Vancouver fieldsite is shown in Table 6. Rates of larvae/deer mouse did not differ significantly over the five month survey period (Newman-Keuls Multiple Comparison, $\mathbf{P} > 0.05$). Rates of nymphs/deer mouse did not differ significantly over the five month survey period (Newman-Keuls Multiple Comparison, $\mathbf{P} > 0.05$). Significantly higher numbers of larvae than nymphs were found to parasitize deer mice from April through July (Student's t, $\mathbf{P} < 0.05$), with larval numbers decreasing in the month of August to a point where no significant difference between larval and nymphal numbers existed ($\mathbf{P} > 0.05$). Frequency distribution of *Ixodes pacificus* subadults is shown in Table 7.

Table 4. Number of subadults of each ixodid species by stadia collected from small mammals trapped in West Vancouver during April-August 1991, by host species.

Host	N	Subadults (Larvae/Nymph) *Ixodes pacificus*	 *Ixodes angustus*	 *Ixodes soricis*
Peromyscus maniculatus	164	243/29	60/28	2/0
Eutamias amoenus	12	14/4	12/8	-/-
Eutamias townsendi	4	11/3	6/1	-/-
Microtus spp.	4	3/0	.3/0	-/-
Tamiasciurus douglasi	4	3/0	2/0	-/-
Sorex spp.	17	16/0	-/-	68/9
Neotoma cinerea	1	21/0	5/2	-/-
Rattus norvegicus	1	-/-	2/0	-/-
Total	207	311/36	90/39	70/9

N = number of small mammals/species trapped at West Vancouver from April-August 1991.

Table 5. Sample population rates of *Ixodes pacificus* subadults/small mammal trapped in different Coastal Douglas Fir ecosystems.

	Site 1 (West Vancouver) mean±SD[1]				Site 2 (Nanoose Bay) mean±SD			
Month	xeric	mesic	hygric	P[2]	xeric	mesic	hygric	P
April	2.20±0.97	1.18±1.07	0.80±1.13	0.02	0.40±0.54	0.50±0.54	0.50±1.2	0.970
May	5.23±4.82	1.37±1.55	1.10±1.41	0.00	1.27±0.90	0.45±0.52	0.20±0.42	0.002
June	3.27±1.19	1.18±0.91	0.60±1.07	0.00	2.33±1.32	0.44±0.726	0.30±0.71	0.000
July	3.00±0.89	1.22±1.02	0.93±1.98	0.001	2.42±1.27	0.63±1.4	1.1±0.30	0.000
August	1.66±0.82	0.69±0.48	0.45±0.52	0.001	1.00±0.71	0.25±0.5	0.00±0.00	0.040

[1] mean ± SD calculated at 95% C.I.

[2] $P=0.05$ for Newman-Keuls Multiple Comparison of populations at the same field site.

Table 6. Parasitism of deer mice by *I. pacificus* subadults by month.

West Vancouver

Month	N[1]	Larvae mean±SD (95% C.I.)	Nymph mean±SD (95% C.I.)	P[2]
April	29	1.0±1.1 (0.63-1.24)	0.4±0.6 (0.10-0.60)	<0.05
May	45	1.8±2.1 (1.1 - 2.4)	0.5±0.8 (0.2 - 0.6)	<0.05
June	31	1.6±1.6 (1.0 - 2.2)	0.2±0.4 (0.1 - 0.3)	<0.05
July	35	1.2±1.2 (0.8-1.6)	0.4±0.7 (0.2-0.6)	<0.05
August	23	0.4±0.6 (0.1-0.7)	0.5±0.7 (0.2-0.8)	>0.05

Nanoose Bay

Month	N[1]	Larvae mean±SD (95% C.I.)	Nymph mean±SD (95% C.I.)	P[2]
April	15	0.4±0.6 (0.1-0.7)	0.1±0.3 (-0.1-0.2)	>0.05
May	25	0.8±0.8 (0.4-1.1)	0.0±0.2 (0.0-0.1)	<0.05
June	25	1.0±1.2 (0.5-1.5)	0.1±0.3 (0.0-0.2)	<0.05
July	23	0.8±1.2 (0.3-1.3)	0.2±0.5 (0.0-0.4)	<0.05
August	12	0.0±0.0 (0.00-0.00)	0.5±0.7 (0.02-1.18)	<0.05

[1] N = number of deer mice/month.
[2] **P** as calculated in Student's t test to compare larvae and nymphs/deer mouse/month.

Table 7. Frequency distribution of *Ixodes pacificus* subadults on deer mice.

	Percentage of deer mice					
	West Vancouver[1]			Nanoose Bay[2]		
Number of subadults	total	larvae	nymphs	total	larvae	nymphs
0	27.6	46.6	65	50.5	54.6	88.7
1	28.2	14.7	28.2	29.9	27.8	10.3
2	15.3	18.4	5.5	8.2	9.3	1.0
3	16.0	11.0	1.2	6.2	6.2	-
4	5.5	4.9	-	5.2	2.1	-
5	4.3	3.1	-	-	-	-
6	1.2	0	-	-	-	-
7	0.6	0.6	-	-	-	-
8	1.2	1.2	-	-	-	-
Total	100%	100%	100%	100%	100%	100%

[1] total trap catch of deer mice at West Vancouver during April-August 1991.
[2] total trap catch of deer mice at Nanoose Bay during April-August 1991.

B. Site 2 (Nanoose Bay)

Small mammals were trapped at the Nanoose Bay field site over a five month period from April to August of 1991. During 750 trap-nights, 116 small mammals were trapped and 171 ixodid tick subadults were removed (Table 8). Eighty-four (49%) of the subadults were *Ixodes pacificus*. The remainder of the subadults identified were *Ixodes angustus* at 27% (46/171) and *Ixodes soricis* at 24% (41/171).

Four small mammal species were trapped at the Nanoose Bay field site (Table 9). The most commonly collected species was the deer mouse (*Peromyscus maniculatus*) at 87% (100/116). The remainder of the small mammals trapped were Townsend's vole (*Microtus townsendii*) at 3% (4/116), Norway rat (*Rattus norvegicus*) at 2% (3/116), and shrews (*Sorex* spp.) at 7% (9/116). Subadults of *Ixodes pacificus* were the commonest species from May through July, reaching a peak of 48% parasitism on small mammals during June of 1991 (Table 8). Deer mice were the primary small mammal host of subadult *Ixodes pacificus* at Site 2.

Table 5 indicates that the xeric ecosystem is the most favored habitat for *Ixodes pacificus* subadults, reaching the highest rate of parasitism in July at a mean ± SD of 2.42 ± 1.27 *I. pacificus*/small mammal host (ANOVA, $n=7$). Group ranking by the Newman-Keuls Multiple Comparison ($P>0.05$) found that no significant difference existed in the parasitism of small mammals in all three ecosystems during the month of April. Comparison of the small mammal populations from the three ecosystems in May, June, and July found significantly higher rates of parasitism by *I. pacificus* subadults in the xeric ecosystem ($P<0.05$). In August, no significant difference was found between the small mammal populations in the xeric and mesic ecosystem but significant differences did exist between the small mammal populations in the xeric and hygric ecosystems. The small mammal populations trapped from the mesic and hygric ecosystems were found to constitute a homogeneous population in May, June, and July ($P>0.05$).

Parasitism of deer mice by both stadia of *Ixodes pacificus* subadults at Nanoose Bay is shown in Table 6. Over the four months in which larvae were collected and the five months of

Table 8. Monthly trap results and collection of subadult ixodid species from small mammals at Nanoose Bay (Site 2) during April-August 1991.

Month	N	%[1] *I.P.*	*Ixodes pacificus*	*Ixodes angustus*	*Ixodes soricis*
April	17	35	8	6	0
May	33	36	20	15	24
June	27	48	27	15	4
July	26	38	23	5	9
August	13	38	6	5	4
Total	116		84	46	41

N= number of small mammals trapped/month during 750 trap-nights.

[1] % of small mammals trapped with at least 1 *Ixodes pacificus* subadult.

Table 9. Number of subadults of each ixodid species by stadia collected from small mammals trapped at Nanoose Bay during April-August 1991, by host species.

Host	N	Subadults (Larvae/Nymphs) *Ixodes pacificus*	 *Ixodes angustus*	 *Ixodes soricis*
Peromyscus maniculatus	100	58 / 23	31 / 12	- / -
Microtus townsendii	4	2 / 0	3 / 0	- / -
Rattus norvegicus	3	- / -	- / -	1 / 0
Sorex spp.	9	1 / 0	- / -	40 / 0
Total	116	61 / 23	34 / 12	46 / 0

N = number of individuals trapped at Nanoose Bay from April-August 1991.

the survey in total, no significant difference was found in the numbers of larvae/deer mouse collected (Newman-Keuls Multiple Comparison, **P**<0.05). The rate of nymphs/deer mouse collected was not found to differ significantly for all five survey months (Newman-Keuls Multiple Comparison, **P**>0.05). Comparison of parasitism by stadia found that no significant difference existed for larvae or nymphs per deer mouse in the month of April (Student's t test, **P**>0.05). In May through July, significantly higher numbers of larvae than nymphs were collected from deer mice (**P**<0.05). In August 1991, no larvae were collected from deer mice trapped at Nanoose Bay. As a result, significantly higher numbers of nymphs/deer mouse were recorded (**P**<0.05). Frequency distribution of *Ixodes pacificus* subadults on deer mice at Nanoose Bay is shown in Table 7.

Collection of Northern Alligator Lizard

Northern Alligator lizards emerged in mid-April at the West Vancouver field site. They were frequently seen until the beginning of May, and then populations disappeared until late June and I first collected them in mid-July. Six adult and one juvenile northern alligator lizards were collected through July and August at West Vancouver, from which 46 *I. pacificus* subadults were collected. All 6 adult northern alligator lizards were heavily parasitized by *Ixodes pacificus* subadults with an mean ± SD of 7.7 ± 2.3 *I. pacificus*/adult lizard (95% C.I. 5.3-10.0). The juvenile lizard was not parasitized. Thirty-two *I. pacificus* larvae were collected with a sample parasitism rate mean ± SD of 5.3 ± 2.7 *I. pacificus*/adult lizard (95.0% C.I. 2.5-8.2). Thirty percent (14/46) of the subadult ticks collected were nymphs with a sample parasitism rate of 2.3 ± 0.8 *I. pacificus*/adult lizard (95.0% C.I. 1.5-3.2). Lizards were not collected from the Nanoose Bay fieldsite although extensive searches were conducted.

Host Preference by *Ixodes pacificus* Subadults

Host preference by *I. pacificus* subadults was determined by a comparison of the sample parasitism rates for the predicted preferred host, the northern alligator lizard, and the likely alternate small mammal host, the deer mouse. Fifty-nine deer mice were examined from Site 1 during the July and August trapping period and the sample rates of parasitism (mean and SD) calculated. The sample rate of parasitism by larvae for this time period was 0.89 ± 1.06 larvae/deer mouse (95.0% C.I. 0.6-1.2). The sample rate of parasitism for *I. pacificus* nymphs was 0.44 ± 0.65 nymph/deer mouse (95.0% C.I. 0.3-0.6). Non-parametric analysis of the sample rates of parasitism (Mann-Whitney test, **P**=0.05) , comparing deer mice to northern alligator lizards, shows significant differences between these species for nymphal and larval stages. For host preference in larvae the Mann-Whitney **U**=330.50, the mean rank of deer mice was 30.40, the mean rank of the northern alligator lizards was 58.58, with **Z**=3.478, and **P**=0.001. For host preference in nymphs the Mann-Whitney **U**=336.00, the mean rank of deer mice=30.31, the mean rank of the northern alligator lizards was 59.50, with **Z**=3.602, and **P**=0.000. In both cases, **P**<0.05 shows that the rate of parasitism of the two host species are significantly different, with northern alligator lizards having significantly higher rates of parasitism for both stadia of *I. pacificus* subadults.

Discussion

Field collections and veterinary submissions of adult *Ixodes pacificus* during the spring and summer of 1991 indicate that environmental considerations may be the primary elements defining the relatively small geographical range of this species in British Columbia. The location of my collections of *Ixodes pacificus* and the records of the Canadian National Collection, Ottawa, reveal that all but two of the 189 collection records are in the Coastal Douglas Fir Zone [Appendix 1].

Unlike many tick species, *Ixodes pacificus* appears be to very susceptible to desiccation. In the only study on the physiology of this species, Arthur and Snow (1968) found that under laboratory conditions, a relative humidity of 90% was required for this species to thrive. When relative humidity decreased to 75%, high rates of mortality occurred. Loye and Lane (1988) found that rising relative humidities and decreasing ambient temperatures spurred questing activity by *I. pacificus* in the field. Since adult *I. pacificus* quest primarily at night when their large mammal hosts are active, this behavior is expected. The response of questing at night under these environmental conditions would allow the tick to escape the risks of desiccation. Desiccation is probably the factor limiting the range of *Ixodes pacificus* to predominantly west of the Coast Mountains in B. C.

The Coastal Douglas Fir Biogeoclimatic Zone offers the mildest winter temperatures in British Columbia. Average maximum and minimum temperatures for the coldest month of the year range between 4.1 °C and 0.6 °C (Klinka, 1983). At these temperatures *Ixodes pacificus* immatures are not in danger of freezing during their transition between stadia. The mild winters of the CDF Zone also increase the questing time available for adults. Collection records indicate that adults have been collected in every month of the year but are most abundant from February through June.

Records from my 1991 survey indicate that questing adults were collected only when the ambient air temperature exceeded 8.5 °C. During surveys at infested sites in January, early February and early March, when ambient air temperatures were 2° C, 2 °C, and 4 °C respectively, I did not collect any questing adults. As well, adult ticks were never found questing once the ambient air temperature exceeded 23 °C. Questing adults were most abundant on days just after precipitation. Thus temperatures would be low and relative humidities high. The numbers of questing adult populations caught diminished with increasing time after precipitation. Since much of the lifecycle of *I pacificus* in the field is unknown, I do not know whether each new rainfall precipitated the emergence of a new wave of questing adults or just made the surrounding environment more hospitable for non-questing ticks.

Loye and Lane (1988) found that questing adults appeared to cluster and quest around 50 cm of height when their substrate would offer this option. The primary host for adult *I. pacificus* in California is Columbia black-tailed deer (*Odocoileus hemionus columbianus*). Questing at 50 cm above the ground would be optimum for contact on the upper leg and ventral part of passing deer. However, because Loye and Lane's (1988) study was done on artificial substrates,(i.e. wooden dowels, without side branches), their estimate of questing height may be invalid in the field situations. In my 1991 field study of *I. pacificus*, the most frequently noted questing substrate for *I. pacificus* was salal. On the exposed, rocky slopes from which this tick is most frequently collected, salal often grows to no more than 36 cm in height. Most of the substrates available in these zones are below the height that Loye and Lane (1988) found to be the optimum for questing.

Loye and Lane (1988) report that questing orientation by adult *I. pacificus* is negatively geotactic and that questing ticks avoided direct sunlight when possible. In my 1991 field survey, *Ixodes pacificus* questing off of salal were almost never observed in these classical positions. Salal does not have straight vertical stems but rather has a relatively prostrate growth form. Many of the ticks I observed were questing off the undersides of salal leaves with the dorsal side of their capitulum oriented towards the ground.

Studies by Loye and Lane (1988) classified *I. pacificus* habitat as either chaparral or woodland-grassland. Neither habitat type resembles habitats occupied by *I. pacificus* in British

Columbia. It is likely that the common factors contributing to the various habitats used by *I. pacificus* long mild winters and high relative humidity rather than the plant species.

The localized abundance of questing adults on south facing slopes was a phenomenon that had been noted for *I. pacificus* (Lane and Stubbs, 1990) and *Dermacentor occidentalis* (Lane et al., 1985) in California. In British Columbia, *Ixodes pacificus* habitat was first described by Gregson (1956) as damp, sunny, rocky slopes with vegetation such as *Spirea* spp. and arbutus. In my 1991 survey, I found that the majority of the slopes inhabited by *I. pacificus* had southern exposures and vegetation with indicator species typical of the Coastal Douglas Fir zone. The Metchosin field site was classified as Dry Coastal Douglas Fir subzone. All other field sites were classified as Wet Coastal Douglas Fir subzone with the exception of the field site at Port Alberni which was in the Coastal Western Hemlock Biogeoclimatic Zone.

A sample of the *I. pacificus* adults that I collected was submitted to the B.C. Center for Disease Control for spirochetal examination. The 189 adults which I submitted were pooled with other submissions from the province and cultured. Thirty cultures of spirochetes were derived from the pooled tick population but efforts to identify the spirochetes to species were unsuccessful to date.

Gregson (1956) described the larvae and nymphs of *Ixodes pacificus* as feeding mainly on lizards and only rarely attacking warm blooded hosts such as small birds and mammals. This stems from the description by Jellison (1934) in California and the 1934 British Columbia description by Gregson of subadult *I. pacificus* species from alligator lizard species (*Gerrhonotus* spp.). Gregson (1942) reported that the record collection for immature *I. pacificus* from northern alligator lizard as 103 immatures from a single host. Gregson (1942) also mentions that although large numbers of other animals from tick infested sites were investigated, only occasionally were immatures removed. These alternate hosts included tree squirrels, deer mice, and grouse.

A review of the collection records of the Canadian National Collection [Appendix 1] indicate 25 records of *Ixodes pacificus* removed from lizards in coastal British Columbia. The range of infestations is from 1 to 57 immatures/lizard with a mean and SD of 9.6 ± 15.4 immatures/lizard (95% C.I. 3.3-16.0). These records also show that the heaviest infestations occurred during the months of April and May. My field observations indicate that northern alligator lizard emerges when ambient temperatures reach 10 °C or above. These temperatures in coastal British Columbia usually occur in the month of April although northern alligator lizards have been observed earlier on warm days. My 1991 field survey and the Canadian National Collection records indicate that *Ixodes pacificus* subadults are rarely collected before the month of April, although mild temperatures in earlier months could cause their emergence. It appears that the emergence of *I. pacificus* subadults is at least coincidental to the emergence of northern alligator lizard if not timed to complement it.

Comparison of the range of northern alligator lizard (Fig. 5) as derived from Appendix 2, with the range of *Ixodes pacificus* (Fig. 4) indicates that the range of the tick falls almost entirely within that of the lizard. The lizard however ranges far inland where *I. pacificus* has yet to be collected. No collection records for *I. pacificus* exist from the Okanagan, Columbia River Valley, or the Princeton area. The Coastal Douglas Fir Biogeoclimatic Zone is limited to the southwest portion of British Columbia (Fig. 6). Comparison of this zone with the range for *I. pacificus* (Fig. 4) indicates that the tick's range falls within this biogeoclimatic zone with only a single range extension up the Fraser and Thompson River Valleys.

Small mammal trapping in the first week of April 1991 yielded small numbers of *Ixodes pacificus* subadults. By the third week of April 1991, northern alligator lizards had emerged and were regularly sighted at the West Vancouver field site. Small mammal trapping suggests that much higher numbers of *Ixodes pacificus* immatures were now questing. My review of the Canadian National Collection records indicate that both larval and nymphal *Ixodes pacificus* were collected from lizards during April and May. Larval *Ixodes pacificus* were collected from April through August, while nymphal *I. pacificus* were collected from April through October. These records also show that the largest collections for both stadia occurred during the months of April and May.

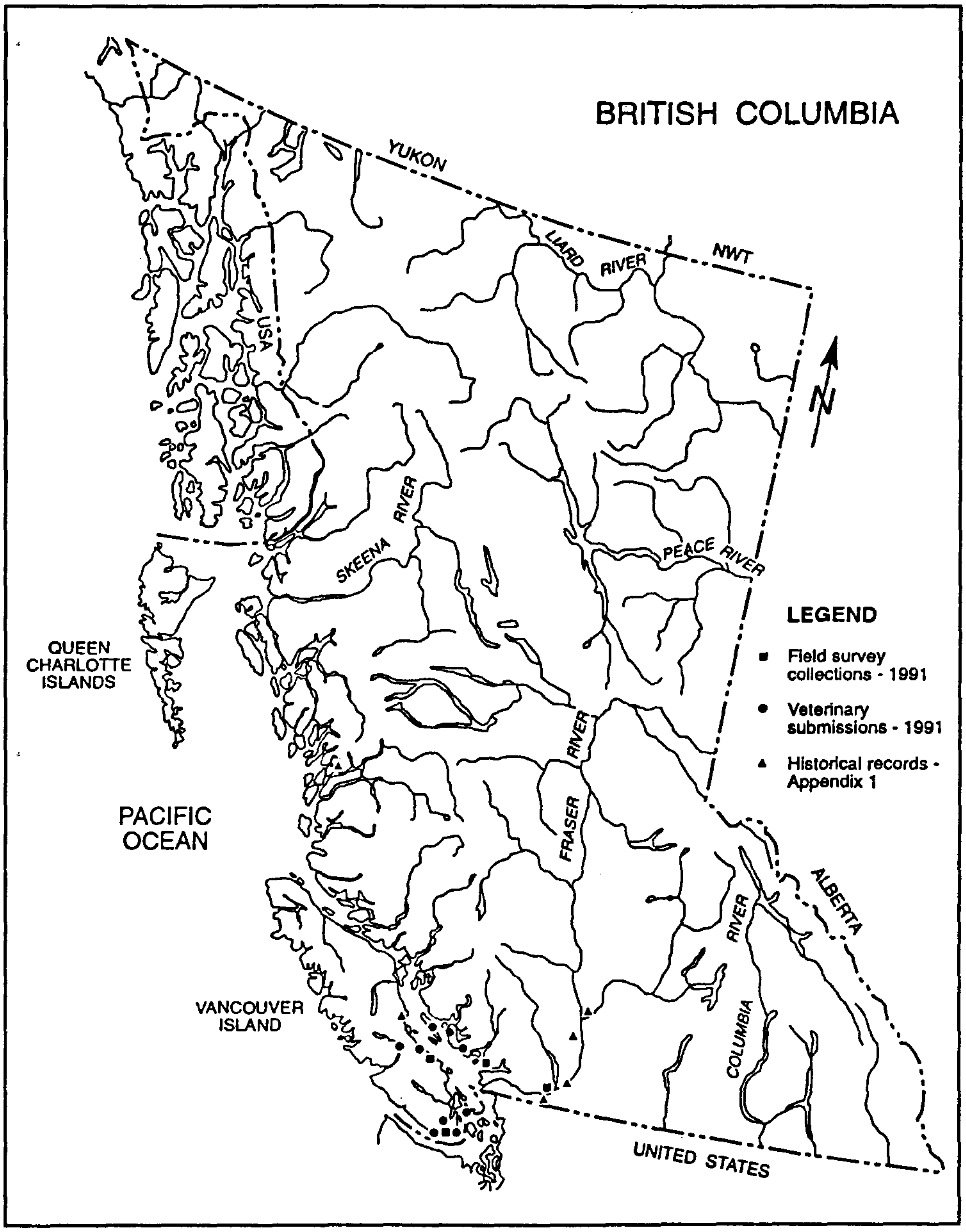

Figure 4. Collection sites defining the known range of *Ixodes pacificus* in British Columbia.

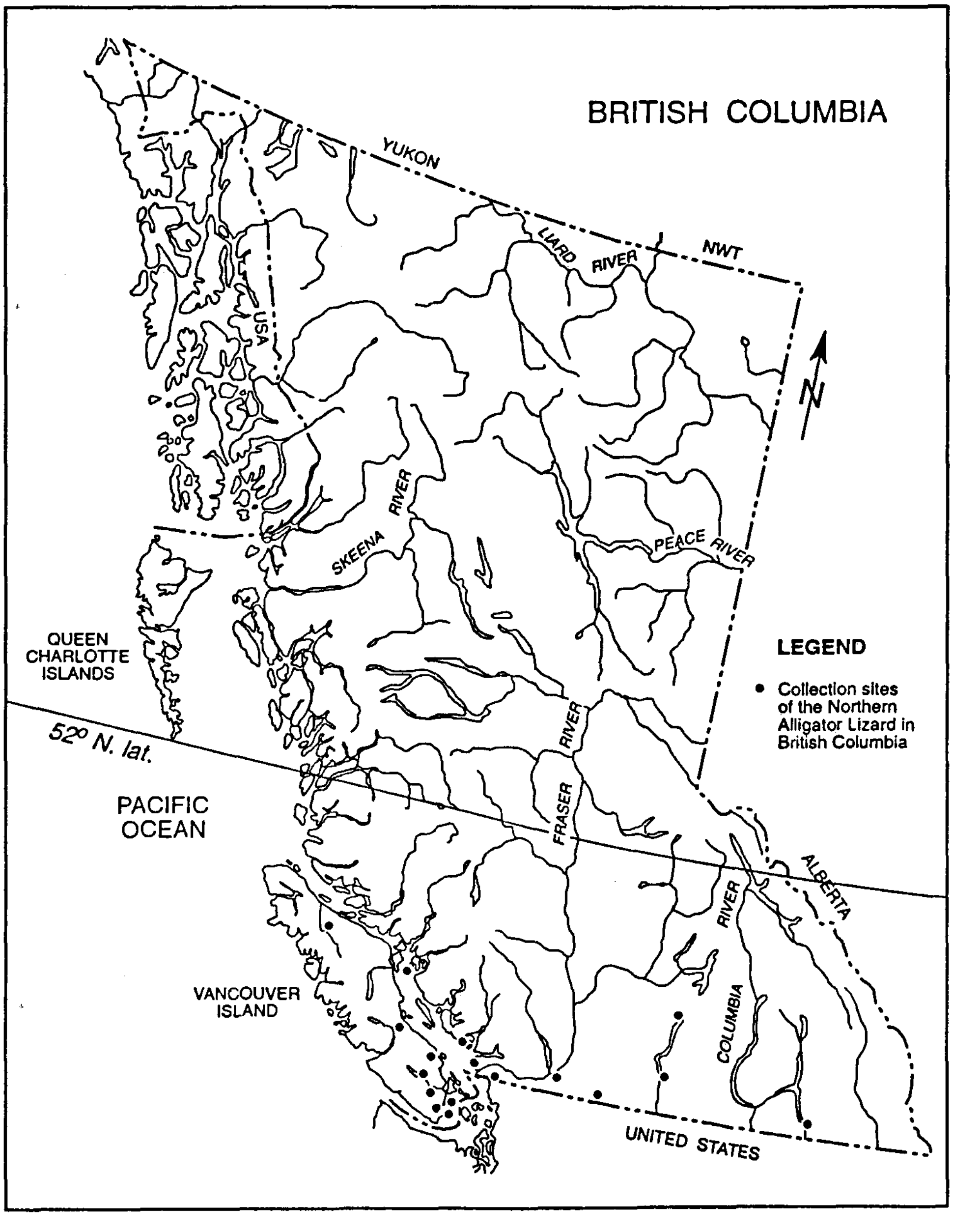

Figure 5. Collection sites of the northern alligator lizard (*Gerrhonotus coeruleus principis*) in British Columbia (derived from Royal British Columbia Museum collection records-Appendix 2).

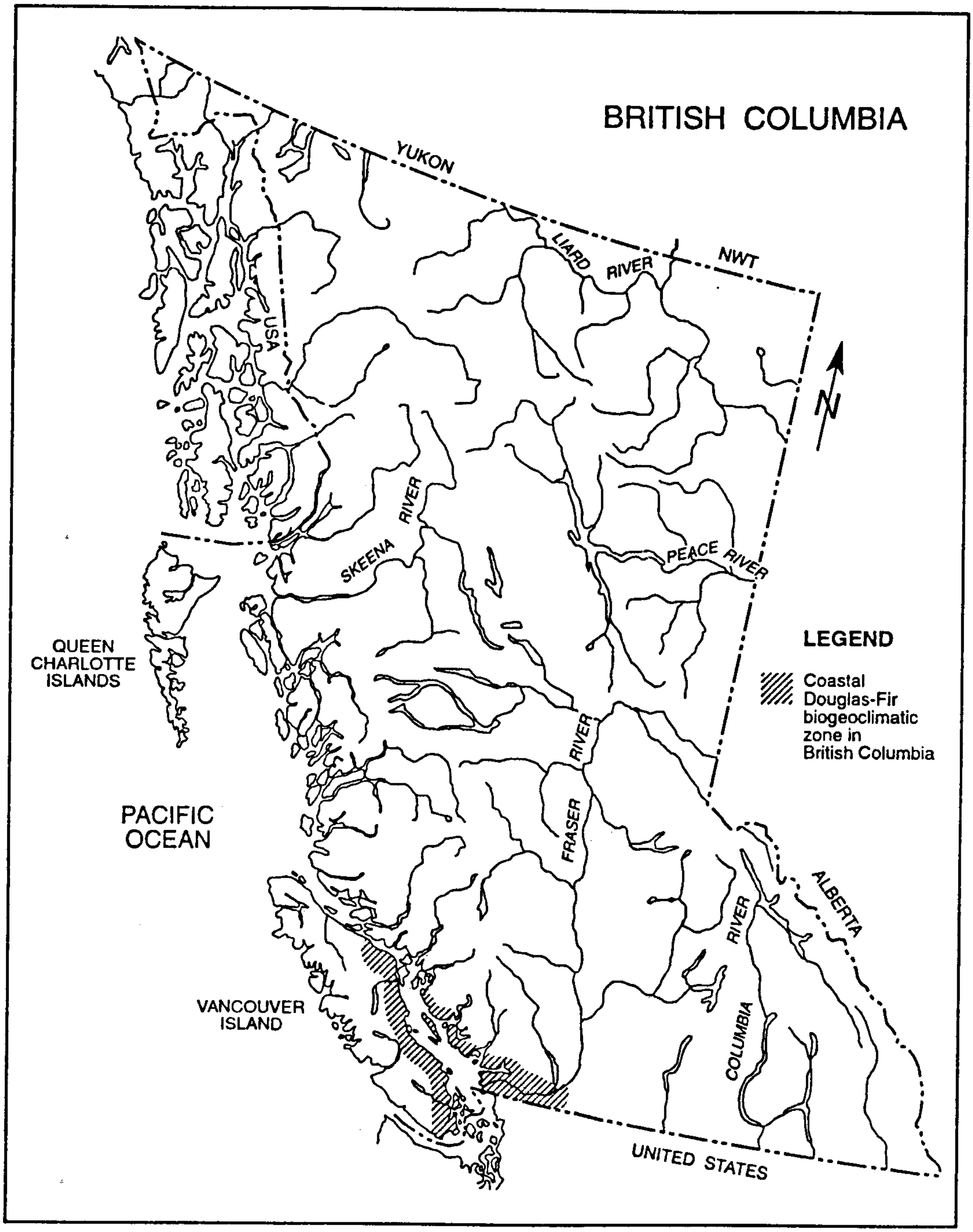

Figure 6. The Coastal Douglas-Fir biogeoclimatic zone in British Columbia (derived from Klinka, 1983).

Collections of northern alligator lizard in my 1991 field survey yielded seven individuals. Six adults and one juvenile were collected at the West Vancouver field site in July and August. All six adults were infested with ticks, with a mean and SD of 7.7 ± 2.3 immatures/ adult lizard. The juvenile lizard, collected in the first week of August, was not infested. Because I could not find published information on the date of emergence for juvenile lizards in British Columbia could be found, I did not include this lizard in my sample. This rate ofinfestation is not significantly different from the mean for the historical collections.

Lane and Loye (1989) found that the preferred host for immature *I. pacificus* in California was the western fence lizard (*Sceloporus occidentalis*). A review of the numbers for *I. pacificus* subadults collected from *S. occidentalis* indicate that the peak abundance for parasitism occurred in April and May. The rate of parasitism declined quickly through June and was very low by July. This trend is also found in the Canadian National Collection records but I did not observe it during my 1991 field season. This lack of decline may be due to the atypical weather of the 1991 season in which cold temperatures and rainfall lasted well into June, and may have delayed the questing season by up to a month.

The sample size for the 1991 northern alligator lizard collection was skewed towards the months of July and August. Because no collections occurred during the months of April and May, the period for which the national collections show to the peak of parasitism, the magnitude of the role of northern alligator lizard as a host of *I. pacificus* subadults is not known. However the rate of parasitism of northern alligator lizard in July and August is much higher than the rate for *S. occidentalis* during the same months (Lane and Loye, 1989).

My 1991 field survey also indicates that deer mice play a important role as hosts of *I. pacificus* larvae and of nymphs. Numbers of nymphs parasitizing deer mice were always less than larval numbers, with the exception of April and August at Nanoose Bay. I do not know whether the statistical differences in parasitism by these stadia represent actual host selection of lizards by nymphs, or differences in the population of nymphs actively questing.

Studies by Gregson (1956) in tick infested areas determined that small mammals were not important hosts of subadult *I. pacificus*. I do not know whether this difference between my study and Gregson's (1956) is due to my more comprehensive sampling or to differences in host availability for *I. pacificus* subadults in West Vancouver. Studies by Lane (1990) found that deer mice and piñon mice served as occasional hosts for *I. pacificus* larvae but almost never for *I. pacificus* nymphs. Lane (1990) collected only one *I. pacificus* nymph from the 104 rodents he examined.

In my 1991 field study, 323 small mammals representing 8 species were examined for parasitism by *I. pacificus* subadults. My West Vancouver field site yielded 207 small mammals from which 556 *Ixodes* spp. subadults were removed. Of these ticks, 62.4% were identified as *I. pacificus* subadults. At this field site, 78.7% of the trap catch was comprised of deer mice. Of the deer mice collected over the five month period from April to August, between 64.5% to 69% were parasitized by *I. pacificus* subadults. At my Nanoose Bay site, deer mice also comprised the majority of the small mammals trapped. The prevalence of deer mice at both field sites and the rate of parasitism that I found indicates that, unlike in California, deer mice play a important role as hosts for *I. pacificus* subadults in British Columbia.

Large differences in the numbers of larvae and nymphs collected from deer mice may reflect either host selectivity by questing nymphs or high mortality in the change between stadia. Lane (1990b) has found a clear expression of host preference towards lizards by nymphal *I. pacificus* populations in California. It is therefore possible that such host preference also exists in the nymphs of the *I. pacificus* population in British Columbia. If host preference by the nymphs can be demonstrated, then the different profile of Lyme disease in western North America could be explained. In eastern North America, *I. dammini* nymphs feed on white-footed mice (*P. leucopus*) just prior to the emergence of the *I. dammini* larvae. The nymphs transmit *B. burgdorferi* to the mice who then infect the larvae, and thus continue the cycle of transmission.

Table 10. Known host-index for *Ixodes pacificus* in western North America.

Host	Common Name	Location
Class Reptilia		
Order Lacertilia		
Family *Anguidae*		
Gerrhonotus coeruleus principis	northern alligator lizard	B.C.[1]
Gerrhonotus coeruleus	alligator lizard	Calif.[2]
Gerrhonotus multicarinatus multicarinatus	California alligator lizard	Calif.[2], Ore.[3], Wash.[3]
Gerrhonotus m. scincicauda	Oregon alligator lizard	Calif.[2]
Family *Iguanidae*		
Sceloporus occidentalis occidentalis	northwestern fence lizard	Calif.[2], Ore.[3]
Sceloporus graciosus	sagebrush lizard	Calif.[2]
Family *Teiidae*		
Cnemidophorus sp.	whiptail	Calif.[2]
Family *Colubridae*		
Thamnophis ordinoides	northwestern garter snake	Ore.[3]
Class Mammalia		
Order Primates		
Family *Hominidae*		
Homo sapiens	human	B.C.[1], Ore.[3] Calif.[2], Wash.[3],Utah[3]
Order Insectivora		
Family *Talpidae*		
Scapanus orarius schefferi	Scheffer's mole	B.C.[1]
Scapanus latimanus	broad-footed mole	Calif.[2]

Table 10. continued

Family *Soricidae*		
Sorex spp.	shrews	B.C.[1], Calif.[2]
Order Rodentia Family *Sciuridae*		
Eutamias amoenus	yellow-pine chipmunk	B.C.[1]
Eutamias townsendi	Townsend's chipmuk	B.C.[1]
Eutamias dorsalis	cliff chipmunk	Utah[3]
Tamiasciurus douglasi	Douglas's squirrel	B.C.[1]
Spermophilus beecheyi	California ground squirrel	Calif.[2]
Spermophilus spp.	ground squirrel	Calif.[2]
Sciurus griseus	western grey squirrel	Calif.[2], Ore.[3]
Family *Heteromyidae*		
Perognathus parvus	great basin pocket mouse	Utah[3], Nevada[3]
Perognathus californicus	California pocket mouse	Calif.[2]
Dipodomys deserti	desert kangaroo rat	Calif.[2]
Dipodomys sp.	kangaroo rat	Calif.[2]
Family *Cricetidae*		
Reithrodontomys megalotis	western harvest mouse	Calif.[2]
Peromyscus maniculatus	deer mouse	B.C.[1],Calif.[2], Utah[3]
Peromyscus boylii	brush mouse	Calif.[2]
Peromyscus truei	piñon mouse	Calif.[2],Utah[3]
Peromyscus eremicus	cactus mouse	Utah[3]

Table 10. continued

Neotoma fuscipes	dusky-footed woodrat	Calif.[2]
Neotoma lepida	desert woodrat	Calif.[2],Utah[3]
Neotoma cinerea	bushy-tailed woodrat	Calif.[2],B.C.[1]
Microtus townsendii	Townsend's vole	B.C.[1]
Microtis californicus	California vole	Calif.[2]
Order Carnivora Family *Canidae*		
Canis latrans	coyote	Calif.[2]
Canis familiaris	dog	B.C.[1],Ore.[3] Calif.[2] Wash.[3],Utah[3]
Urocyon cinereoargenteus	grey fox	Calif.[2]
Urocyon littoralis littoralis	insular grey fox	Calif.[2]
Family *Ursidae*		
Ursus americanus	black bear	Calif.[2]
Family *Procyonidae*		
Procyon lotor	raccoon	Calif.[2]
Family *Mustelidae*		
Mustela vison	mink	B.C.[1]
Mustela frenata	long-tailed weasel	Calif.[2]
Taxidea taxus	badger	Calif.[2]
Family *Felidae*		
Felis domesticus	cat	B.C.[1], Calif.[2]
Felis concolor	cougar	Calif.[2]
Felis rufus	bobcat	Calif.[2]

Table 10. continued

Order Artiodactyla Family *Suidae*		
Sus scrofa	wild boar	Calif.[2]
Family *Cervidae*		
Odocoileus hemionus	mule deer	B.C.[1]
Odocoileus hemionus columbianus	Columbia black tailed deer	Calif.[2] Utah[3]
Cervus elaphus nannodes	Tule elk	Calif.[2]
Family *Bovidae*		
Bos taurus	domestic cow	Calif.[2], B.C.[1], Ore.[3]
Order Marsupalia Family *Didelphidae*		
Didelphis marsupialis virginiana	Virginia opossum	Calif.[2]
Class Aves **Order Galliformes** Family *Phasianidae*		
Lophortyx californica	California Quail	Calif.[2]
Dendragapus obscurus	blue grouse	B.C.[1]
Order Piciformes Family *Picidae*		
Colaptes cafer	red-shafted flicker	Calif.[2]
Order Passeriformes Family *Corvidae*		
Cyanocitta stelleri	Steller's jay	Calif.[2]
Aphelocoma californica	scrub jay	Calif.[2]

Table 10. continued

Family *Troglodytidae*		
Troglodytes troglodytes	winter wren	Calif.[2]
Thryomanes bewickii	Bewick's wren	Calif.[2]
Family *Turdidae*		
Catharus ustulata	Swainson's thrush	Calif.[2]
Family *Parulidae*		
Wilsonia pusilla	Wilson's warbler	Calif.[2]
Vermivora celata	orange-crowned warbler	Calif.[4]
Family *Fringillidae*		
Aimophila ruficeps	rufous-crowned sparrow	Calif.[2]
Aimophila sp.	"sparrow"	Calif.[2]
Junco oreganus	Oregon Junco	Calif.[2]
Zonotrichia leucophrys nuttalli	Nuttall's white-crowned sparrow	Calif.[2]
Zonotrichia atricapilla	Golden-crowned sparrow	Calif.[2]
Passerella ileaca	fox sparrow	Calif.[2]
Melospiza melodia	song sparrow	Calif.[2]
Passerina amoena	lazuli bunting	Calif.[4]
Spizella passerina	chipping sparrow	Calif.[4]

[1] Gregson, 1956
[2] Furman and Loomis, 1984
[3] Arthur and Snow, 1968
[4] Manweiler *et al.*, 1990

By feeding on lizards, a group of animals apparently refractory to infection by *B. burgdorferi* (Lane, 1990b), the *I. pacificus* nymphs would break the cycle of transmission. Larvae would not acquire the infection by feeding on deer mice and the spirochete would be transmitted through the tick population mainly by transtadial transmission. Lane (1991) has proposed several other factors that could account for the different profile of Lyme disease in western North America. These include a peak of feeding by larval ticks that precedes feeding by nymphs, and the lack of feeding by nymphs on reservoir competent hosts like deer mice.

A comparison of the rates of parasitism by nymphs for both deer mice and northern alligator lizard during the months of July and August 1991 indicates that lizards are the preferred host choice for nymphs. Parasitism of deer mice by *I. pacificus* nymphs produced a mean and SD of 0.44 ± 0.64 (range 0-2, n=59) with 64% of the deer mice not being parasitized by nymphs. The parasitism rate for northern alligator lizard during the same period of time yields a rate of 2.3 ± 0.75 (range 1-3, n=6). Although sample sizes were small it appears that even at this period of the season, there is some host selectivity occurring. Unfortunately, I did not collect northern alligator lizard during April and May, the period which the historical collection records indicate are the peak periods for nymphal parasitism.

No new host records for *Ixodes pacificus* were derived from my 1991 field survey. New records have recently been made in California and have been compiled into the host index (Table 9). These records cover the entire known geographical range of *Ixodes pacificus*.

Without a more comprehensive knowledge of the prevalence of northern alligator lizards in the regions of the Coastal Douglas Fir Biogeoclimatic Zone that are the principal habitat of *Ixodes pacificus*, the exact importance of its role as a host of *I. pacificus* subadults in British Columbia cannot be determined. It appears likely that deer mice are the most abundant host species in the tick's range. Even if deer mice are less preferred hosts than northern alligator lizards, sheer numbers of mice may mean that more *I. pacificus* larvae feed on deer mice. With nymphs of *I. pacificus*, it would appear that northern alligator lizard is probably the preferred host and that host preference may preclude any significant feeding by the nymphal population on deer mice. Aside from Arthur and Snow's (1968) laboratory study with guinea-pigs, no studies exist to demonstrate whether feeding on lizards or rodents may effect either survival rates or fertility of ticks.

Conclusion

In British Columbia, *Ixodes pacificus* appears to thrive mainly in one biogeoclimatic zone , the Coastal Douglas Fir Zone. Within the Coastal Douglas Fir Zone, the highest populations of *I. pacificus* subadults occur in the driest subzone and the driest ecosystem of the wet subzone. These sites are indicated by the presence of arbutus, Garry oak, and shore pine, and usually occur on south facing, rocky slopes. Subadults of *I. pacificus* parasitize both small mammals and the northern alligator lizard. Larvae are apparently not host selective but evidence indicates a distinct preference by the nymphal stage for the northern alligator lizard as host.

In other parts of its range, Lyme disease seems to be transmitted to man by the nymphal stage of the tick. The preference of *I. pacificus* nymphs for lizards in British Columbia would be consistent with a low incidence of spirochetes in adult ticks as in California. Because Lyme disease spirochetes were not present in any of the adult ticks submitted to the B.C. Center for Disease Control, it seems more likely that the disease is not yet endemic in the province.

The geographical range of *I. pacificus* and its range of hosts does not seem to have changed significantly since the studies of Gregson more than 50 years ago, although the extent to which this tick species range extends into the interior of British Columbia is not known.

References

Anonymous, 1991, Lyme Disease in Canada, Can Med. Assoc. J. **144(2):177**.

Anonymous, 1990, Tickborne diseases-Georgia 1989, MMWR **39:397-399**.

Aeschlimann, A., E. Chamot, F. Gigon,. J.-P. Jeanneret, D. Kessler, *et al.*, 1986, *B. burgdorferi* in Switzerland, Zentralbl. Bakteriol. Mikrobiol. Hyg. A **263:450-458**.

Afzelius, A., 1921, Erythema chronicum migrans, Acta Derm. Venereol. (Stokh) **2:120-125**.

Anderson, J.F., 1988, Mammalian and avian reservoirs for *Borrelia burgdorferi*, Ann. N.Y. Acad. Sci. **539:180-191**.

Anderson, J.F., R.C. Johnson, L.A. Magnarelli, and F.W. Hyde, 1985, Identification of endemic foci of Lyme disease: isolation of *Borrelia burgdorferi* from feral rodents and ticks (*Dermacentor variabilis*), J. Clin. Microbiol. **22:36-38**.

Arthur, D.R., 1957, The capitulum and feeding mechanism of *Dermacentor parumapertus*, Parasitol. **47:169-184**.

Arthur, D.R., 1961, Ticks and Disease, Pergamon Press, Oxford, Eng., 445 pp.

Arthur, D.R., and K. Snow, 1968, *Ixodes pacificus* Cooley and Kohls, 1943: its lifehistory and occurence, Parasitol. **58:893-906**.

Ashbrink, E., and A. Hovmark, 1988, Early and late manifestations of *Ixodes*-borne borreliosis (erythema migrans borreliosis, lyme borreliosis), Ann. NY Acad. Sci. **539:4-15**.

Balashov, Y.S., 1972, Bloodsucking ticks (Ixodidae)-vectors of disease of man and animals, Misc. Publ. Ent. Soc. Amer. **8(5):161-376**.

Barbour, A.G., 1984, Isolation and cultivation of Lyme disease spirochetes, Yale J. Biol. Med. **57:521-525**.

Barbour, A.G., and S. Hayes, 1986, Biology of *Borrelia* species, Microbiol. Rev. **50(4):381-400**.

Burgdorfer, W., A.G. Barbour, S.F. Hayes, J.L. Benach, E. Grunwaldt, and J.P. Davis, 1982, Lyme Disease - a tick-borne spirochetosis?, Science **216:1317-1319**.

Burgdorfer, W., 1984, The New Zealand white rabbit: an experimental host for infecting ticks with Lyme disease spirochetes, Yale J. Biol. Med. **57:609-612**.

Burgdorfer, W., R.S. Lane, A.G. Barbour, R.A. Grisbrink, and J.R. Anderson, 1985, The western black-legged tick, *Ixodes pacificus*: A vector of *Borrelia burgdorferi*, Am. J. Trop. Med. Hyg. **34(5):925-930**.

Burgdorfer, W., and S. Hayes, 1989, "Vector/spirochete relationships in louseborne and tickborne borreliosis with emphasis on Lyme disease" in Advances in Disease Vector Research. **6:127-150**, New York: Springer-Verlag.

Cooley, R.A., and G.M. Kohls, 1943, *Ixodes californicus* Banks 1904, *Ixodes pacificus* n.sp., and *Ixodes conepati* n.sp. (Acari:Ixodidae), Pan-Pacific Entomol. **19(4):139-147**.

Cooley, R.A., and G.M. Kohls, 1945, The Genus *Ixodes* in North America, Nat. Inst. Health Bull. No. 184, 246 pp.

Donahue, J.G., J. Piesman, and A. Spielman, 1987, Reservoir competance of white-footed mice for Lyme disease spirochetes, Am. J. Trop. Med. Hyg. **36:92-96**.

Durey, P.H., and A.C. Steere, 1988, Clinical pathologic correlations of Lyme disease by stage, Ann. N.Y. Acad. Sci. **539:65-79**.

Furman, D.P., and E.C. Loomis, 1984, The ticks of California, Bull. Calif. Insect. Surv. Vol.25, 356 pp.

Gregson, J.D., 1935, A preliminary report of the lizard-tick relationship on the coast of British Columbia, Proc. B.C. Entomol. Soc. **31:17-21**.

Gregson, J.D., 1942, The coast tick (*Ixodes californicus* Banks) problem in British Columbia. Can. Entomol. **74:3-5**.

Gregson, J.D.,1956, The Ixodidae of Canada, Can. Dept. Agric. Publ. 930, 92 pp.

Hoogstrall, H., 1970, Bibliography of ticks and tickborne diseases, Vol.2 (from Homer - 800 B.C. to Dec. 1969), U.S. Naval Med. Res. Unit 3, 495 pp.

Hovind-Hougen, K., E. Ashbrink, G. Stiernstedt, A.C. Steere, and A. Hovmark, 1986, Ultrastructural differences among spirochetes isolated from patients with Lyme disease and related disorders, and from *Ixodes ricinus*, Zentralbl. Bakteriol. Mikrobiol. Hyg. [4]. **263:103-111**.

Jellison, W.L., 1934, The parasitism of lizards by *Ixodes ricinus californicus* (Banks), J. Parasit. **20:243**.

Johnson, R.C., C. Kodner, M. Russel, and P.H. Durey, 1988, Experimental infection of the hamster with *Borrelia burgdorferi*, Ann. N.Y. Acad. Sci. **539:258-263**.

Klinka, K., 1983, "Coastal Douglas Fir Zone" in Forestry Handbook for British Columbia, 4th ed., S.B. Watts Ed., Forestry Undergraduate Society, University of British Columbia, Vancouver, B.C., 611 pp.

Krantz, G.W., 1978, A Manual of Acarology, 2nd ed., Oregon State University Bookstores, Inc., Corvallis, Ore., 509 pp.

Lane, R.S., J.R. Anderson, J.S. Yaninek, and W. Burgdorfer, 1985, Diurnal host seeking of adult Pacific Coast ticks: *Dermacentor occidentalis* (Acari:Ixodidae), in relation to vegetational factors, meteorological factors, and rickettsial infection rates in California,USA, J. Med. Entomol. **22:558-571**.

Lane, R.S., and W. Burgdorfer, 1987, Transovarial and transtadial passage of *Borrelia burgdorferi* in the western black-legged tick, *Ixodes pacificus* (Acari:Ixodidae), Am. J. Trop. Med. Hyg. **37:188-192**.

Lane, R.S., and J.E. Loye, 1989, Lyme disease in California: interrelationship of *Ixodes pacificus* (Acari:Ixodidae), the western fence lizard (*Sceloporus occidentalis*), and *Borrelia burgdorferi*, J. Med. Entomol. **26:272-278**.

Lane, R.S., 1990a, Susceptibility of the western fence lizard (*Sceloporus occidentalis*) to the Lyme disease spirochete (*Borrelia burgdorferi*), Am. J. Trop. Med. Hyg. **42:75-82**.

Lane, R.S., 1990b, Infection of deer mice and piñon mice (*Peromyscus* spp.) with spirochetes at a focus of Lyme borreliosis in northern California,USA, Bull. Soc. Vector. Ecol. **15:25-32**.

Lane, R.S., and H.A. Stubbs, 1990, Host-seeking behavior of adult *Ixodes pacificus* (Acari:Ixodidae) as determined by flagging vegetation, J. Med. Entomol. **27:282-287**.

Lane, R.S., J. Piesman, and W. Burgdorfer, 1991, Lyme borreliosis: Relation of its causative agent to its vectors and hosts in North America and Europe, Ann. Rev. Entomol. **36:587-609**.

Loye, J.E., and R.S. Lane, 1988, Questing behavior of *Ixodes pacificus* (Acari:Ixodidae) in relation to meteorological and seasonal factors, J. Med. Entomol. **25(5):391-398**.

Magnarelli, L.A., J.F. Anderson, and D. Fish, 1987, Transovarial transmission of *Borrelia burgdorferi* in *Ixodes dammini* (Acari:Ixodidae), J. Infect. Dis. **156:234-236**.

Manweiler, S.A., R.S. Lane, W.M. Block, and M.L. Morrison, 1990, Survey of birds and lizards for ixodid ticks (Acari) and spirochetal infection in northern California, J. Med. Entomol. **27(6):1011-1015**.

Marcus, L.C., A.C. Steere, P.H. Durey, A.E. Anderson, and E.B. Mahoney, 1985, Fatal pancarditis in a patient with coexistant Lyme disease and babesiosis: demonstration of spirochetes in the myocardium, Ann. Intern. Med. **103:374-376**.

Matuschka, F.R., and A. Spielman, 1986, The emergence of Lyme disease in a changing environment in North America and central Europe, Exp. Appl. Acarol. **2:337-353**.

Obenchain, F.D., and R. Galun, 1982, Physiology of ticks, Pergamon Press, Oxford, Eng., 509 pp.

Pachner, A.R., and A.C. Steere, 1985, The triad of neurologic manifestations of Lyme disease: meningitis, cranial neuritis, and radiculneuritis, Neurology **35:47-53**.

Piesman, J., T.N. Mather, R.J. Sinsky, and A. Spielman, 1987, Duration of tick attachment and *Borrelia burgdorferi* transmission, J. Clin. Microbiol. **25:557-558**.

Piesman, J., and R.J. Sinsky, 1988, Ability of *Ixodes scapularis*, *Dermacentor variabilis*, and *Amblyomma americanum* (Acari:Ixodidae) to acquire, maintain , and transmit Lyme disease spirochetes (*Borrelia burgdorferi*), J. Med. Entomol. **25:336-339**.

Ribiero, J.M., T.N. Mather, J. Piesman, and A. Spielman, 1987, Dissemination and salivary delivery of Lyme disease spirochetes in vector ticks (Acari:Ixodidae), J. Med. Entomol. **24:201-205**.

Schmidli, J., T. Hunziker, P. Moesli, and U.B. Schaad, 1988, Cultivation of *Borrelia burgdorferi* from joint fluid three months after treatment of facial palsy due to Lyme borreliosis, J. Infect. Dis. **158:905-906.**

Schwan, T.G., W. Burgdorfer, and C.F. Garon, 1988, Changes in infectivity and plasmid profile of the Lyme disease spirochete, *Borrelia burgdorferi*, as a result of invitro cultivation, Infect. Immun. **56:1831-1836.**

Spielman, A., C.M. Clifford, J. Piesman, and D. Corwin, 1979, Human babesiosis on Nantucket Island, USA: description of the vector *Ixodes (Ixodes) dammini* n.sp. (Acari:Ixodidae), J. Med. Entomol. **15:218-234.**

Spielman, A., J,F. Levine, and M.L. Wilson, 1984, Vectorial capacity of North American *Ixodes* ticks, Yale J. Biol. Med. **57:507-513.**

Spielman, A., M.L. Wilson, J.F. Levine, and J. Piesman, 1985, Ecology of *Ixodes dammini*-borne human babesiosis and Lyme disease, Ann. Rev. Entomol. **30:439-460.**

Stanck, G., M. Pletschette, H. Flamm, A.M. Hirschl, E. Aberer, W. Kristoferitsch, and E. Schmutzhard, 1988, European Lyme Borreliosis, Ann. N.Y. Acad. Sci. **539:274-282.**

Steere, A.C., S.E. Malawista, and D.R. Snydham, 1977, Lyme arthritis: an epidemic of oligoarticular arthritis in childern and adults in three Connecticut communities, Arthritis Rheum. **20:7-17.**

Steere, A.C., N.H. Bartenhagen, and J.E. Craft, 1983, The early clinical manifestations of Lyme disease, Ann. Intern. Med. **99:76-82.**

Steere, A.C., R.T. Scheon, and E. Taylor, 1987, The clinical evolution of Lyme arthritis, Ann.Intern. Med. **107:725-731.**

Steere, A.C., 1989, Lyme Disease, New England J. Med. **32(9):586-596.**

Stiernstedt, G.T., 1985, Tick-borne Borrelia infection in Sweden, Scand. J. Infect. Dis. **(Suppl. 45):1-70.**

Wilson, M.L., S.R. Telford III, J. Piesman, and A. Spielman, 1988, Reduced abundance of immature *Ixodes dammini* (Acari:Ixodidae) following elimination of deer, J. Med. Entomol. **25:224-228.**

World Health Organization, 1967, Joint FAO/WHO expert committee on zoonoses, Third report, World Health Organization Technical Report Series No. 378.

Zung, J.L., S. Lowengrub, M.A. Rudzinska, A. Spielman, S.R. Telford, and J. Piesman, 1989, Fine structural evidence for the penetration of the Lyme disease spirochete *Borrelia burgdorferi* through the gut and salivary tissues of *Ixodes dammini*, Can. J. Zool. **67:1737-1748.**

Appendix 1. Canadian National Collection records of the western black-legged tick, *Ixodes pacificus*, in British Columbia.

Location	Mon.	Yr.	*L	N	Ad	M	F	Tot	Host	Cat.#
Cherry Lake	6	1931	0	3	0	0	0	3	bluegrouse	CNC124
Wellington	9	1929	0	0	1	0	1	1	man	CNC249
Malahat	2	1932	0	0	19	10	9	19	man	CNC296
Malahat	3	1932	0	0	14	8	6	14	man	CNC298
Powell River	4	1932	0	0	1	0	1	1	man	CNC310
Cowichan	4	1932	0	0	3	1	2	3	man	CNC311
Powell River	7	1932	0	0	1	0	1	1	man	CNC323
Courtney	5	1933	0	0	1	0	1	1	man	CNC439
Agassiz	3	1933	0	0	3	0	3	3	man	CNC593
Duncan	12	1910	0	0	2	1	1	2	dog	CNC627
Duncan	1	1934	1	0	1	0	1	2	dog	CNC627
Gleneagles	1	1934	0	0	9	7	2	9	man	CNC634
Tumbo Is	6	1932	0	0	2	0	2	2	silverfox	CNC635
Pender Harbour	5	1929	0	0	1	0	1	1	man	CNC640
Lasquete Is	3	1932	0	0	1	0	1	1	coast deer	CNC697
Vancouver	1	1927	0	0	1	0	1	1	man	CNC699
Tofino	5	1931	0	0	0	0	0	0	Dgssquirrel	CNC702
West Vancouver	10	1933	0	1	0	0	0	1	coastlizard	CNC709
Victoria	10	1933	0	1	0	0	0	1	coastlizard	CNC710
West Vancouver	11	1934	0	0	2	1	1	2	drag	CNC712
Pender Harbour	5	1931	0	0	3	0	3	3	man	CNC713
Vancouver	3	1934	0	0	1	0	1	1	dog	CNC727
Whytecliff		1935	0	0	6	0	6	6	man	CNC814
Caulfield	4	1935	0	0	0	0	0	13	drag	CNC815
Caulfield	9	1935	0	0	18	9	9	18	drag	CNC816
Caulfield	9	1935	0	0	1	0	1	1	dog	CNC817
Caulfield	9	1935	0	3	0	0	0	3	lizard	CNC818
Caulfield	12	1934	0	0	0	0	0	1	man/w	CNC819
Fishermans Cove	4	1935	0	0	0	0	0	4	drag	CNC822
Gleneagles	4	1935	0	8	14	7	7	22	drag	CNC823
Malahat	4	1935	0	0	4	1	3	4	dog	CNC824
Finlayson Arm	4	1935	0	2	1	0	1	3	drag	CNC827
Malahat	4	1935	0	0	1	1	0	1	drag	CNC829
Retreat Cove	4	1935	0	0	2	0	2	2	cat	CNC831
Retreat Cove	4	1935	0	0	0	0	0	0	cow	CNC832
Retreat Cove	4	1935	0	0	0	0	0	0	drag	CNC834
Retreat Cove	4	1935	0	0	1	1	0	1	drag	CNC835
Victoria	4	1935	0	0	1	0	1	1	dog	CNC837
Whytecliff	4	1935	0	0	3	0	3	3	drag	CNC838
Fishermans Cove	4	1935	0	6	5	0	5	11	drag	CNC840
Hope	4	1935	0	0	0	0	0	0	drag	CNC841
Yale	4	1935	0	0	1	1	0	1	drag	CNC842
Caulfield	4	1935	3	7	0	0	0	10	lizard	CNC843
Retreat Cove	4	1935	0	0	6	0	6	6	cow	CNC850
Retreat Cove	4	1935	0	0	0	0	0	0	cow	CNC850a
Ocean Falls	11	1934	0	0	1	0	1	1	man	CNC860

---

*L = larvae, N = nymphs, Ad = adults total, M = males, F = females, Tot = total number of ticks.

Victoria	12	1934	0	0	1	0	1	1	cows	CNC873
Victoria	9	1935	0	0	1	0	1	1	dog	CNC878
Victoria	9	1935	0	0	1	0	1	1	mink	CNC879
Caulfield	7	1934	0	1	0	0	0	1	lizard	CNC1102
Gleneagles	7	1934	12	1	0	0	0	13	lizard	CNC1106
Gleneagles	7	1934	1	1	0	0	0	2	lizard	CNC1113
Gleneagles	7	1934	0	2	0	0	0	2	lizard	CNC1114
Gleneagles	7	1934	0	3	0	0	0	3	lizard	CNC1116
Malahat	8	1934	1	2	0	0	0	3	lizard	CNC1121
Malahat	8	1934	5	5	1	0	1	11	squirrel	CNC1122
Malahat	8	1934	0	1	0	0	0	1	grouse	CNC1124
Malahat	8	1934	0	0	1	0	1	1	man	CNC1125
Horseshoe Bay	8	1934	1	5	0	0	0	6	grouse	CNC1126
Horseshoe Bay	8	1934	0	2	0	0	0	2	lizard	CNC1128
Copper Cove	8	1934	0	0	1	0	1	1	man	CNC1138
Agassiz	8	1934	2	11	6	0	6	19	grouse	CNC1140
Milnes Landing	1	1936	0	0	1	0	1	1	dog	CNC1168
Caulfield	7	1936	0	0	2	1	1	2	man	CNC1213
Caulfield	7	1936	1	1	0	0	0	2	lizard	CNC1217
Caulfield	7	1936	3	2	0	0	0	5	mouse	CNC1218
Fishermans Cove	7	1936	7	0	0	0	0	7	lizard	CNC1221
Kew Beach	7	1936	4	3	0	0	0	7	lizard	CNC1223
Caulfield	7	1936	2	1	0	0	0	3	lizard	CNC1224
Gleneagles	7	1936	0	2	0	0	0	2	lizard	CNC1225
Whytecliff	7	1936	1	1	0	0	0	2	mouse	CNC1227
Caulfield	7	1936	3	0	0	0	0	3	lizard	CNC1235
Howe Sound	7	1936	2	0	0	0	0	2	lizard	CNC1236
Caulfield	7	1935	2	1	0	0	0	3	chipmunk	CNC1247
Gleneagles	7	1935	0	3	0	0	0	3	grouse	CNC1248
Cultus Lake	6	1935	0	0	19	7	12	19	dog	CNC1267
Cultus Lake	3	1935	0	0	5	0	5	5	dog	CNC1268
Abbotsford	1	1937	0	0	0	0	0	0	dog	CNC1273
Pender Harbour	6	1935	0	0	4	0	4	4	man	CNC1277
Victoria	11	1934	0	0	0	0	0	0	dog	CNC1280
Cultus Lake	4	1937	0	0	1	0	1	1	cat	CNC1300
Cultus Lake	4	1937	0	0	1	0	1	1	dog	CNC1301
Cultus Lake	4	1937	0	0	1	0	1	1	dog	CNC1303
Caulfield	4	1937	0	0	1	0	1	1	dog	CNC1304
Caulfield	4	1937	0	0	22	10	12	22	drag	CNC1305
Gleneagles	4	1937	0	0	19	10	9	19	drag	CNC1306
Caulfield	4	1937	0	0	34	13	21	34	drag	CNC1307
Gleneagles	4	1937	0	0	44	33	11	44	drag	CNC1308
Gleneagles	4	1937	0	0	23	12	11	23	drag	CNC1309
Gleneagles	3	1937	0	0	12	7	5	12	drag	CNC1310
Gleneagles	4	1937	0	0	11	6	5	11	drag	CNC1311
Gleneagles	4	1937	0	0	27	15	12	27	drag	CNC1312
Gleneagles	4	1937	0	0	47	24	23	47	drag	CNC1313
Horseshoe Bay	4	1937	0	0	7	5	2	7	drag	CNC1320
Kew Beach	8	1937	1	0	0	0	0	1	mouse	CNC1414
Courtney	4	1938	0	0	1	0	1	1	dog	CNC1474
Cultus Lake	3	1941	0	0	1	1	0	1	goat	CNC1495
Goldstream	1	1938	5	3	1	0	1	9	deer	CNC1503
Gambier Is	7	1939	0	0	0	0	0	0	squirrel	CNC1518
Gambier Is	7	1939	0	0	1	0	1	1	grouse	CNC1520

Agassiz	4	1939	2	0	0	0	0	2	mole	CNC1560
Harrison Bay	4	1941	0	21	41	80	61	143	drag/lizard	CNC1607
Gleneagles	5	1941	2	0	0	0	0	2	grouse(3)	CNC1622
Victoria	1	1939	0	0	0	0	0	0	dog	CNC1715
West Vancouver	2	1940	0	0	0	0	0	0	drag	CNC1735
Cultus Lake	3	1941	0	0	2	0	2	2	man	CNC1749
Alex. Lodge ?	4	1940	0	0	1	0	1	1	dog/MrsC	CNC1775
Caulfield	4	1940	30	27	0	0	0	57	lizard	CNC1786
Harrison	5	1940	0	2	0	0	0	2	lizard	CNC1787
Harrison	5	1940	2	0	0	0	0	2	mouse w-f	CNC1789
Caulfield	5	1940	0	0	4	2	2	4	drag	CNC1791
Harrison Bay	5	1940	0	0	4	2	2	4		CNC1793
Alex. Lodge	5	1940	0	0	0	0	0	0	dog	CNC1795
Fishermans Cove	5	1940	0	0	0	0	0	0	drag	CNC1797
Yale	5	1940	0	0	0	0	0	0	dog	CNC1798
Caulfield	4	1940	0	0	0	0	0	0	dog	CNC1799
Victoria	5	1940	0	24	0	0	0	24	lizard	CNC1903
Coast ?	8	1940	0	1	1	0	1	2	deer	CNC1918
North Vancouver	3	1940	0	0	0	0	0	0	dog	CNC1922
Abbotsford	6	1940	0	0	1	0	1	1	dog	CNC1933
Harrison HS	7	1940	0	0	0	0	0	0	man	CNC1969
Burnaby	5	1941	0	0	1	0	1	1	dog	CNC2037
Cultus Lake	4	1941	0	0	2	0	2	2	goat	CNC2059
Harrison Bay	4	1942	2	2	0	0	0	4	lizard	CNC2166
Gleneagles	5	1943	38	9	0	0	0	47	lizard	CNC2215
Gleneagles	5	1943	0	0	12	6	6	12	drag	CNC2216
Harrison Bay	5	1943	0	0	25	10	15	25	drag	CNC2217
Gambier Is	2	1943	0	0	0	0	0	1	squirrel	CNC2395
Victoria	11	1947	0	0	1	0	1	1	man	CNC2914
Chemainus	5	1948	0	0	0	0	0	1	dog	CNC2926
West Vancouver	9	1948	0	0	1	0	1	1	drag	CNC3352
Harrison Bay	3	1949	0	0	0	0	0	0	drag	CNC3423
West Vancouver	4	1949	0	0	0	0	0	0	drag	CNC3427
Sooke	4	1946	0	0	0	0	0	2	man/c	CNC3606
Victoria	4	1949	0	0	0	0	0	0	dog	CNC3815
Wellington	6	1950	0	0	0	0	0	0	dog	CNC3821
Hardy Is ?	4	1943	0	0	0	0	0	0	deer	CNC3958
North Vancouver	4	1943	0	0	2	0	2	2	dog	CNC3959
Galiano Is	3	1935	0	0	1	0	1	1	man	CNC3960
Hardy Is ?	4	1943	0	0	30	16	14	30	deer	CNC3966
Cultus Lake	4	1961	0	0	22	22	0	22	drag	CNC3986
Cultus Lake	3	1953	0	0	12	6	6	12	drag	CNC4023
S Pender Is	6	1961	0	0	2	0	2	2	man	CNC4190
Hope	5	1955	0	0	1	0	1	1	man	CNC4252
Cultus Lake	4	1948	0	0	0	0	0	9	drag	CNC4316
Cultus Lake	4	1959	0	0	0	0	0	15	drag	CNC4317
Vancouver Is	5	1964	0	0	1	0	1	1		CNC5265
Mission Flats	0	1963	33	6	1	1	0	40	sheep/lizard	CNC4947
L Fraser Valley	5	1963	0	0	1	0	1	1	man	CNC5145
Cultus Lake	3	1963	0	0	10	2	8	10	drag	CNC5172
Florence Lake	11	1964	0	0	5	2	3	5	dog/cat/man	CNC5216
North Vancouver	12	1959	0	0	1	0	1	1		CNC5218
Nanaimo	7	1959	0	0	2	1	1	2	man	CNC5219
Mt Finlayson	4	1963	0	0	0	0	0	0	drag	CNC5233

Horseshoe Bay	4	1963	0	0	0	0	0	0	drag	CNC5234
Yale	4	1965	0	0	4	2	2	4	drag	CNC5330
Kawkawa Lake	4	1965	0	0	4	2	2	4	drag	CNC5331
Abbotsford	4	1965	0	0	1	0	1	1	dog	CNC5298
Stump Lake	4	1965	0	0	1	0	1	1	drag	CNC5365
Fishermans Cove	5	1966	0	0	21	11	10	21	drag	CNC5449
Boston Bar	4	1967	0	0	10	0	10	10	drag	CNC5483
North Vancouver	2	1968	0	0	3	3	0	3	drag	CNC5517
Agassiz	2	1968	0	0	24	8	16	24	drag	CNC5537
Yale	2	1968	0	0	2	0	2	2	drag	CNC5539
Pemberton	5	1968	0	0	22	9	13	22	drag	CNC5564
Hope/Ross Lake	5	1968	0	0	1	0	1	1	drag	CNC5565
Hope/Ross Lake	5	1968	0	0	0	0	0	0	deer	CNC5565
Brocklehurst	12	1968	0	0	1	0	1	1	dog	CNC5587
Vancouver	10	1968	0	0	1	0	1	1	man	CNC5613
Texada Is	3	1970	0	0	0	0	0	3	dog	CNC5625

Appendix 2. Collection records for the northern alligator lizard, *Gerrhonotus coeruleus principis*, in British Columbia. (Royal British Columbia Museum Collection as of 1991)

Date	Number	Locality
March 22, 1928	1	Victoria, V.I.
May, 1926	1	Victoria, V.I.
May 6, 1939	6	Cowichan Lake, V.I.
April 13,1925	1	Goldstream, V.I.
April 17, 1938	1	Sidney, V.I.
June 20, 1910	1	Hope
July 10, 1914	1	Okanagan Landing
May, 1929	1	Vedder River
May 25, 1926	4	Creston
June 1931	1	Crescent Beach
September 15, 1931	1	Howe Sound
April 11, 1931	1	Point Grey
March 15, 1940	1	Victoria, V.I.
June 10, 1926	1	Errington, V.I.
May, 1926	1	Creston
April 13, 1926	1	Goldstream, V.I.
April 13, 1926	1	Creston
August 19, 1932	2	Keats Island
August 7, 1941	1	Lumby
June 8, 1942	1	Victoria, V.I.
July 28, 1943	1	Cortes Island
April 15, 1944	1	Victoria, V.I.
May 27, 1945	1	Oyama
September 1, 1945	1	Princeton
June 11, 1946	1	Read Island
April 16, 1970	4	Victoria, V.I.
May 23, 1970	1	Victoria, V.I.
May 2, 1970	1	Cedar, V.I.
May 3, 1970	1	South Wellington, V.I.
May 30, 1970	1	Extension
May 5, 1970	2	Cedar, V.I.
May 25, 1970	3	Port Alberni, V.I.
May 18, 1970	1	Victoria, V.I.
August 15, 1941	1	Koksilah River
April 1, 1976	1	Woss, V.I.