THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ENTOMOLOGY

Longitudinal Survey on Ticks and Rodents in Center County, Pennsylvania

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SPRING 2024

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Veterinary and Biomedical Sciences
with honors in Entomology

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ABSTRACT

With the resurgence of protected forests in the past century, alongside white-tailed deer and white-footed mice to support the parasite, tick-borne disease have grown in concern over the years. In order to understand the spread of disease across a human population, one must understand the underlying parasite and reservoir populations keeping the disease endemic to the region. I. scapularis, the primary vector for many of these diseases tends to feed on white-footed mice; chipmunk and red-backed vole blood feeds just as well. The variance in behavior between juvenile and adults age classes may also change the associated tick burden. Data from 2018-2022 in Center County, Pennsylvania game lands was analyzed. While chipmunks or white-footed mice may lead in burdens in a given year, red-backed voles consistently carried the least. Especially in the last two years, juveniles consistently carried larger burdens over adults. Pennsylvania sits in the middle of Midwest and coastal America with very different tick and hosts populations and this data sheds light what is both an important and often unclear region.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Machtinger for her help and guidance through this project and in the function of lab work. I would like to thank Dr. Valcin for her help in teaching about regression and other analysis techniques. I cannot thank the others in the lab enough for allowing me to use their data in the first place, especially Kylie Green who helped with the protocol.

Chapter 1 Introduction

It flies without wings, it crisscrossed continents while only being a few millimeters across, it reconquered territory without eyes. On the back of birds, mice, humans and others, I. scapularis has cemented itself as endemic. Passing disease between reservoirs and itself, the ectoparasite preserves many diseases in it environment. It is impossible to even think of combatting these diseases that cause such economic and human cost without understanding the underlying dynamics of the reservoir and the parasite.

Chapter 2 Literature Review

Sub-Chapter 1: Ticks as Vectors

When discussing data over the course of five years, almost everything changes. The habitat, the treatments, even the species measured changes. The deer tick, often referred to as the black-legged tick remains the one constant, the dependent variable in everything, chelicerae dug deep into the research. The ultimate, fundamental goal of reducing the spread of tick-borne disease necessitates this focus on the arthropods themselves.

Ixodes scapularis, the deer tick, evolved over the course of millions of years to be one of the preeminent ectoparasites. In contrast to other vectors of concern like mosquitoes or flies, the tick bites and holds onto the host, often for days. The capitulum, the pseudo-head of the organism, houses all the machinery needed for the task. Palps, oblong structures on the sides of the capitulum, provide tactile information to the parasite similar to the whiskers of a cat. This allows guidance to proper feeding points. The chelicerae, jetting from the anterior end of the capitulum, have cheliceral digits on the ends to cut into host tissue and blood vessels. Ventral to this structure, the hypostome hooks the tick into the host and guides blood into the alimentary channel proper. The pharynx posterior to this channel provides the necessary force through the vacuum created by the dilator muscles. The ducts from the salivary glands join the rest of digestive tract at this point. Constrictions of the constrictor muscles eventually push the meal through the esophagus and midgut (Sonenshine et al., 2021).

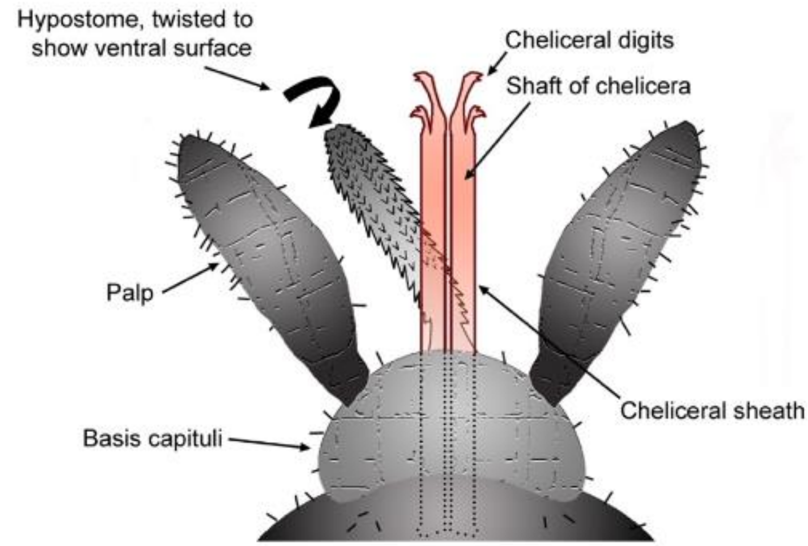

Figure 1: Tick mouthparts with ventral side down. From Sonenshine et al., 2021

Beyond the storage of many pathogens, the salivary glands of the parasite serve many functions. The cells within the gland secrete various compounds through granules to assist in feeding on the host. They may secrete cement components to stick to the surface. Glycoproteins assist in preventing immune and hemostatic responses to the puncture wound (Sonenshine et al., 2021). Often pathogens will enter the tick via the midgut via the blood meal. B. burgdorferi, for example, travels through the midgut wall into the hemolymph, ending up in the salivary glands, ready for expulsion into the next host (Pal et al., 2004). The pathogens often bind to the inside of the gland such as B. burgdorferi with OspC (Sonenshine and Macaluso, 2017). More than just help in digesting, the salivary glands remain the cornerstone to the tick's evolutionary success and pathogen transmission ability.

While the adults are of most concern when discussing disease transmission to humans and pets, the nymphs and larvae have to feed on a small mammal host first. I. scapularis in central Pennsylvania operates on a two-year life cycle. In year 1, larvae emerge and quest to find a small mammal, often a white-footed mouse, to take its first blood meal. Regardless of if the larvae find a blood meal, it then overwinters. The larvae activity peaks in mid-spring (eggs laid the year before but could not find a blood meal as larvae) and mid-summer (larvae hatched and fed in the same year). In year 2 after the winter, the larvae molt into a nymph and again takes a blood meal. The nymphs' activity peak occurs largely occurs within the first larval peak. The nymph then molts into an adult to eventually lay eggs in year 3 (Simmons et al., 2015). In order to disease to spread between the tick and host populations, uninfected larvae must bite an infected host after an infected nymph bite said host. If the host is a white-footed mouse, as it often is in central Pennsylvania, this interaction must happen in the same year as the lifespan for the rodent is only about a year. Lyme, among other tick-borne diseases, is of such concern in Pennsylvania in part because of quirks in the activity between larvae and nymphs. In the Midwest, larvae still quest in peaks around the same time. The greater temperature swings between summer and winter, compared to Pennsylvania and coastal United Sates, induces premature diapause in the larvae (Gatewood et at., 2009). The population questing in midspring due to this diapause vs questing in the mid-summer are about equal (Simmons et al., 2015). This results in a substantial proportion of the tick larvae population feeding on uninfected host, before any potentially infected nymphs could. Pennsylvania larvae, by contrast, quest mostly in the midsummer. More larvae feed after the infected nymphs and therefore tick-borne diseases can cross tick and host populations easier.

Sub-Chapter 2: Rodents and Reservoirs

The white-footed mouse (WFM), the tiny rodent that it is, dominates the literature on I. scapularis, especially in Central Pennsylvania. Its behavior and sheer population size makes it conducive to feed ticks and act as a reservoir to various diseases. The rodents generally live in solitary environments. Females tend to have relatively smaller, exclusive ranges. Male ranges tend to overlap but encompass a larger area. Still, WFM do not pair bond, they do not form proper social hierarchies as seen in many other rodent species. The closest would be around weaning litters, especially toward the fall. The father would nest with the pups and lead in scavenging with them. Females may nurse litters from sisters in the nest as well. WFM would nest communally during the winter. Populations start to spike starting in the spring peaking around the late summer. WFM reach sexual maturity at 3-4 weeks at which point they disperse out from the parental nest (Vessey & Vessey, 2007). They tend to nest in areas with relatively high densities of low-lying vegetation (M'Closkey & Lajoie,1975). This provides enough cover from predators as well as structure to nest in. This centralizes populations, providing easy areas of blood meals for parasites like the tick. WFM, through occasional communal nesting together with rapid dispersal, easily spread ticks across their massive population.

The second most abundant species in the analysis is the red backed vole (RBV). They hold many similarities to the WFM, adapting to their local environment. They tend to live in high moisture forests, feeding on leaves, berries, fungi insects among others. Due to their ability to carry B burgdorferi as well as similar burdens of ectoparasites, many have expressed concern of the ability of the rodent to carry the black legged tick. The literature itself does not bore out this suspicion. White footed mice on average carry ten times the ticks compared to their red-backed counter parts. Although mostly theoretical in the context of red-backed voles, white footed mice tend exhibit a more ineffective immune response and poorer grooming behavior (Brown et al., 2023). Especially with their young RBV tend exhibit more prolific grooming (Gromov, 2009). Although in the shadow of the white-footed mouse, in order to properly represent central PA's ecosystem, the red backed vole as an effective carrier of ticks and Lyme should be included.

Although not that common in central PA relative to the WFM, the chipmunk carries unique attributes in its ability to act as a host for ticks. The main advantage is the longer life span. As noted earlier, in order for Lyme or similar tick-borne diseases to spread across a tick population, the larvae must feed on the host after an infected nymph does. Because the WFM only survives for about a year, carrying the pathogen through winter for the larvae is highly unlikely; this sequence must be over the course of a single year to be effective. The chipmunk lives for 3-4 years and can carry the pathogen across the winter (Sidge et al., 2021). The scenario where differing population peaks would inhibit disease transmission is simply less likely to occur with the more long-lived rodent. The chipmunk also does not suffer from the same low tick counts of the red-backed vole, with burdens equaling or exceeding WFM. The main limitation in the effectiveness of chipmunks as a host is their population size. In the Midwest, where WFM can crash in response to drought, chipmunks can become the preeminent host in an area (Slajchert et al., 1997). In the Northeast however, the WFM dwarf chipmunks in population. Still with their long lives, the chipmunks must be included in order to model the local ecology.

Sub-Chapter 3: Transmission in Other Regions

Most of the research on interactions between WFM and ticks focuses on the east coast of the United States. Those focusing on chipmunks tend to look at the Midwest especially around Michigan as noted earlier with swings in the climate allowing for lower WFM populations (Slajchert et al., 1997). Being geographically situated between the two, central Pennsylvania lacks the firm foundation to establish population dynamics as they do. However, due to high WFM population and a similar climate, the region should operate similar to the east coast (Simmons et al., 2015). In general, adults have higher burdens relative to juveniles (Kiffner et al 2010). Smaller hosts carried more than the larger ones (Brunner and Ostfield, 2008). This does not seem like a strong correlation as the counterfactual of larger host carrying larger burdens does occur (Caron-Lévesque et al., 2023). Males tend to have higher burdens than their female counter parts (Brunner and Ostfield, 2008). This mainly stems from larger territorial ranges of the male population. (Schug et al., 1991).

Chapter 3 Methods

Sub-Chapter 1: Data Collection

Although the data across the five years were initially for different purposes, the protocol across them was largely the same. Trapping occurred around four nights in a trapping week, two weeks per month, from April to October in the game lands in and around State College, PA; this did differ slightly between the varying experiments within the five-year period. Thirty perforated Sherman traps (LFAHD folding trap, 7.62 × 8.89 × 22.86 cm, Sherman Trap Company, Tallahassee, FL) were placed 10m apart in a general line in a given transect: primed in the evening and then collected the next morning. They were baited with a combination of peanut butter, oats, sunflower seeds, apple slices and some sort of bedding, usually cotton or a synthetic analog.

After collection, filled traps would be brought to a central location for data collection where the animal would be anesthetized with isoflurane. It received an ear tag (Stoetling Co., Wood Dale, IL) or the number was recorded if it had one already. Number of ticks was recorded as well as general morphometrics such as sex, life stage (adult or juvenile), weight, body length, right hind limb length, and right ear length. Although not used in this thesis, other measures were taken for other experiments. Tissue samples were collected via 2-mm ear punch (Kent Scientific, Torrington, CT) and placed in RNAlater Stabilization Solution (Thermo Fisher Scientific, Waltham, MA). Blood samples were collected via submandibular puncture using a 4-mm Goldenrod lancet (Braintree Scientific, Braintree, MA) and stored on filter paper in microcentrifuge tubes. All samples were kept on ice until transported to the laboratory and stored at 4°C. After data collection, the animals were released at their captured location.

Sub-Chapter 2: Data Organization and Cleaning

The first issue when viewing such data is the possibility of double counting ticks. Through the method above, one cannot distinguish any given tick on a given host versus any given tick on the same host a week later. In order to entirely prevent this, the analysis excluded any host caught a second time within a week of the first catch. A host caught a third time would be counted even if it was within the week timeframe of the second catch as long as it did not overlap with week period of the first. This ensures a tick feeding on a given host is never counted twice.

The regression compared the effects of age class and species on total tick count. Due to their lack of non-WFM hosts, species was excluded from a predictor for the 2020-22 regressions. Other calculations include abundance, mean number of ticks on given host, prevalence, percentage of hosts carrying at least one tick, and intensity, mean number of ticks on a host with at least one tick. The goal would be those of the general trends of the regression would holds through other measurements; would the same species with higher burdens also be more likely to fall victim to tick parasitism in the first place.

Chapter 4 Results

Sub-Chapter 3: Regression Analysis

Table 1: Regression Analysis 2018. This table represents the data set of hosts collected in 2018. J refers to the Juvenile age class. RBV and WFM refer to the red-backed vole and white-footed mouse respectfully. The coefficients are relative to the adult age class and chipmunk.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	6.467	0.995	6.50	0.000	
Age class					
J	1.02	1.05	0.98	0.330	1.00
Species					
RBV	-6.38	1.12	-5.71	0.000	4.20
WFM	-3.34	1.02	-3.28	0.001	4.20

Table 2: Regression Analysis 2019. This table represents the data set of hosts collected in 2019. J refers to the Juvenile age class. RBV and WFM refer to the red-backed vole and white-footed mouse respectfully. The coefficients are relative to the adult age class and chipmunk.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.368	0.784	6.85	0.000	
Age class					
J	0.676	0.551	1.23	0.220	1.02
Species					
RBV	-4.844	0.811	-5.98	0.000	4.96
WFM	2.744	0.855	3.21	0.001	5.01

Table 3: Regression Analysis 2020. This table represents the data set of hosts collected in 2020. J refers to the Juvenile age class. Only white-footed mice were collected and analyzed this year. The coefficient is relative to the adult age class.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.371	0.741	11.29	0.000	
Age class					
J	3.91	2.61	1.50	0.136	1.00

Table 4: Regression Analysis 2021. This table represents the data set of hosts collected in 2021. J refers to the Juvenile age class. Only white-footed mice were collected and analyzed this year. The coefficient is relative to the adult age class.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	6.052	0.314	19.26	0.000	
Age class					
J	2.065	0.719	2.87	0.004	1.00

Table 5: Regression Analysis 2022. This table represents the data set of hosts collected in 2022. J refers to the Juvenile age class. Only white-footed mice were collected and analyzed this year. The coefficient is relative to the adult age class.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.782	0.276	20.91	0.000	
Age class					
J	2.313	0.759	3.05	0.002	1.00

The data from the regression largely demonstrates predictors in line with the literature. RBV consistently carry the lowest tick burden relative to the other two species. This is likely due to a better immune and grooming response to the ticks as noted earlier. Juveniles also tend to carry a higher burden relative to adults, at least in WFM. 2018 and 2019, where the other two species are present, did not establish age class as a statistically significant factor in tick burdens. The idea of juvenile carrying larger burdens does contradict some of the literature which states older animals should have larger burdens (Kiffner et al 2010). The younger mice lack much of the acquired immunity that would inhibit tick feeding (Ornstad et al., 2002). They may exhibit different behaviors such as grooming and feeding ranges which would predispose them toward tick feeding. With the older demographic simply being sexually mature adults, they are likely not old enough to predispose them to the immunocompromised state and therefore higher burdens. The largest inconsistency of the regression revolves around the burden dynamic between WFM and chipmunks. Chipmunks are expected to carry equal or higher burdens in areas where they dominate. In this area of Pennsylvania however, WFM far outstrip their long-lived counterparts in population; this dynamic may not hold true. As seen in Table 1 in 2018, chipmunks had a statically higher burden (P =.001) relative to WFM while in Table 2 and 2019, inverse is true (P=.001). This likely stems from the poor sample size of chipmunks in 2018 (n=15) and 2019 (n=19). There may be also underlying confounding factors such as preference for certain areas or transects that varied between years, hence the steep rise of mice burdens after 2018.

Sub-Chapter 4: Morphometrics

Table 6: Weight and Length in Various Hosts. CHIP, RBV, and WFM refer to chipmunks, red-backed voles, and white-footed mice respectfully. The Juvenile and Adult age classes are represented by J and A respectfully. Null values indicate no suitable hosts of that type were measured. SE refers to standard error.

		Weight		Body Length	
		Mean (SE)	Count	Mean (SE)	Count
CHIP	J	Null	0	Null	0
	A	66.75 (8.112)	4	12.2 (0)	1
RBV	J	16.68 (.946)	5	6.96 (.202)	24
	A	25.92 (.549)	118	9.18 (.098)	111
WFM	J	15.27 (.207)	275	7.37 (.098)	74
	A	22.23 (.123)	1678	8.49 (.037)	712

Table 7: Right Hind Limb Length and Right Ear Length in Various Hosts. CHIP, RBV, and WFM refer to chipmunks, red-backed voles, and white-footed mice respectfully. The Juvenile and Adult age classes are represented by J and A respectfully. Null values indicate no suitable hosts of that type were measured. SE refers to standard error.

		Right Hind Limb Length		Right Ear Length	
		Mean (SE)	Count	Mean (SE)	Count
CHIP	J	Null	0	Null	0
	A	13 (0)	1	1.5 (0)	1
RBV	J	1.64 (.033)	24	0.96 (.034)	24
	A	1.77 (.035)	111	1.13 (.024)	110
WFM	J	1.88 (.030)	32	1.35 (.013)	275
	A	1.99 (.021)	369	1.45 (.006)	1622

The morphometrics generally do not add any not known via the regression. Juveniles tend to be smaller than adults which predisposes them toward higher tick burdens. The trend tends to not hold between species as seen above with the RBV and WFM being of similar sizes. The chipmunk tends to the largest of the three species. In general, morphometrics tends to act as poor predictor of tick burden besides a small preference of smaller animals within a species (Brunner and Ostfield, 2008).

Sub-Chapter 5: Other Metrics

Table 8: Abundance in Various Hosts. Abundance was calculated as the mean number of ticks on a given host category. CHIP, RBV, and WFM refer to chipmunks, red-backed voles, and white-footed mice respectfully. The Juvenile and Adult age classes are represented by J and A respectfully. Null values indicate no suitable hosts of that type were measured. SD refers to standard deviation.

		2018		2019		2020		2021		2022	
		Mean (SD)	Count	Mean (SD)	Count	Mean (SD)	Count	Mean (SD)	Count	Mean (SD)	Count
CHIP	J	Null	0	null	0	null	0	null	0	null	0
	A	6.47 (8.33)	15	5.37 (5.08)	19	null	0	null	0	null	0
RBV	J	.50 (.50)	2	.52 (1.24)	25	null	0	null	0	null	0
	A	.11 (.31)	56	.59 (1.21)	263	null	0	null	0	null	0
WFM	J	4.25 (3.27)	12	9.68 (6.84)	19	12.28 (16.41)	18	8.12 (8.94)	137	8.09 (8.47)	116
	A	3.12 (3.87)	336	7.92 (5.77)	89	8.69 (10.62)	205	6.05 (7.20)	581	5.81 (7.47)	754

Table 9: Other Metrics. Abundance was calculated as the mean number of ticks on a given host category. Prevalence is calculated as the percentage of host carrying at least one tick. Intensity is the mean number of ticks on hosts with at least one tick. CHIP, RBV, and WFM refer to chipmunks, red-backed voles, and white-footed mice respectfully. Null values indicate no suitable hosts of that type were measured. SD refers to standard deviation.

		2018	2019	2020	2021	2022
Abundance (SD)	CHIP	6.47 (8.33)	5.37 (5.08)	null	null	null
	RBV	.12 (.33)	.58 (1.21)	null	null	null
	WFM	3.16 (3.85)	8.23 (6.01)	8.69 (10.62	6.45 (7.61)	6.09 (7.64)
Prevalence	CHIP	60%	89%	null	null	null
	RBV	13%	31%	null	null	null
	WFM	76%	92%	87%	76%	78%
Intensity (SD)	CHIP	10.78 (8.23)	6.00 (5.01)	null	null	null
	RBV	1.00 (0)	1.91 (1.51)	null	null	null
	WFM	4.15 (3.92)	8.98 (5.72)	9.93 (10.80	8.21(7.69)	7.79 (7.84)

The other metrics reinforce the findings of the regression. The regression model used abundance as the varying factor so as expected it follows the same trends: RBV consistently had the lowest burden: juveniles tend to have equal or higher burdens, dynamics between CHIP and WFM are unclear due to poor sample sizes. As seen in Table 9, RBV were less likely to carry a burden and if they did, it tended to be lower than those of the other species. This reinforces the idea of differing behaviors, internal immune responses, something protecting the host from parasitism. Intensity continues the inconsistency between WFM and CHIP while prevalence shows equal or higher rates of parasitism in WFM relative to CHIP.

Chapter 5 Conclusion

Long have these animals unwittingly spread disease across continent. The host's specie sand age class largely demonstrated trends consistent with the literature. Although not negligible, the lack of chipmunks demonstrates distribution much more similar to the coastal regions of the United Sates vs the Midwest. Juveniles have also consistently shown higher burdens. The underlying demographics allow for a better understanding of how ticks, and by proxy the pathogens they carry, spread across central Pennsylvania.

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Academic Vita

Pre-Veterinary Education

Pennsylvania State University- Schreyer Honors College — Class of 2024

- Majoring in Veterinary and Biomedical Sciences

Work with Mice in Research- through CITI Program — 2023

Bergen County Community College — 2020

- Introduction to Veterinary Technology
- Veterinary Medical Terminology

Animal and Medical Experience

Veterinary Entomology Lab at PSU — 2022-present

- Volunteer to tag, anesthetize, and draw blood from white footed mice populations to test tick repellent methods.
- Model tick and white footed mice population distribution for 4000 subject longitudinal survey to better understand relationships between sex, age, habitat, and tick bites

Volunteer Veterinary Assistant at Animal Hospital of Hasbrouck Heights — May to August 2023

- Monitored heart rate, respiratory rate, among other vital during surgery and dentistry procedures to maintain stable patients for veterinarian
- Assisted handling aggressive patients during exams to minimize stress
- Drew up vaccines and medications for patients under technician supervision

Bergen County Zoo Educator — May to August 2022

- Hosted programs about zoo animals to hundred-person audiences to encourage interests in conservation and wildlife sciences
- Experienced in handling various animals such as rabbit, cockroach, guinea pig, hedgehog, bearded dragon, box turtle, and ball python
- Marshaled and coordinated fellow employees during county wide events like Pride and World Ocean Day with about a thousand attendees
- Managed education department activities and educational animal exercise on weekends

Internship at Valley Health System — 2020-2021

- Gained knowledge of hospital administration and operation
- Learned from specialists about field advancements in the medical field

Leadership

Scholar Ambassadors — 2021-present

- Inspire hundreds of students per year about honors college opportunities via tours and panels
- Engage with honors college alumni to ensure continued communication with current students

Merit Badge Counselor - Citizenship in the World and in the Nation — 2020-present

- Pioneered new online citizenship merit badge classes and lessons for local BSA troop.
- Coordinated weekly zoom meetings to cover essential content

Eagle Scout — 2019

- Budgeted and raised funds for historical collection of marine memorabilia such as helmets, radios, and uniforms for the West Hudson Detachment of the Marine Corps. League
- Delegated duties to group of ten Boy Scouts to complete project encompassing a total of 124 service hours