Ecology of ticks & *B. burgdorferi*

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The British tick fauna

22 species recorded
19 Hard ticks (Ixodid)
- 15 *Ixodes* species
- *Dermacentor reticulatus*
- *Haemaphysalis punctata*
- *Hyalomma marginatum* – (imported by migrant birds)
- *Rhipicephalus sanguineus* (imported by pets, not native)

3 Soft ticks (Argasid)
- 2 *Argas/Carios*
- 1 *Ornithodoros* – rarely imported on seabirds
Hard ticks (Ixodid ticks)

- Live outdoors, some are *nidiculous* (i.e. nest-dwelling); arduous lifestyle, require a chance meeting with animals.

- Once attached, they **engorge slowly**, dispersed by their hosts - long distances on migratory birds.

- Spend most of their time ‘questing’ for blood hosts and attached to their hosts - high mortality rates due to host grooming, predation and environmental factors.

- **Hard sclerotised plate** (scutum), forward-projecting capitulum.

- Except in male, all stages have a small scutum to allow them to **engorge**.

- In the male the scutum completely covers its body. It does not engorge. It has **armoured plates**, to retain moisture levels.
Ixodes – specialist parasites of wildlife

7 species are principally bird ticks:

- **Ixodes arboricola**
  - Tree-hole nesting birds
- **Ixodes caledonicus**
  - Cliff nesting birds
- **Ixodes frontalis**
  - Passerine birds
- **Ixodes lividus**
  - Sand martins
- **Ixodes rothschildi**
  - Burrow nesting birds
- **Ixodes unicavatus**
  - Coastal birds
- **Ixodes uriae**
  - Cliff colony birds

Humans are rarely bitten, only as accidental hosts.
6 species are principally mammal ticks:

- *Ixodes acuminatus*: Small mammals
- *Ixodes apronophorus*: Wetland mammals
- *Ixodes canisuga*: Fox tick
- *Ixodes ventalloi*: Rabbit tick
- *Ixodes trianguliceps*: Burrowing small mammals
- *Ixodes vespertilionis*: Horseshoe bats

Humans are rarely bitten, only as accidental hosts.
**Ixodes** – parasites of humans

2 species are mammal ticks but do bite humans:

*Ixodes ricinus*
Deer/Sheep/Pasture/Caster bean tick

*Ixodes hexagonus*
Hedgehog tick

Humans are occasional hosts

Humans are frequent hosts
Hedgehog tick, Ixodes hexagonus
Unusual & Imported ticks

Importation of non-native ticks & EU policy

Rhipicephalus sanguineus

Hyalomma marginatum

Monitoring for ticks on migratory birds

970 birds sampled, 7% infested, 21% *Hyalomma marginatum*

Wheatear, whitethroat, Sedge warbler, Redstart
**Ixodes ricinus** (Deer/sheep tick)

- **Larva** – 3 pairs of legs
- **Male** – scutum covers entire body
- **Nymph and Female** are similar – female much larger with genital aperture and porose area

**Measurements**:
- Larva: 1.4 mm
- Nymph: 1.4 mm
- Adult male: 3.3 mm long
- Adult female: 3.3 mm long
Nationwide tick surveillance

Tick distribution in the UK

~8000 ticks since 2005 from TRS

Public, GPs, Vets, Wildlife charities

Further 10,000 ticks from field studies

Advice to public on tick bites

Advice on managing ticks in gardens

Tick awareness material

Tick identification to public, GPs and Vets

tick@phe.gov.uk
Public Health England

BRC Tick surveillance

**Ixodes ricinus distribution**

(1880 - 2004)

(2005 - 2009)

Contains Ordnance Survey data © Crown copyright and database rights 2013
Using surveillance data for predictive mapping
Mapping *Ixodes ricinus* at a landscape scale, e.g. national park / AONB

Mapping ticks in an AONB/National Park

Surveying publicly accessible sites

Eco/environ variables

Refining risk

Predictor variables (landscape)
- W, SW, SE and E aspects
- Calcareous & neutral grassland; heathland
- Impermeable soils
- Impermeable bedrock & superficial geologies
- Presence of cattle & sheep grazing
- Reduced slope
- High soil moisture
- Lower midday temperatures

Identifying risk factors
Mapping *Ixodes ricinus* at a habitat scale - implications for woodland management

1. Management that promotes sunny south-facing rides promote nymph activity
2. Additional ride management is recommended in these locations
3. Regular mowing (and raking) of 1m path-side strip in spring should:
   a. Keep nymph activity down
   b. Reduce public exposure
   c. Benefit rare herb growth and bare-soil invertebrates
4. Mat/mulch management – raking/stacking of leaf litter
   a. Limits survival of ticks
   b. Promotes biodiversity – reptiles, herbs, invertebrates
5. Scalloped edges in bramble areas
6. Spot treatment with bracken herbicide in hot-spots

Figure 2: Schematic depiction of ride management strategies (after Warren & Fuller, 1993)
Example of peri-urban tick & *Borrelia* area
Tick activity for seasonal forecasting

Tick abundance

0
2
4
6
8
10
12

Temperature

0
5
10
15
20
25
30

Vegetation height

0
10
20
30
40
50
60
70

Ticks/10m

Temp

Vegetation

Seasonal activity of questing ticks:

Weekly/fortnightly transects

20 - 40 across England

Linked to synoptic weather stations and Met Office data
Mapping *Borrelia* infection rates in ticks across a landscape – South Wiltshire

- Heterogeneity of infection rates
- Impact of habitats and hosts
- Differences in genospecies rates

![Wiltshire tick abundance](image)

Understanding ecological drivers of *Borrelia burgdorferi* – heterogeneity of prevalence at a regional scale
Ticks abundance (per sq metre) by location across a landscape (black spring 2013, grey spring 2014)
Tick abundance (per sq metre) by location across a landscape (black autumn 2013, grey autumn 2014)
Tick abundance by habitat - south Wiltshire landscape study

Ticks being tested for *Borrelia*
Impact of habitat corridors on *Ixodes ricinus* - the role of field margins as habitats for ticks

Understanding impact of habitat connectivity on ticks across landscapes
## Prevalence rates of *Borrelia* in ticks

<table>
<thead>
<tr>
<th>Location</th>
<th>Habitat</th>
<th>Nymphs tested</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coed y Brenin, Gwynedd</td>
<td>Mixed woodland</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Dalby, Yorkshire</td>
<td>Mixed woodland</td>
<td>237</td>
<td>8.02</td>
</tr>
<tr>
<td>Glisland, Northumbria</td>
<td>Conifer/grassland</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>Gisburn Forest, Lancashire</td>
<td>Conifer/grassland</td>
<td>253</td>
<td>0.79</td>
</tr>
<tr>
<td>Graig-fechan, Clwyd</td>
<td>Moorland</td>
<td>212</td>
<td>0.94</td>
</tr>
<tr>
<td>Hampfell woods, Cumbria</td>
<td>Decid woodland</td>
<td>245</td>
<td>7.75</td>
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<tr>
<td>Harwood, Northumberland</td>
<td>Conifer/grassland</td>
<td>167</td>
<td>0</td>
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<tr>
<td>Kielder Forest, Northumberland</td>
<td>Conifer/grassland</td>
<td>185</td>
<td>0.54</td>
</tr>
<tr>
<td>Loch Doon, Ayrshire</td>
<td>Conifer/grassland</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Madie Forest, Dumfries</td>
<td>Decid woodland</td>
<td>232</td>
<td>8.19</td>
</tr>
<tr>
<td>Mell Fell, Cumbria</td>
<td>Decid woodland</td>
<td>28</td>
<td>3.57</td>
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<tr>
<td>Naddle Forest, Cumbria</td>
<td>moorland</td>
<td>249</td>
<td>0</td>
</tr>
<tr>
<td>4 woodlands, Wiltshire</td>
<td>Woodland</td>
<td>215</td>
<td>1.4</td>
</tr>
<tr>
<td>Exmoor, Somerset</td>
<td>Woodland</td>
<td>120</td>
<td>9.9</td>
</tr>
<tr>
<td>4 woodlands, New Forest, Hants</td>
<td>Woodland</td>
<td>120</td>
<td>0.8</td>
</tr>
<tr>
<td>Richmond Park, London</td>
<td>Parkland</td>
<td>83</td>
<td>0</td>
</tr>
<tr>
<td>Swinley, Surrey</td>
<td>Pine woodland</td>
<td>94</td>
<td>2.12</td>
</tr>
<tr>
<td>Salisbury, Wiltshire</td>
<td>Urban fringe</td>
<td>111</td>
<td>6.3</td>
</tr>
<tr>
<td>3 sites, Dartmoor, Devon</td>
<td>Woodland/moorland</td>
<td>107</td>
<td>8.41</td>
</tr>
<tr>
<td>Cirencester, Glos</td>
<td>Woodland/edge</td>
<td>252</td>
<td>5.62</td>
</tr>
<tr>
<td>South Downs, Suffolk</td>
<td>Woodland/edge</td>
<td>252</td>
<td>1.93</td>
</tr>
<tr>
<td>Thetford, Norfolk</td>
<td>Woodland/edge</td>
<td>253</td>
<td>2.08</td>
</tr>
<tr>
<td>Wytham, Oxon</td>
<td>Woodland/edge</td>
<td>9</td>
<td>0</td>
</tr>
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</table>

Bettridge et al. 2013; Hansford et al. 2014; Layzell et al.
### Genospecies prevalence

<table>
<thead>
<tr>
<th>Study</th>
<th>Genospecies</th>
<th>Prevalence</th>
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</thead>
<tbody>
<tr>
<td>Bettridge et al. 2013</td>
<td>B. valaisiana</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>B. garinii</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>B. afzelii</td>
<td>3%</td>
</tr>
<tr>
<td>Hansford et al. 2014</td>
<td>Glos</td>
<td>5.5%</td>
</tr>
<tr>
<td></td>
<td>B. garinii</td>
<td>3.2%</td>
</tr>
<tr>
<td></td>
<td>B. valaisiana</td>
<td>2.3%</td>
</tr>
<tr>
<td>South Downs</td>
<td>all</td>
<td>2%</td>
</tr>
<tr>
<td>Norfolk</td>
<td>B. garinii</td>
<td>2.2%</td>
</tr>
<tr>
<td></td>
<td>B. afzelii</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

Huge variation in genospecies dominance geographically

-> Implications for clinical presentation
## Ongoing work – National Parks / AONBs

<table>
<thead>
<tr>
<th>Region</th>
<th>Sites</th>
<th>Years</th>
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</thead>
<tbody>
<tr>
<td><strong>North of England</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kielder Forest (Northumberland)</td>
<td></td>
<td>2014, 2015</td>
</tr>
<tr>
<td>Grizedale forest, Lake District</td>
<td></td>
<td>2014, 2015</td>
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<tr>
<td>Forest of Bowland (Lancashire)</td>
<td></td>
<td>2014, 2015</td>
</tr>
<tr>
<td>Dalby Forest, North Yorkshire Moors</td>
<td></td>
<td>2014</td>
</tr>
<tr>
<td><strong>Central &amp; Eastern England</strong></td>
<td></td>
<td></td>
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<tr>
<td>Cotswolds (Gloucestershire)</td>
<td></td>
<td>2014</td>
</tr>
<tr>
<td>Thetford Forest (Norfolk)</td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>South Downs (Sussex)</td>
<td></td>
<td>2014, 2015</td>
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<tr>
<td>Richmond Park (London)</td>
<td></td>
<td>2014, 2015</td>
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<tr>
<td>Cannock Chase AONB</td>
<td></td>
<td>2015</td>
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<tr>
<td><strong>Southern and South-west England</strong></td>
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<tr>
<td>Swinley Forest (Surrey heaths)</td>
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<td>2014, 2015</td>
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<tr>
<td>New Forest (Hampshire)</td>
<td></td>
<td>2014, 2015</td>
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<tr>
<td>Wiltshire (CCWWD AONB)</td>
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<td>2014, 2015</td>
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<tr>
<td>Quantocks (Somerset)</td>
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<td>2014, 2015</td>
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<tr>
<td>Dartmoor (Devon)</td>
<td></td>
<td>2014, 2015</td>
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<tr>
<td>Exmoor (Somerset/Devon)</td>
<td></td>
<td>2014, 2015</td>
</tr>
<tr>
<td>Forest of Dean (Gloucestershire)</td>
<td></td>
<td>2014</td>
</tr>
<tr>
<td>Mendip Hills AONB</td>
<td></td>
<td>2015</td>
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<tr>
<td><strong>Wales</strong></td>
<td></td>
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<tr>
<td>Snowdonia (Gwynedd)</td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Brecon Beacons (Powys)</td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Pembrokeshire coast</td>
<td></td>
<td>2014, 2015</td>
</tr>
<tr>
<td>Gower (Glamorgan)</td>
<td></td>
<td>2014, 2015</td>
</tr>
<tr>
<td>Wye valley (Monmouthshire)</td>
<td></td>
<td>2014, 2015</td>
</tr>
</tbody>
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Ticks being tested for *Borrelia*
Could understanding the ecology of *Borrelia burgdorferi* be employed in understanding:

1. Rates of exposure
2. Determinants for high risk areas
3. Targeted management/grazing regimes to minimise ticks and *Borrelia*
Role of small mammals at *I. ricinus* hosts

- **Wood mouse** (*Apodemus sylvaticus*) most important rodent host of larvae in UK (Dorset)
  - Peak infestation in August
  - Support 120/larvae/hectare/day
  - **Higher than Bank vole** (Dorset: 30/larvae/ha/day)
  - Similar reports across Europe
- **Bank vole** (*Myodes glareolus*) **develops resistance to tick bites**
  - Reduced rates of engorgement
  - Reduced moulting rates
  - **Wood mice support higher tick fecundity**
- **Yellow-necked mouse** (*Ap. flavicollis*) – No UK studies, but similar data in Europe to WM
- **Black striped mouse** (*Ap. agrarius*) **most important rodent host in continental Europe**: UK absent
  - Larval infestation rates 2-3 x other small mammals
  - Nymphal infestation rates 5x
  - Infection rates 58% higher
  - In Germany contributes 5 times more spirochetal infection
  - **Absence in UK is therefore important**
Small mammals and *Borrelia afzelii*

- Small mammals are important amplifying hosts of *B. burgdorferi*, particularly *B. afzelii*

- Infected by infective nymphs or transovarially infected larvae

- Life long infection (7-40 months)

- **Bank voles develop lower immunity to spirochaetes** -> develop higher infection rates: possibly more important in transmission cycles, however engorged ticks develop less well

- **Strong association between small mammal rodents with B. afzelii**

- Studies in Slovakia on infection rates
  - Engorged nymphs from small mammals: 47% infected
  - Questing nymphs: 7% infected
Role of other small/medium sized mammals

- Shrews (*Sorex araneus, S. minutus*)
  - Efficient tick predators
  - European studies: **80% infestation rates**; mean 40-60 larvae/shrew; 18% infect

- Dormice
  - Hazel dormouse (*Muscardinus avellanarius*) – arboreal, winter hibernation
  - Fat dormouse (*Glis glis*) – Germany: L infest 2-3x, N infest 20x
    - 9 yrs, synanthropic, 70% infected, 95% derived N

- Grey squirrel (*Sciurus carolinensis*)
  - Norfolk studies: mean L 8-19 compared to mouse L 1-4: upto 100 larvae
  - More important in spring/early summer – more arboreal in autumn

- Red squirrel (*Sciurus vulgaris*)
  - Switzerland study: 370L (64%), 380N (69%), 1 F on 1 animal cf. QL 3%, Qn 34%
  - **70% infection rates** (*Bbss, Ba*) – Important for Scotland?

- Siberian chipmunk (in France)
  - potential new host and reservoir
Role of other animals

- **Hedgehog** (*Erinaceus europaeus*)
  - Highly infested with ticks: Ireland study - >400L, 60N on 1 adult
  - Also infested with *I. hexagonus*:
    - In Switzerland – means 50L, 11N, 2.5 F *I. ricinus*
    - Co-infested in woodlands, mono-infested (IH) in urban areas: IH 24%
  - Silent cycle of transmission

- **Lizards**
  - Important **dilution hosts** in North America
  - Intensity of LD transmission negatively associated with Sand lizard dist in Ger.

- **Migratory birds (Swedish study)**
  - 23000 migrant birds surveyed, 2% infest, mean 2 ticks/bird, 98% IR
  - 30% of ticks in spring infected
  - >6.8m ticks enter Sweden each spring, 4.7m leave in autumn; 1.3m infected
  - Redwing – migratory restlessness reactivating latent infections
Role of woodland birds

- Ground feeding passerines are very important in Bb transmission
- Most important species (83% infested) are (Czech studies):
   - Robin (*Erithacus rubecula*)
   - Blackbird (*Turdus merula*)
   - Song thrush (*Turdus philomelos*)
- Robin fed 51% of all larvae feeding on birds
- Blackbird fed 54% of all nymphs (highest infestations 50 L and 20N/bird)
- Infection rates: 6-16% in larvae; 12-22% in nymphs
- *Turdus* sp. and *E. rubecula* very important amplifiers for *B. garinii* and *B. valaisiana*
Role of pheasant

- ~20 million pheasant (*Phasianus colchicus*) released in UK each year
- Densities in Dorset/Wiltshire studies: 500-1200 birds/km²
- **Feed large numbers of nymphs:**
  - 43n/bird in April; 23n/bird in June
  - Most important host nymphal host
- Male birds 4x infestation rates – testosterone and immunosuppression
- Infection rates in ticks from pheasant (Dorset):
  - 22% infected, cf. 0% questing population
  - Mostly *B. garinii* (neuroborreliosis) and *B. valaisiana* – important amplifiers – no evidence of *B. afzelii*: possibly eliminated
- Feed large numbers of questing nymphs -> exposure; infected adult ticks
- Reduction in *B. afzelii* – zooprophylactic role
Role of deer

- Very important host for all stages

- Irish studies on Fallow deer:

<table>
<thead>
<tr>
<th></th>
<th>L/50m</th>
<th>N/30s</th>
<th>A/30s</th>
<th>Inf qN</th>
<th>Inf qA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer</td>
<td>22-118</td>
<td>33-34</td>
<td>5-6.6</td>
<td>1.7%</td>
<td>3.1%</td>
</tr>
<tr>
<td>No deer</td>
<td>1.5-5.5</td>
<td>1.6-12.5</td>
<td>0.1-1.2</td>
<td>12.4%</td>
<td>17.9%</td>
</tr>
</tbody>
</table>

- Dilution hosts for *Bb*
  - Swedish studies
    - Compared moulted ticks from deer (0%) to questing N (7-11%)
    - 20% n infection rates: need 300,000 nymphs for infection
    - Typical infestation <100 nymphs
    - 100 ticks/kg vole v 3.7 ticks/kg deer -> immunity, low infection rates
  - Role of deer: increase tick numbers; dilute infection rates -> sustain tick pop
Role of livestock

- **Sheep**
  - Upland sheep – feed 80% of all larvae, >95% all N and A
  - **No systemic infection in sheep**
  - Studies in Scotland confirm *co-feeding transmission*
    - N:A 9cms; transmission during max. peaks of infestation

- **Cattle**
  - **Zooprophylactic role** on transmission
  - French studies: infection rates in questing ticks inside/outside cattle enclosures
    - 4x lower infection rates in Nymphs inside enclosures
    - 6x lower in Adults
  - **Could we use cattle to dilute infection rates, and mop up ticks?**
Pathogen detection in vectors

Ticks:

- First detections of potentially pathogenic TB rickettsiae (Tijssse-Klasen et al 2011, 2013):
  - *Rickettsia helvetica* in *Ixodes ricinus*
  - *Rickettsia raoultii* in *Dermacentor reticulatus*
  - *Rickettsia massiliae* in *Haemaphysalis punctata*

- First detection of *Borrelia miyamotoi* – cause of Tick-borne relapsing fever (Hansford et al. in prep)
  - 3/951 ticks – low prevalence, however potential novel disease assoc with UK
Medical Entomology team

Jolyon Medlock

Kayleigh Hansford

Maaike Pietzsch

Alex Vaux

Liz McGinley

Ben Cull

Thanks for listening.

Any questions?