The importance of differentiating between LLIN durability and LLIN serviceability

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Components of LLIN durability (WHOPES 2011)

1) Survivorship/Attrition: Proportion of nets still in service
2) Insecticidal activity: Level of insecticide remaining in/on net fibres
3) Physical or Fabric integrity: The number, location and size of holes in each net.

The WHOPES assessment of bed net physical integrity measures holes >0.5cm, assigns each to a size classes and weights the size classes to calculate the proportionate hole index (pHI):

Table 1: Suggested categorization of proportionate Hole Index data

Category	pHI value range	Approximate total hole surface area in cm^2	
		If circle*	If rectangular*
Good	0-64	<79	<100
Damaged	65-642	80-789	100-1,000
Too torn	643+	>790	>1,000

*refers to the assumed functional shape of the hole

VCTEG report to MPAC (2013)

The pHI is then equated to the protective value of the net:
A “Good” or “Damaged” net is considered **serviceable**, i.e., provides more protection than no net at all
A “Too torn” net is not considered **serviceable**, i.e., it is not likely to provide significant protection and should be replaced

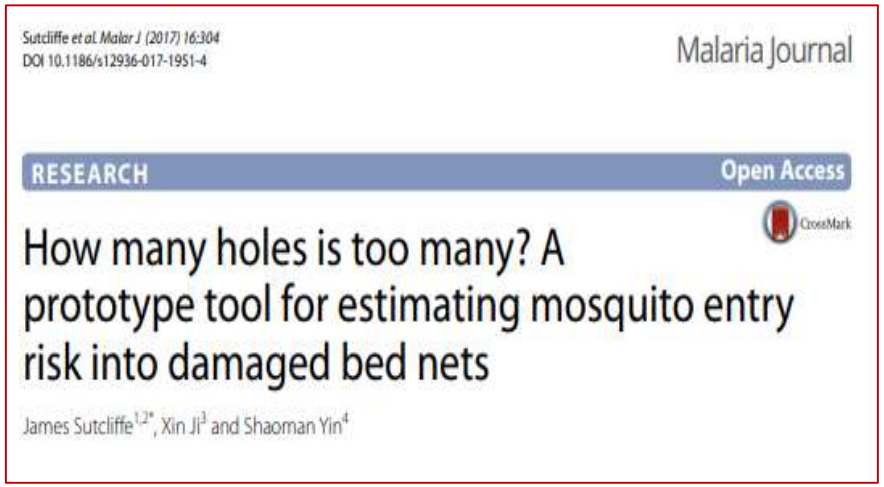
In this presentation, I contend that the WHOPES-approved method cannot accurately assess physical integrity aspects of bed net serviceability for two reasons:

1) It doesn’t adjust the assessment for the **location** of the damage on the net

2) Each pHI **hole size** category represents an overly large range of net entry risks

These points are addressed as follows:

1) Location of damage Where do mosquitoes go around the occupied bed net?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Malaria Journal

RESEARCH

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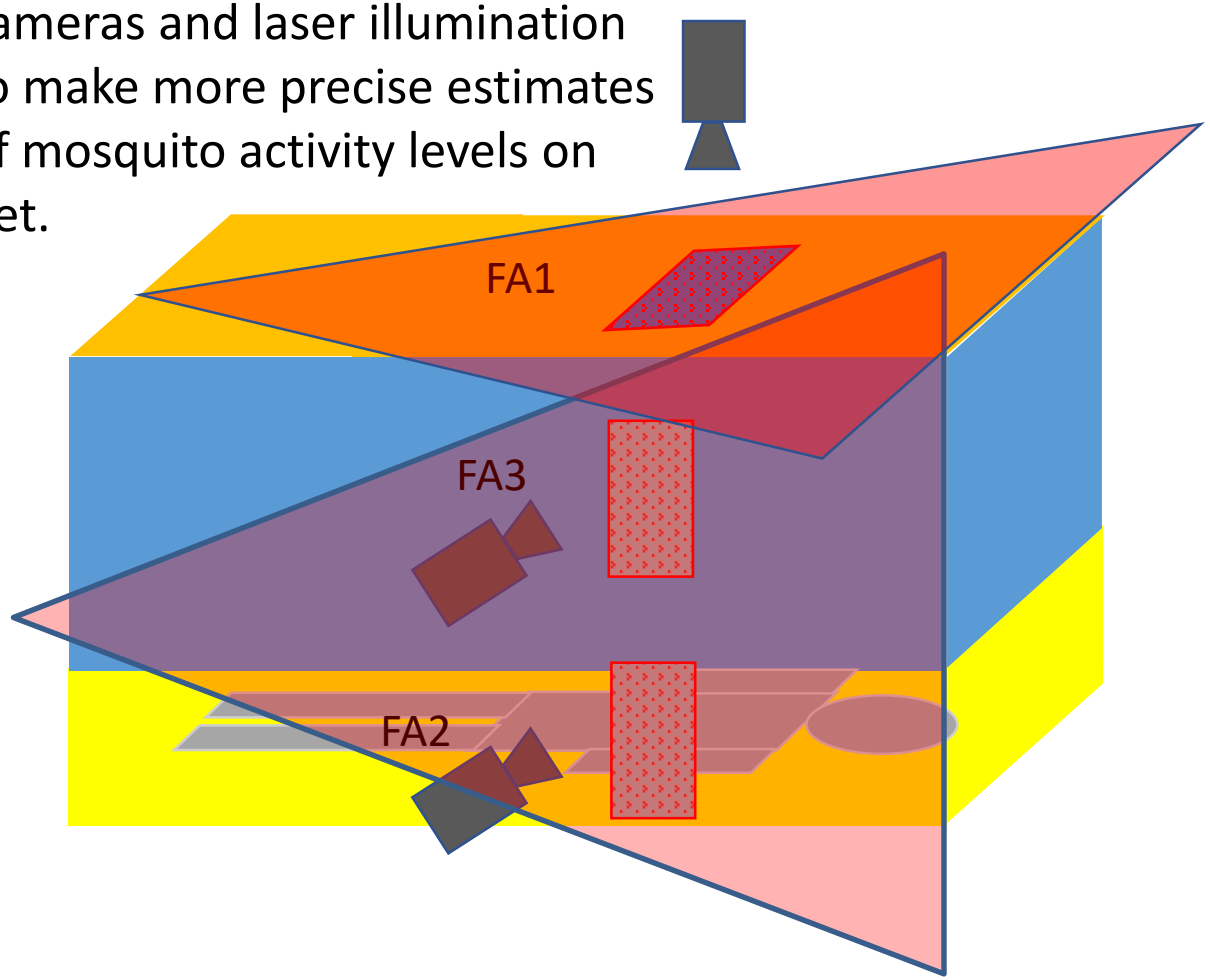
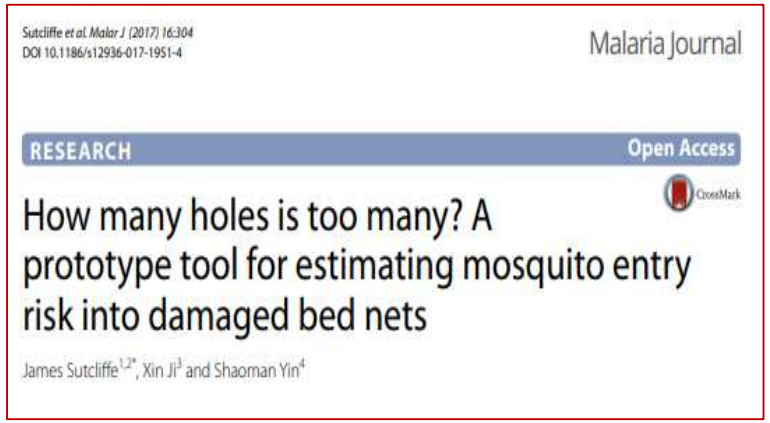
How many holes is too many? A prototype tool for estimating mosquito entry risk into damaged bed nets

James Sutcliffe[1,2*], Xin Ji[3] and Shaoman Yin[4]

Previous work using sticky squares on nets (Sutcliffe and Yin, 2014) had shown *An. gambiae* distribute non-uniformly around the ne: roof (FA1) – 80-90%, lower third of sides (FA2) – 10-15%, upper two thirds of sides (FA3) - <1%).

Sutcliffe et al. (2017) used video cameras and laser illumination to make more precise estimates of mosquito activity levels on net.

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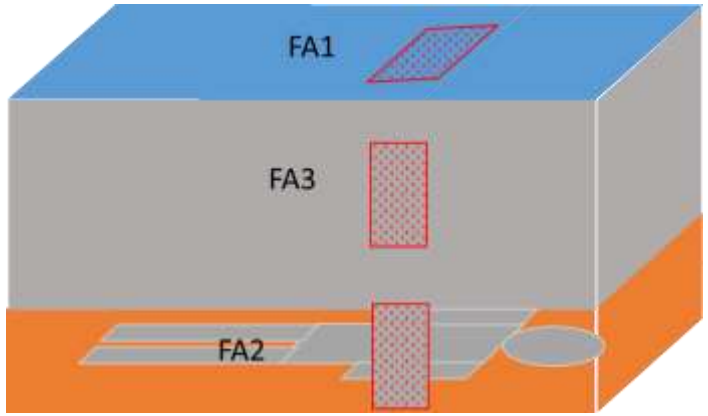
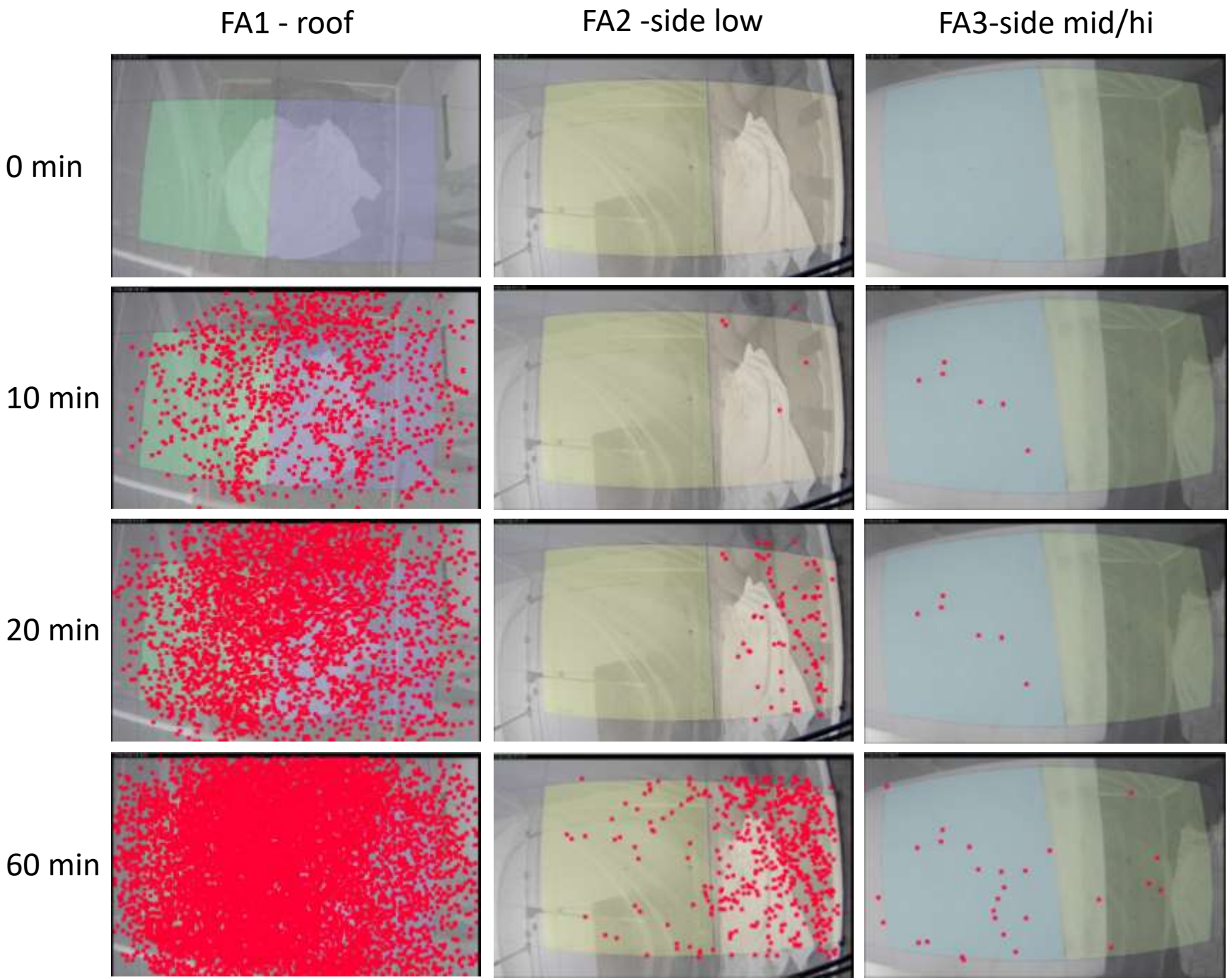
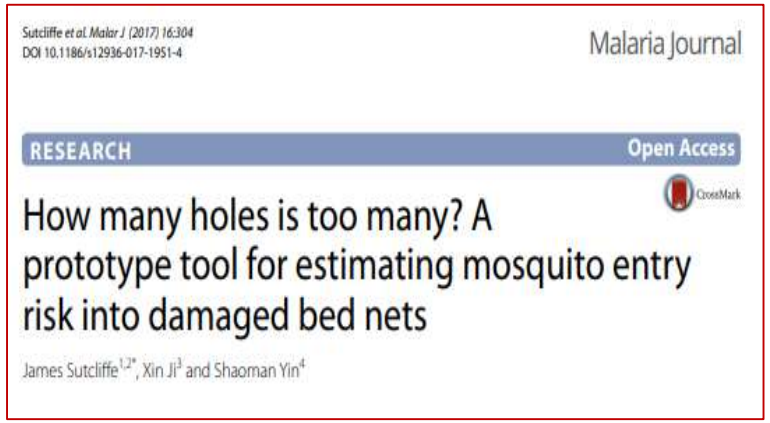
Ethovision-logged mosquito appearances in 30X60cm sections of functional areas (FAs) of occupied bed net (time sequence at right)…



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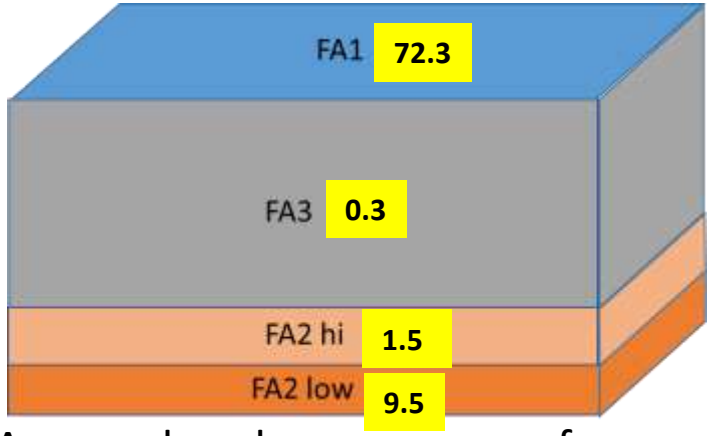
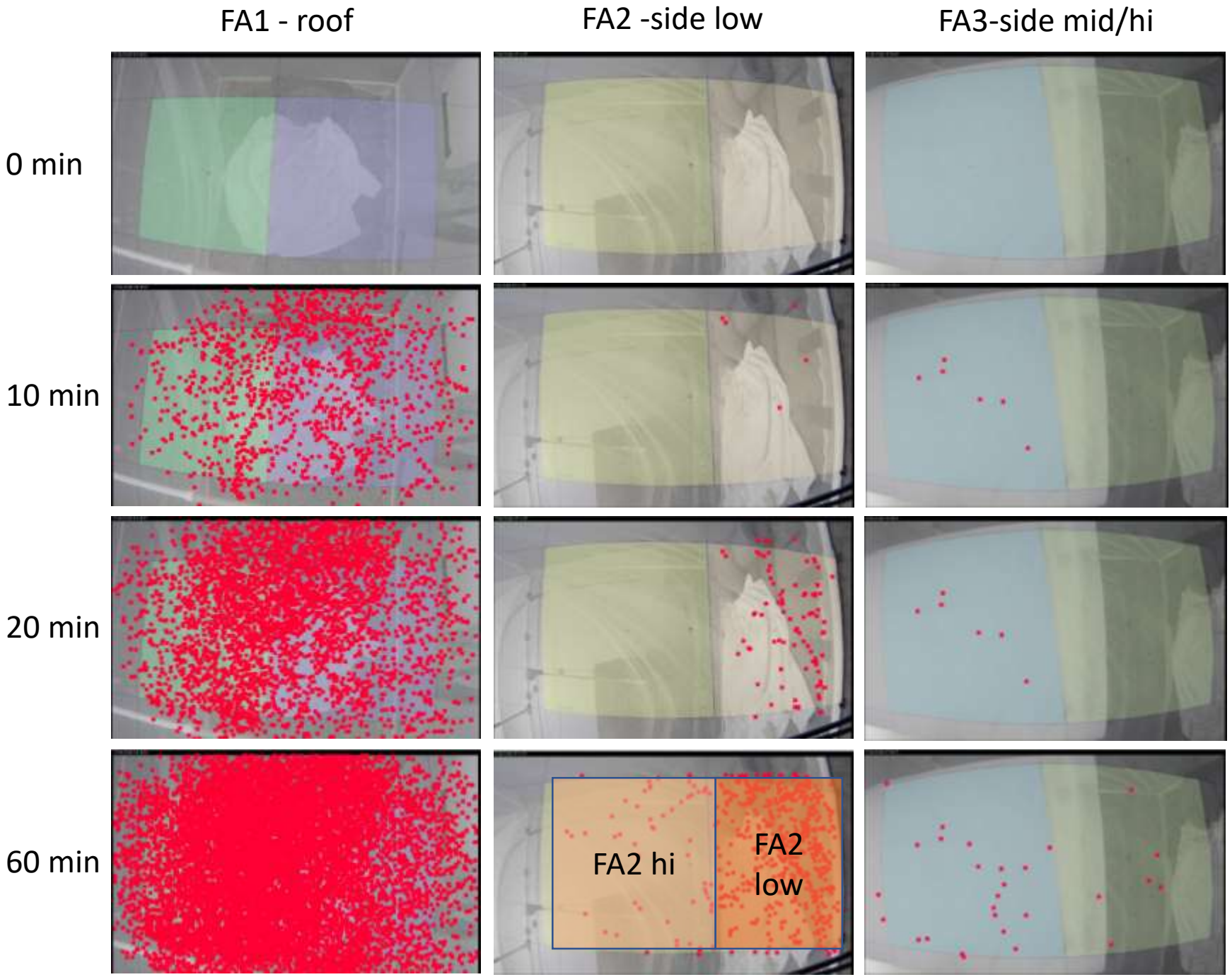
...resulting in a more precise map of net FAs and quantitative estimates of mosquito activity levels (appearances) in each FA

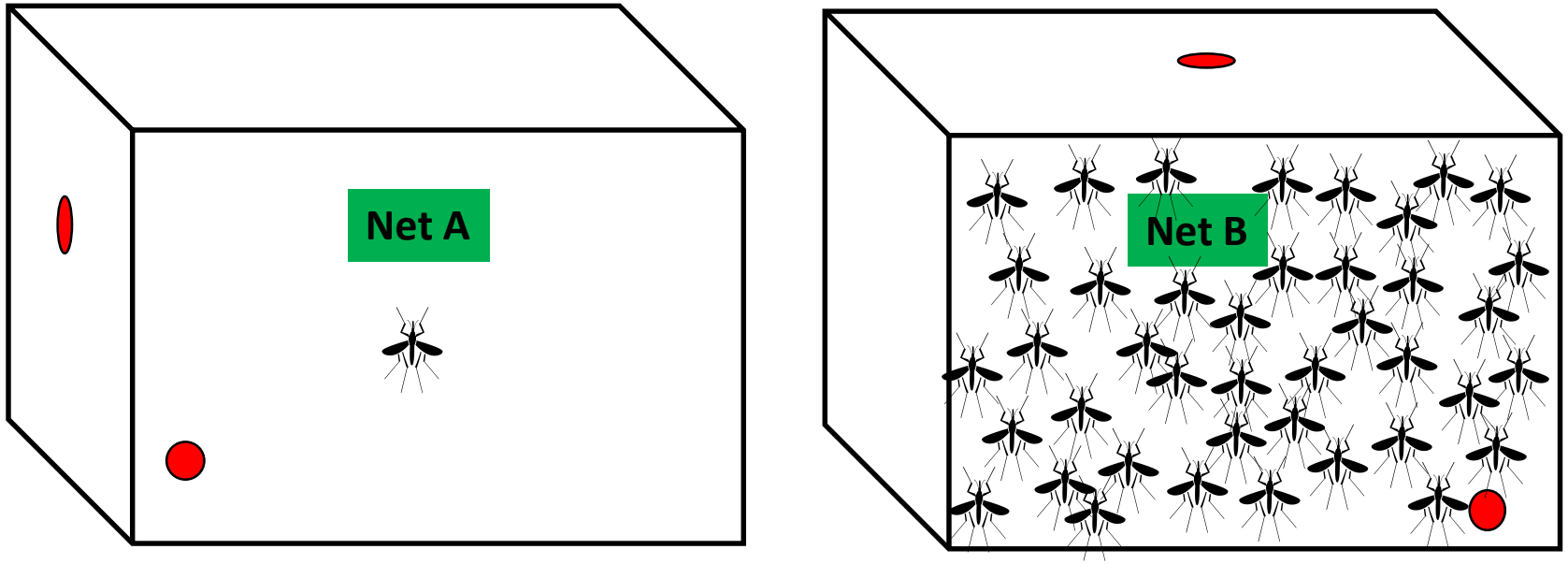


Average hourly appearances for one mosquito per 30X30cm area each FA



Effect of hole location on net serviceability based activity levels on the net (one of many possible scenarios)

Net A – two holes, one in FA2 hi, one in FA3
Net B – two identical holes, one in FA2 low, one in FA1



The entry risk for Net B is approximately 46X greater than for Net A even though both nets are in the same physical condition; therefore,

fabric integrity (durability) ≠ net serviceability

2) Hole size – do all holes in a given pHI size category pose the same, or close to the same, net entry risk? For example, do 2cm size 2 holes represent the same risk as 10cm size 2 holes?

pHI Hole Size Categories

Category of Hole	Hole Size Description	Hole Size
Size 1	Smaller than a thumb (finger)	**0.5 - 2 cm diameter**
Size 2	Larger than a thumb but smaller than fist (hand)	**2 - 10 cm diameter**
Size 3	Larger than a fist but smaller than a head (head)	**10 - 25 cm diameter**
Size 4	Larger than a head	**> 25 cm diameter**

World Health Organization. Guidelines for monitoring the durability of long-lasting insecticidal mosquito nets under operational conditions. (2011)

www.durabilitymonitoring.org

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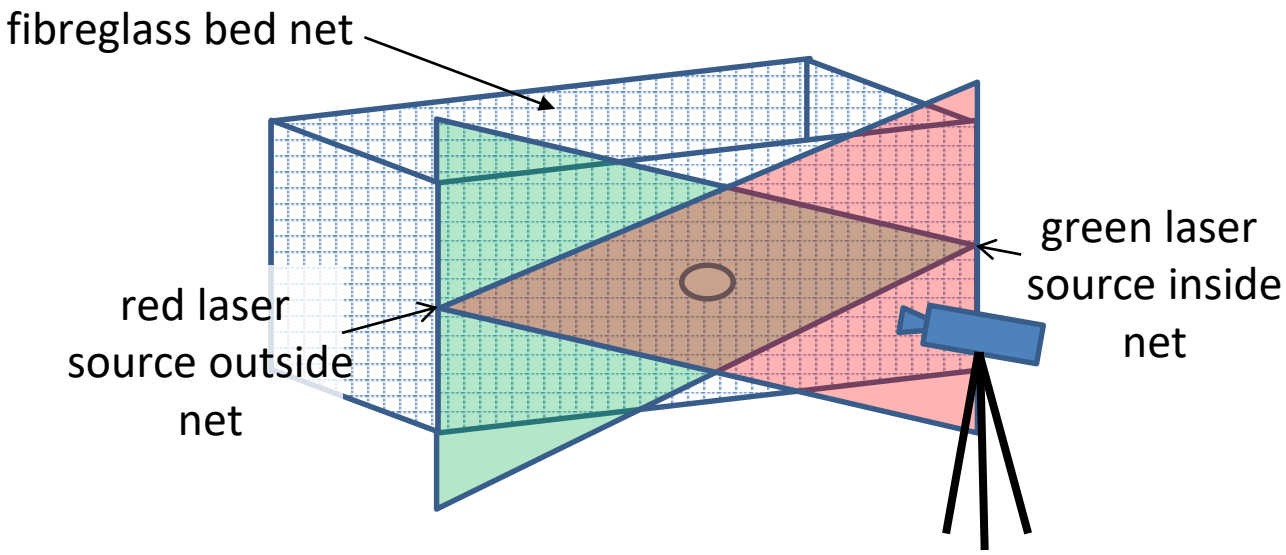
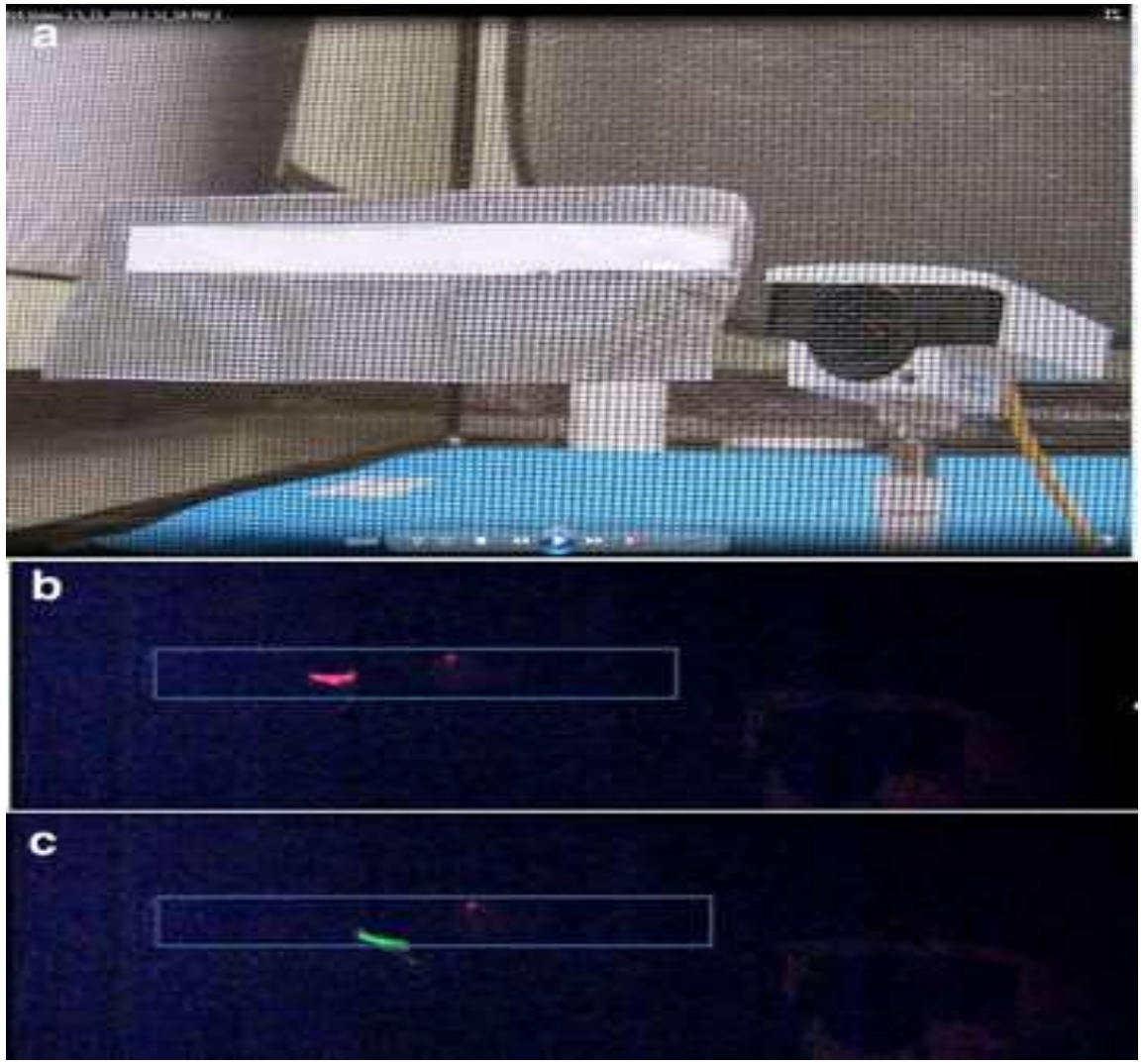


Use a) video and laser illumination to detect b) mosquito encounter with hole and c) passage through hole into net.



Effects of hole size and shape on net entry risk (Sutcliffe, Ji, Yin, 2017)

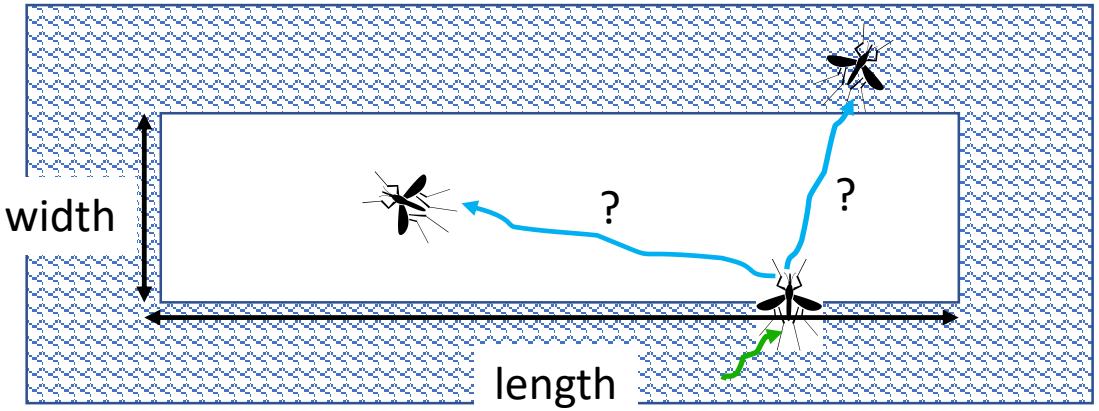
Probability of net entry

=

Probability of hole encounter/appearance

X

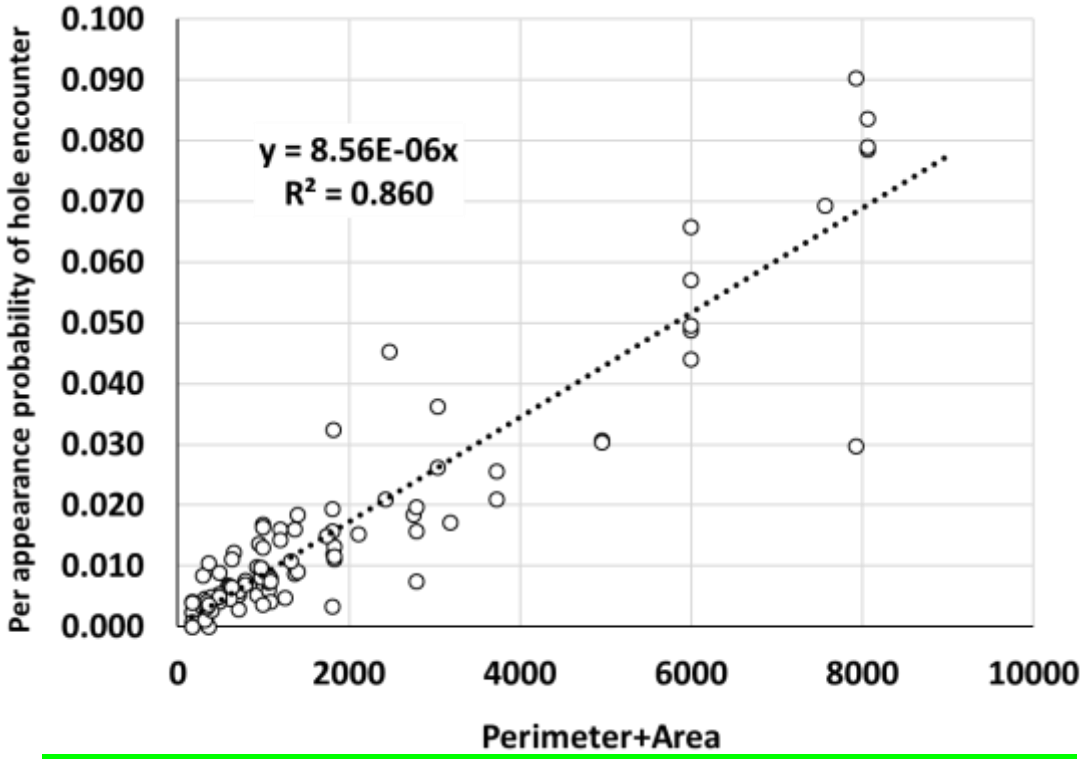
Probability of hole passage/encounter



Are there hole dimension predictors of encounter and hole passage that can be used as parameters to flesh out this equation?

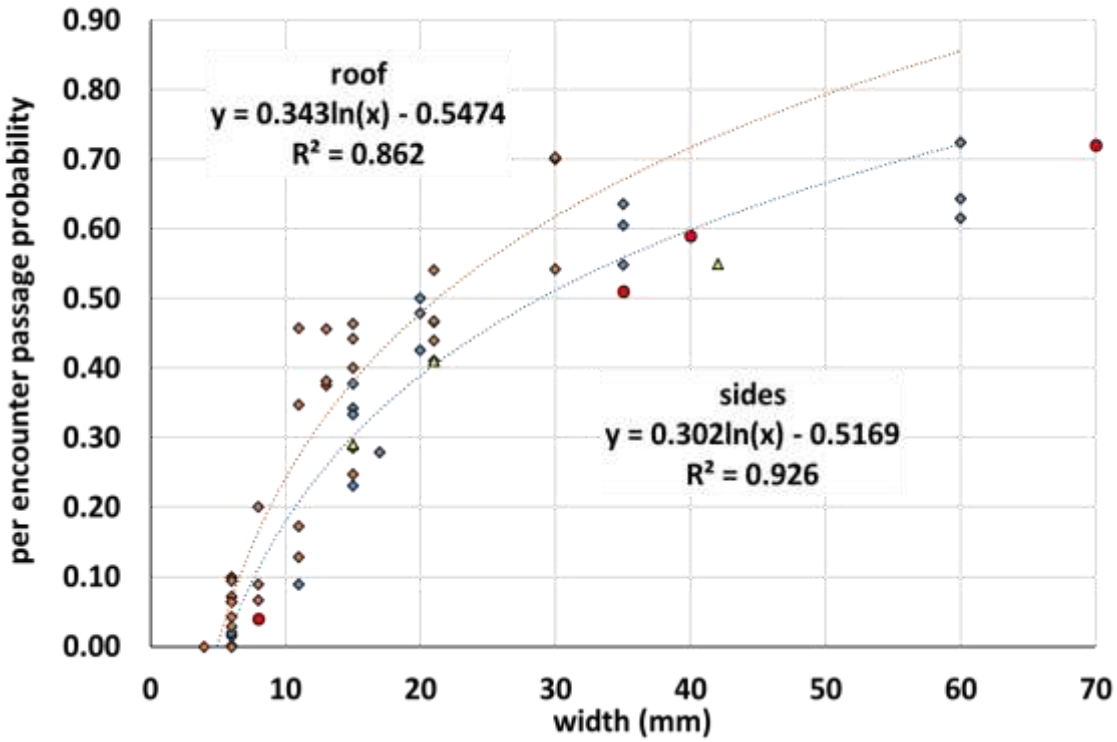
Hole dimension predictors for net entry risk (Sutcliffe, Ji, Yin, 2017)

P(encounter/appearance)



Hole encounter is strongly predicted by the sum of numerical values of hole perimeter plus hole area

P(passage/encounter)



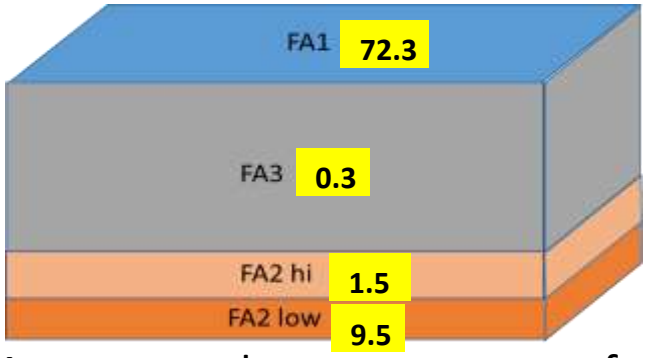
Hole passage per encounter is strongly predicted by the width of the hole

Resulting in two equations for probability of net entry for a single mosquito:

P(roof hole entry) = [$9X10^{-6}$(perimeter+area)] X [0.34(ln hole width) – 0.55]

P(side hole entry) = [$9X10^{-6}$(perimeter+area)] X [0.30(ln hole width) – 0.52]

Combining hole size effects and mosquito activity effects…



Average per hour appearances for one mosquito in each 30X30cm area by FA

✖

P(hole passage)

=

P(hole encounter/appearance)

X

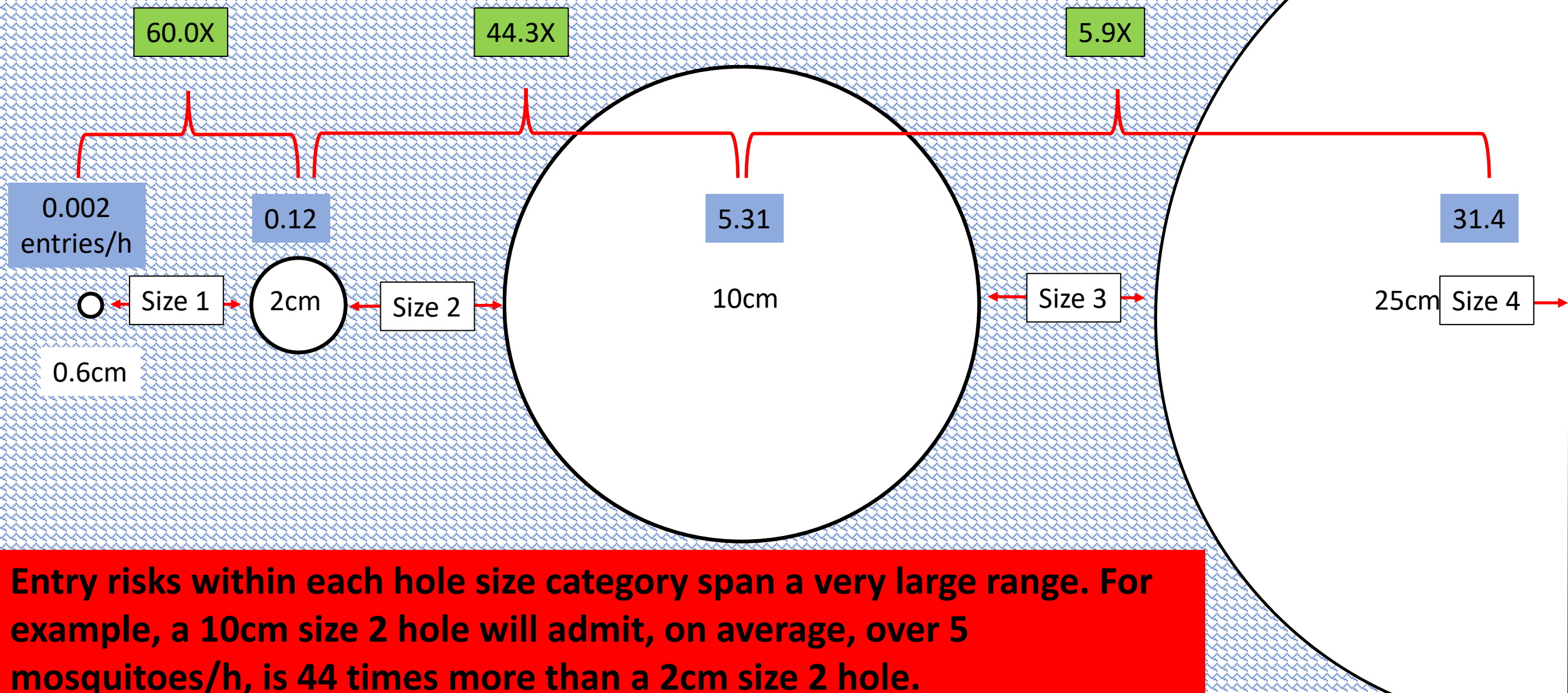
P(hole passage/encounter)

…results the entry risk tool, a quantitative prediction of the average number of mosquitoes expected to enter a damaged net per unit time:

net entries/h = [(FA mean apps./h) X P(encounter)/app.)] X P(passage/encounter)

Entry risk tool predictions of hourly entry risks for pHI hole size classes (roof)

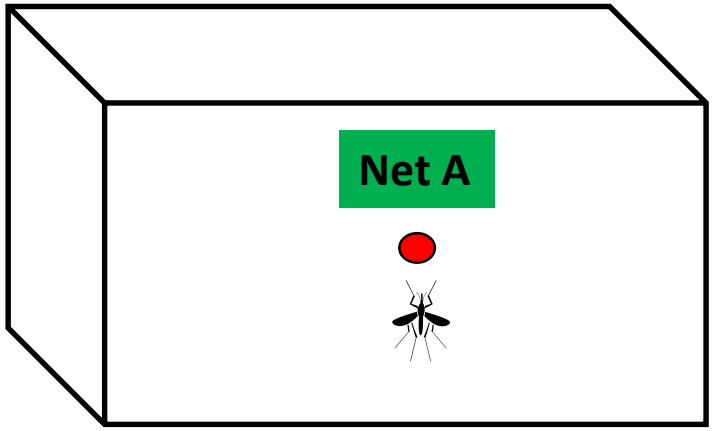
(assuming one mosquito is present outside the net at all times)

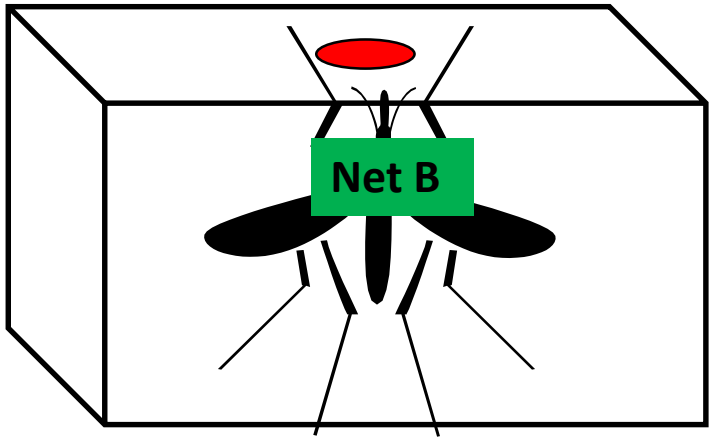


Entry risks within each hole size category span a very large range. For example, a 10cm size 2 hole will admit, on average, over 5 mosquitoes/h, is 44 times more than a 2cm size 2 hole.

The entry risk tool predicts that hole size and mosquito activity can combine to make similarly assessed nets very different in terms of protection offered:

For example, one 2cm (size 2) hole in FA3 (Net A) and one 10cm (size 2) hole in FA1 (Net B)





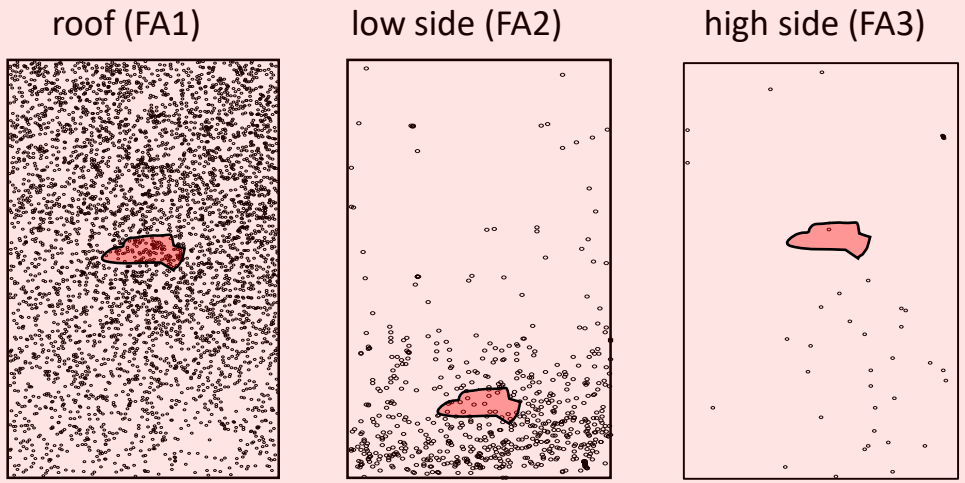
Net B will admit, on average, 289 times more mosquitoes than Net A even though both would be classified as “good” using current WHOPES criteria.

Conclusion

1. Does mosquito behaviour around bed nets support the notion that net damage maps directly to net serviceability?

No. Mosquitoes orient preferentially to certain parts of the net; as a result, holes in highly-visited areas (where mosquito pressure is higher) will admit more mosquitoes than similar damage in less frequented areas (by a factor of up to 50).

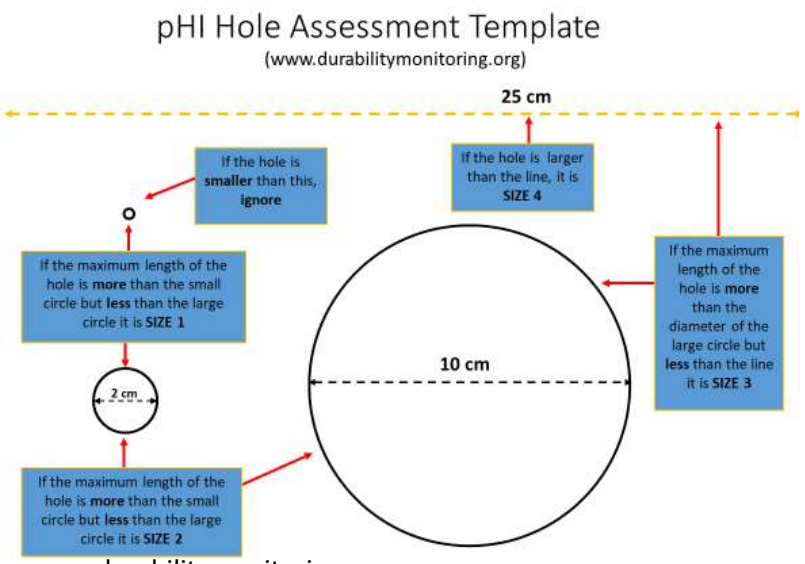
An. gambiae near-net activity plots around an occupied bed net.



2. Does mosquito behaviour around net holes support current hole assessment methods?

No. Entry risk represented by each hole size may range by a factor of 50 or more.

WHOPES hole measurement methods assign a diameter to net holes whether they are circular or not making meaningful entry risk calculation impossible.



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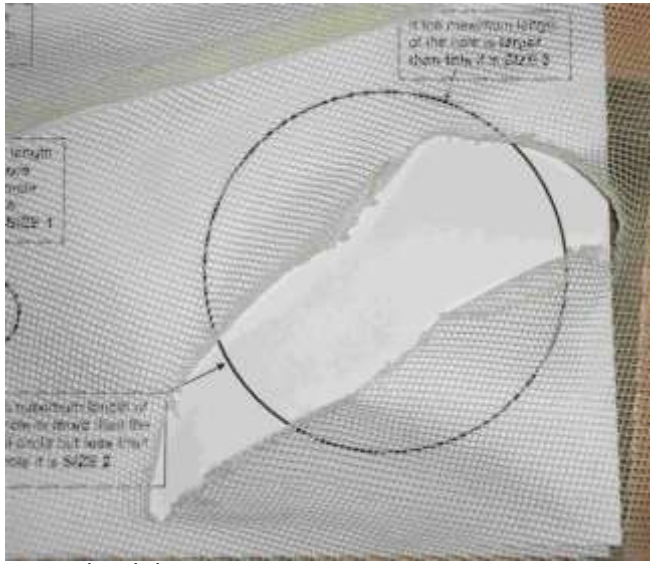

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Conclusion

Net durability and net serviceability are both important but have different uses and cannot be measured the same way – it is important that the two concepts be disentangled and assessed separately and appropriately

fabric integrity (durability)

- overall resistance to normal physical wear
- burst strength, number of holes, hole area, broken threads, ravels…?
- net design and procurement decisions

net serviceability

- protection from mosquito bites
- entry risk units

- net design
- timing of net replacement
- messaging to users

[in the future it will be important…]*"to understand better the determinants of mosquito entry into a damaged net and to improve—if needed—the weighting system for hole counts in the proportionate hole index, there is a need to study the relationship between hole size and position on an effective LLIN and the influence of total net size compared to the size of the hole*." (VCTEG, 2013)

Acknowledgements

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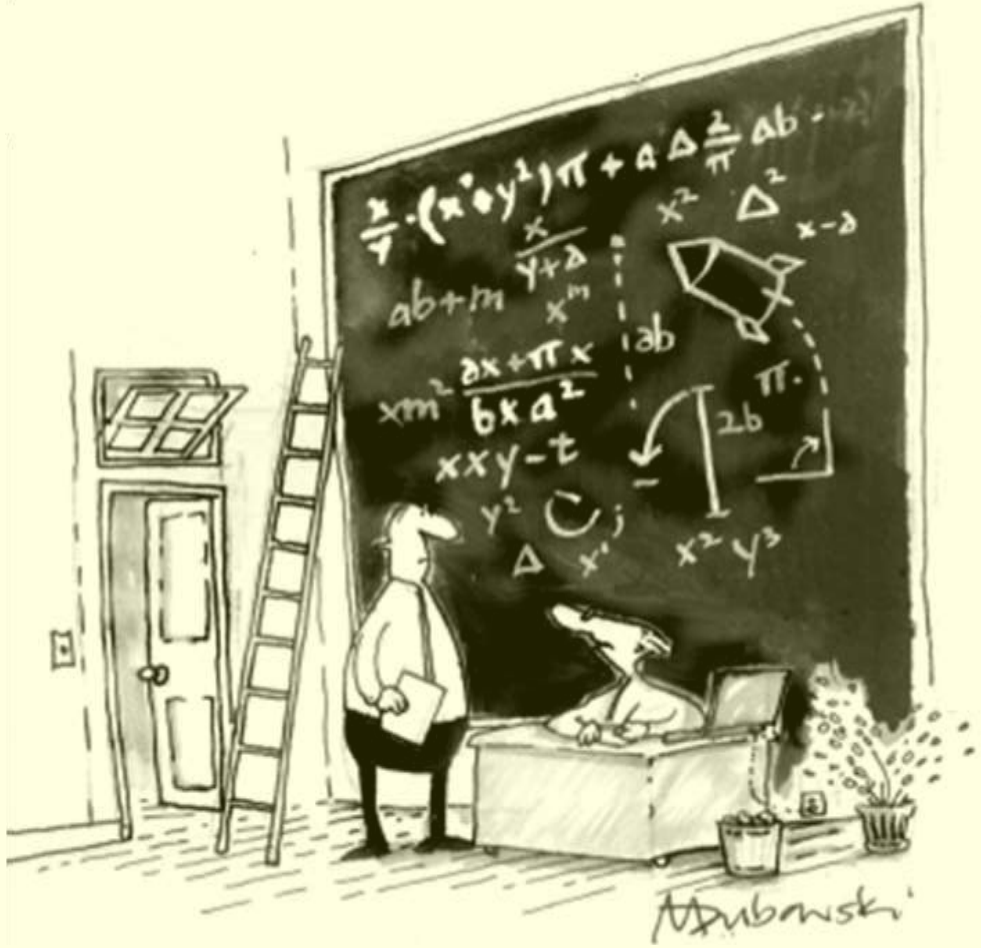

Confound it Fenwick, how hard can it be!?
It's not like this is entomology!