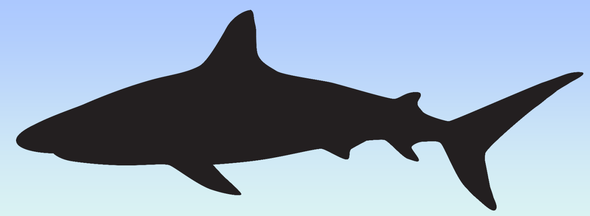
Sound localisation in sharks

Investigating the inner ear morphology of sharks

Derek Sauer
University of Auckland, Institute of Marine Science
Supervisors: Craig Radford, Kara Yopak, and John Montgomery



Introduction

While you may not be able to see them, fish have inner ears that allow them to detect and even localise sound underwater.

Our current understanding of how fish localise sound relies on them being able to detect both components of sound: particle motion and sound pressure[1].

While all fish have sensory hair cells (epithelia) within their inner ears that can detect particle motion[2], only some fish have a swim bladder (or other gas-bladder) that can detect sound pressure.

Sharks are among a group of fishes (Elasmobranchii) that have no form of gas-bladder. Yet open ocean studies have shown that sharks can localise sounds from as far as 250 metres away[3]!

How sharks are able to localise sound without a gas-bladder is unknown, leaving a significant gap in our understanding of shark biology and the evolution of vertebrate hearing.

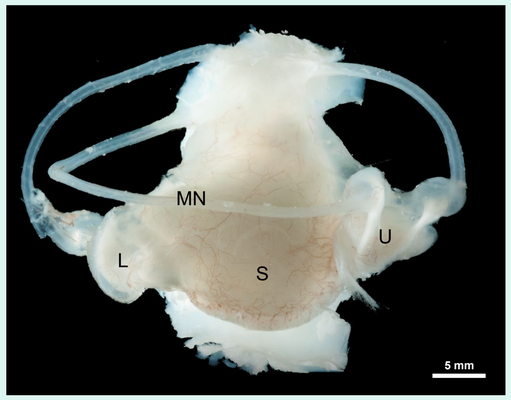
Project Summary

The aim of this study was to use fluorescent microscopy to characterise the inner ear hair cells in a range of sizes of school sharks (*Galeorhinus galeus*).

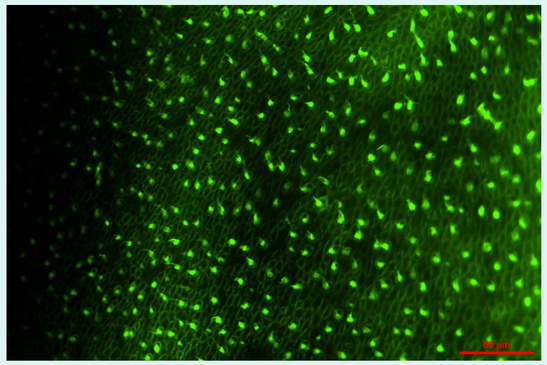
The hair cells of the inner ears are vital for sound localisation in sharks. These data will establish what "machinery" is available for sound localisation and how it changes throughout ontogeny.

Methods

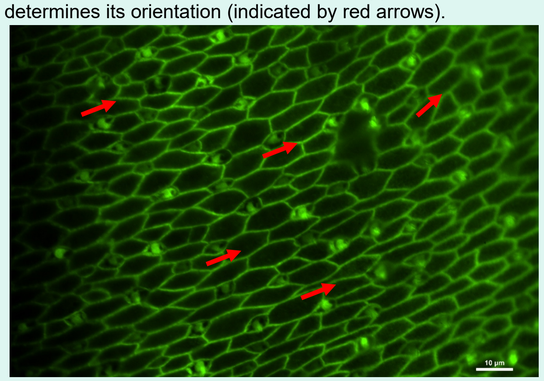
1. Extract the inner ears from school sharks and isolate the four hearing epithelia: sacculus (S), utricle (U), lagena (L), and macula neglecta (MN).



2. Fluorescently stain the epithelia, image under a fluorescent microscope, and quantify hair cell number and density.



3. Map the orientation (axis of sensitivity) of hair cells within the epithelia. The kinocilium of each hair cell appears dark and determines its orientation (indicated by red arrows).



Results

- Here, we only present results from the sacculus for conciseness, however patterns were generally the same across all four epithelia.
- Total hair cell number significantly increases as size increases (Figure 1).
- Hair cell density significantly decreases as the size of the shark increases (Figure 2).
- There is a consistent bi-directional pattern of hair cell orientation throughout the entire epithelium (Figure 3).
- There are significant differences in the density of hair cells in the different hearing epithelia (Figure 4).

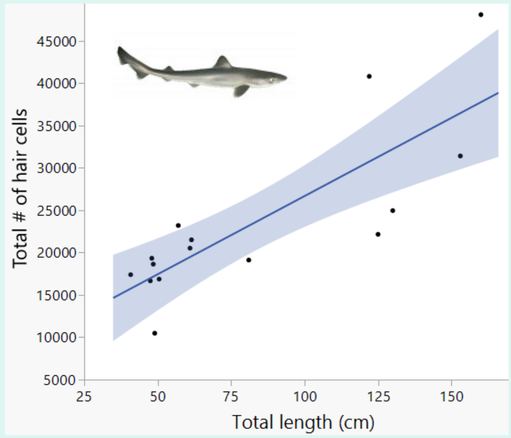


Figure 1. The total number of saccular hair cells significantly increases with total length ($F_{1,13}$ = 24.29, p = 0.003, r^2 = 0.65).

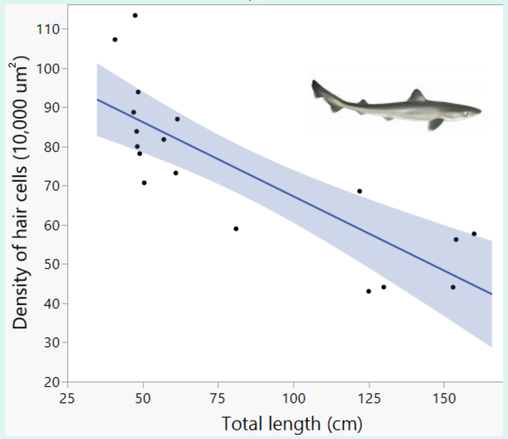


Figure 2. Saccular hair cell density significantly decreases as total length increases ($F_{1,16}$ = 30.71, p < 0.0001, r^2 = 0.66).

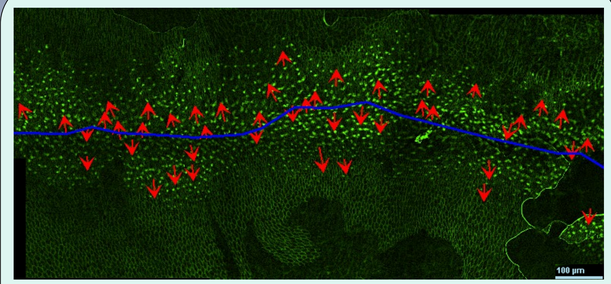


Figure 3. Bi-directional pattern of hair cell orientations in the sacculus of a school shark.

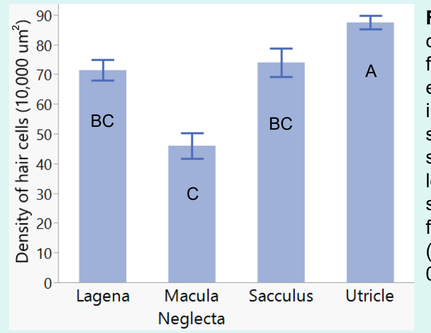


Figure 4. Mean hair cell density in the four hearing epithelia from the inner ears of school sharks. Groups that share the same letter do not significantly differ from each other ($F_{3,33}$ = 24.99, p < 0.0001).

Conclusions

As sharks grow and add new hair cells to their inner ears, this results in lower hair cell density throughout the epithelia. Since the hearing abilities of large sharks have never been tested, it remains to be determined if hair cell density or total hair cell number is most influential on hearing abilities.

Hair cell orientation patterns are established early in development and do not change with the addition of new hair cells throughout ontogeny.

The utricle, which has hair cells oriented laterally outwards from the shark, is relatively large and has the highest density of hair cells in school sharks.

References

1. SCHUIJF, A. & BUWALDA, R. J. A. 1975. On the mechanism of directional hearing in cod (*Gadus morhua*). *Journal of Comparative Physiology A*.
2. POPPER, A. N. & HAWKINS, A. D. 2018. The importance of particle motion to fishes and invertebrates. *The Journal of the Acoustical Society of America* 143:470–488.
3. MYRBERG, A. A., BANNER, A. & RICHARD, J. D. 1969. Shark attraction using a video-acoustic system. *Marine Biology*.