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“Accessory corner cones” as putative UV-sensitive photoreceptors in the retinas of seven adult nototheniid fishes

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Abstract We describe “accessory corner cones” contained in the retinas of seven species of Antarctic adult nototheniid fishes (Nototheniidae, Perciformes) and suggest, on the basis of morphology, that they are UV-sensitive photoreceptors. The potential significance of the presence of UV-sensitivity in Antarctic fish is that it might increase foraging efficiency by enhancing the contrast of important prey. Krill (Euphausia superba), for example, are probably silhouetted against UV-background space light during the Antarctic summer.

Introduction

Nototheniid fishes (Nototheniidae, Perciformes) are confined to the cold waters of the Antarctic, and are the most numerous and biologically important group (about 13 genera and 49 species) of Antarctic fishes (Nelson 1994). Photo-environments in the Southern Ocean are unique (24 h daylight in the summer and continual darkness in winter), and specialized photoreceptors appear to exist in the pineal organs of at least two species of Antarctic nototheniids (Meyer-Rochow et al. 1999). However, extreme ocular specializations have never been described in nototheniid eyes (Meyer-Rochow and Klyne 1982; Eastman 1988; Pankhurst and Montgomery 1989; Morita et al. 1997).

During the course of studying the biology of nototheniid fishes, we have recognized “accessory corner cones (ACCs)” in the retinas of all seven species examined. In most cyprinids (Avery et al. 1983; Harosi and Hashimoto 1983; Harosi and Fukurotani 1986), salmonids (Bowmaker and Kunz 1987; Hawryshyn et al. 1989), and percids (Loew and Wahl 1991), it is well established that the ACCs represent the UV-sensitive visual cells (Kunz et al. 1994; Bowmaker 1995). There is no report describing the ACCs as possible UV-sensitive cones in the retina of Antarctic fishes (Eastman 1993). The main objective of this note is, therefore, to describe the ACCs as possible UV-sensitive cones in the retina of adult nototheniid fishes and to speculate about their possible visual function as it relates to foraging behaviour.

Materials and methods

The seven species examined in the present study are listed in Table 1. All specimens were adults. The fish were collected from Lutzow-Holm Bay (69°S, 39°E) and Prydz Bay from depths of 20–200 m, during the 34th and 35th Japanese Antarctic Research Expedition (1992–1994). After being collected, the entire bodies of the fish were immediately fixed in 10% formalin. Right eyes were enucleated, and cornea, lens and sclera were removed. Each retina was dissected into 5-mm squares, and 8–36 pieces were taken from each retina of differently sized fish. The pieces were dehydrated in alcohol and embedded in paraffin. Tangential sections were cut at 4–7 μm thickness and radial sections were 10 μm thick. The sections were stained with haematoxylin and eosin. The photoreceptor cell layer was observed with a photomicroscope.

Results

In the retina of adult Trematomus bernacchii, the cone photoreceptor cell layer contained double cones and two
Table 1  Morphological details of specimens used in this study

<table>
<thead>
<tr>
<th>Figure no.</th>
<th>Species</th>
<th>Eye radius (mm)</th>
<th>Total length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td><em>Trematodus bernacchii</em></td>
<td>17</td>
<td>215</td>
</tr>
<tr>
<td>3a</td>
<td><em>T. newnesi</em></td>
<td>12</td>
<td>165</td>
</tr>
<tr>
<td>3b</td>
<td><em>T. hansi</em></td>
<td>17</td>
<td>215</td>
</tr>
<tr>
<td>3c</td>
<td><em>T. pennelli</em></td>
<td>20</td>
<td>170</td>
</tr>
<tr>
<td>3d</td>
<td><em>Pagothenia borchgerevinski</em></td>
<td>11</td>
<td>210</td>
</tr>
<tr>
<td>3e</td>
<td><em>Lepidonotothen kemp</em></td>
<td>12</td>
<td>135</td>
</tr>
<tr>
<td>3f</td>
<td><em>T. scotti</em></td>
<td>18</td>
<td>160</td>
</tr>
</tbody>
</table>

Types of single cones, arranged in a typical square mosaic (Fig. 1a, b). Double cones (DC) formed the sides of the square, and their axes were directed toward a central single cone (CC) at the centre of the square unit at right angles to each other (Fig. 2a). Another type of single cone, the ACC, was located at the corner of the square mosaic (Fig. 2a). This retinal mosaic containing the ACCs is similar to that of the brown trout *Salmo trutta* (Bowmaker and Kunz 1987). This morphological similarity indicates that the ACCs are possibly UV-sensitive. On the basis of the sections, it was found that the inner segments of the ACCs were slightly thinner than those of the central single cones. Further, in radial sections of *T. bernacchii*, the double and single cones were alternately ranked (Fig. 2b, c). Both the length and width of single cones were slightly different in sections of neighbouring elements of the serial section. There were shorter single cones representing ACCs (Fig. 2b, d) and longer single cones representing central single cones (Fig. 2c, d), as shown by Bowmaker and Kunz (1987). ACCs were thinner than the central single cones, and this fact corroborates the difference between ACCs and central single cones with regard to size (as shown in Fig. 1a).

These complete square mosaics of cones were also observed in *T. newnesi*, *T. hansi*, *T. pennelli*, *Pagothenia borchgerevinski*, and *Lepidonotothen kemp* (Fig. 3a–e). These species also had the ACCs. However, *T. scotti* exhibited a different retinal cone mosaic pattern. This species lacked the central single cones but not the ACCs (Fig. 3f). This may indicate that the ACCs are more essential for the mode of life *T. scotti* leads than are the central single cones. Mosaic squares with ACCs shown in Fig. 3 were observed in all dissected species and an absence of ACCs was not found in any of the retinal pieces examined.

![Figure 1](image1.png)  
**Fig. 1**  
a. Left Tangential section of cone photoreceptor layer in retina of *Trematodus bernacchii*. Scale bar = 20 μm.  
b. Right Tracing of section on the photograph a. Accessory corner cones in black (ACCs)

![Figure 2](image2.png)  
**Fig. 2**  
a. Diagram of cone square mosaic indicating location of double cone (DC), central single cone (CC), and accessory corner cone (ACC) (terminology from Bowmaker and Kunz 1987).  
b. Radial section of retina of *Trematodus bernacchii* showing part of a double cone and an accessory corner cone (ACC), with section cut along dotted line indicated in photograph (Fig. 1a). Scale bar = 20 μm.  
c. Similar section showing part of a double cone and a central single cone (CC), cut along the broken line indicated in photograph (Fig. 1a). Scale bar = 20 μm.  
d. Left Tracing of accessory corner cone (ACC) and double cone (DC) of photograph b.  
e. Right Tracing of central single cone (CC) and double cone (DC) in photograph e.