2.0 Otolith Structure and Function

Most lower vertebrates utilize inner ear elements to process sensory information regarding movement, momentum, spatial orientation, and sound. The dorsal portion of the teleost inner ear includes three semicircular canals each with their own ampullae, a fluid filled chamber for sensing inertia (Figure 2.1A and B). The canals are oriented in such a way as to include the horizontal, lateral, and vertical planes allowing detection of pitch (head up or down), roll (rotation on the head-tail axis), and yaw (head side to side). Movement of the fluid (endolymph) within the ampulla impinges on sensory hair cells lining the walls of the chamber allowing the sensory system to process directional acceleration and deceleration. The dorsal portion also includes the utriculus and the utricular otolith, or the lapillus, which is used primarily to detect gravitational force as well as sound (Popper and Lu 2000).

The ventral portion of the teleost inner ear includes the sacculus and lagena which in turn contain their own otoliths, the sagitta and the asteriscus, respectively. This area of the inner ear appears to be used for both sound detection and acoustic transduction. Sound vibrations differentially affect the otoliths due to their higher density relative to the fluid filled chambers they occupy. As sound waves are intercepted, the otoliths move independent of the surrounding chamber causing mechanical stimulation of the hair cells. This process results in an auditory signal allowing the fish to “hear.”

The sagittae, described here in detail, are typically the largest otoliths in most fishes and are therefore the most often used for ageing. Please note, however, that some researchers strongly recommend the use of other otolith pairs (Secor et al. 1991).

The sagittae lie within the saccus and are attached to a noncellular, oolithic membrane. Along the medial surface of the otolith lies a gelatinous pad within an area of the otolith known as the sulcus acusticus and the nervous tissue called the macula acustica. This nervous tissue extends from the auditory nerve. Innervation of the gelatinous pad functions to receive stimuli due to angular accelerations, gravity, and sound. Surface features that can be distinguished on some sagittal otoliths include the rostrum and the anterostrum on the

Figure 2.1. A). Location of the otolith pairs within a generalized fish (modified from Secor et al. 1991) and B). medial view of the inner ear (modified from Moyle and Cech 1988).
anterior end of the otolith and the sulcus acousticus that forms a furrow (sulcal groove) along the medial surface of the otolith (Figure 2.2). The sulcus acousticus can be divided into an anterior ostium section and a posterior cauda section. In some otoliths (e.g., those of certain sciaenid species) a marginal groove is present near the dorsal side of the inward facing surface of the sagitta.

Otoliths are crystalline in nature and are built up around a primordium/core region outward by the process of biomineralization, where calcium carbonate, mainly in the form of aragonite, is precipitated on a protein matrix of otolin. The otolin layers are generally oriented parallel to the outer surface of the otolith and are most densely aligned during periods of slower growth (usually associated with cooler months), thus forming characteristic, concentric opaque rings in otolith cross sections (Blacker 1974). Layers that are less densely spaced during periods of faster growth during warmer months make up the translucent ring (Figure 2.3). When the formation of successive opaque and translucent rings occur on an annual basis, they are collectively referred to as an annual growth zones. The winter growth zones, represented by opaque rings, are frequently called annuli (singular: annulus). Otolith growth in the linear dimension is usually greatest on the axis facing the sagittal midline of the fish.

When the alternating bands or rings of an otolith cross section are viewed under magnification, the opaque rings lying along a 'reading' or 'counting' axis, described by a line on one side or the other of the sulcus extending from the core to the outer edge (Figure 2.4), are conventionally the ones tallied for age estimates. The counting of presumed annuli for the purpose of assigning age estimates is analogous to the practice of dendrochronology, the ageing of trees using tree ring counts from a cross section of the trunk.

Daily growth microincrements in otoliths, first described by Pannella (1971) and later reported by Pannella (1974), Brothers et al.
Brothers (1984), Campana and Neilson (1985), and Radtke (1989) are used to infer growth events during the first year of life and during specific intervals later in the fish’s life. Lapilli also have also been shown to provide daily growth increments or rings (Wenner et al. 1990). The astericii are not typically used for daily growth because they are formed later in life than the other two pairs of otoliths.

Otolith morphology differs by species (Figure 2.5). Otolith shape analyses use information extracted from digitized images for species identification (by matching archived key shape descriptors) and, in some cases, to resolve fish populations for the purpose of stock discrimination (Castonguay et al. 1991, Campana and Casselman 1993, Friedland and Reddin 1994, Colura and King 1995, Stransky 2001).

In summary, otoliths are anatomical structures that accrete recognizable layers as the result of differential deposition of organic and inorganic material. These layers may correlate with fish growth that varies with time and season and may provide a cumulative historical record of changes in climate, nutrition, hydrographic environment, and other ecological parameters. Their value are as biological and ecological information storage units (akin to "CD-ROMs of fish biology") that record the temporal signatures of various environmental conditions to which a fish has been subjected from hatching to time of death (Radtke 1990, Kingsmill 1993, C. Wilson personal communication). When comparing otoliths to other fish hard parts such as vertebral bones, scales, fin rays, and spines, otoliths often provide more accurate ageing data due to their continuous accumulation and limited resorption whereas other hardparts tend to underestimate age.

The successful application of techniques to enhance the detection of age marks in the otoliths of Gulf finfish species is of vital importance in estimating growth and mortality rates, population age structure, and other parameters needed for understanding the population dynamics of important fish stocks and their response to natural phenomena and exploitation.

Figure 2.5. Variation in sagittal otolith size and shape by species. From left to right: black drum (Pogonias cromis), red drum (Sciaenops ocellatus), spotted seatrout (Cynoscion nebulosus), gray snapper (Lutjanus griseus), sheepshead (Archosargus probatocephalus), southern flounder (Paralichthys lethostigma), and striped mullet (Mugil cephalus).