BRIEFING NOTE

Small but mighty: The humble mullet and their ecological importance

Prepared by

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Objective: A briefing note aims to provide a concise outcome-based synopsis of recent research or expert opinion that may inform decision making and activities by Authorities, Industry, NGOs and NPOs. The briefing note series complements the academic peer-reviewed literature or reports published by NRF-SAIAB. NRF-SAIAB is a Research Institution and not management agency, and as such, the views presented here are for consideration by all stakeholders and are non-binding.

BACKGROUND

Estuaries are highly productive ecosystems, serving an important nursery function for many estuary-associated species through provision of abundant food sources, habitats for shelter, and protection from predators. Unfortunately, these ecosystems are amongst the most impacted by anthropogenic activities, with things like infrastructure development and water abstraction leading to habitat transformation and destruction. Additionally, many estuaries are also overfished, with climate exacerbating all these activities.

Small-bodied and juvenile fish communities dominate these environments, including numerous mullet species. The mullet family, Mugilidae, is a diverse group of fishes consisting of 70 species and 20 genera, which occur in various coastal habitats across the world. The high abundance of mullet in many estuarine systems and coastal habitats globally is attributed to their broad tolerance of environmental variables such as salinity, temperature, dissolved oxygen and turbidity regimes, which fluctuate throughout the tidal cycles. Mullet generally spawn in the marine environment and the larvae are transported by currents into the nearby estuaries which they use extensively as juveniles (as nurseries) and as adults.

Mullet play an important ecological role in the environments in which they occur. Not only do they serve as food sources with larger predatory species including piscivorous fish and birds, but are also important to subsistence, recreational and commercial fishers who either rely on them for food or being used as live bait for targeting larger predatory species. Their broad environmental tolerances and relative ‘hardiness’ (of some species) also make them suitable candidate species for fishery and aquaculture ventures (e.g., flathead mullet *Mugil cephalus* in Greece, Taiwan, etc.).

MULLET: SOME SOUTH AFRICAN CONTEXT

Fifteen species of mullet occur in South African estuaries in generally greater abundances relative to other smaller bodied species. Despite their generally high abundances, some species of mullet are facing overexploitation in South Africa, mostly through illegal gillnet fisheries; for example, striped mullet *Chelon richardsonii* along the West Coast. Current regulations for all mullet in South Africa allow for bag sizes of 50 fish per person per day for recreational and subsistence activities, and an unlimited bag limit for commercial fisheries, with no minimum size or closed season for all fisheries.

Despite their importance from a fisheries perspective, mullets are also excellent indicator species, not only of the relative health of an estuary, but also for a changing climate (James et al. 2016). As such, keeping an eye on the mullet in a system is one relatively easy way of getting a better understanding of the relative health of a system. From an overfishing perspective and potential adjustments of current or development of new fishery regulations, understanding the habitat use and movement patterns of important fishery species is crucial, as this information can identify important or high use areas or habitats within an estuary. While movement data are being incorporated into fisheries regulations elsewhere in the world (Crossin et al. 2017; Lowerre-Barbieri et al. 2019), South Africa is somewhat lagging. Considering that mullet species dominate the catch composition of estuarine fisheries, with caught individuals being used either as live bait to target bigger piscivorous species, or as a food source, understanding their movement and habitat use patterns in estuaries is important for the development of appropriate conservation measures and management regulations that not only protect the species, but also the environments in which they occur.

MULLET ON THE MOVE

Movement behaviour of aquatic animals can be studied in multiple ways including using mark-recapture, acoustic telemetry, genetics, otolith microchemistry, etc. Acoustic telemetry has gained popularity over the past two decades and is currently the primary tool used worldwide to study fish movements and behaviour of submerged aquatic animals in numerous environments, including inland lakes and rivers to the high seas, and from polar regions to the tropics (Hussey et al. 2015, Matley et al. 2022). This methodology comprises two main pieces of equipment; acoustic transmitters or tags that (in this study) are surgically inserted into aquatic animals, and acoustic receivers that are deployed in the environment in which you wish to study the movements of the tagged species. The transmitter sends out a sound signal which is then recorded by the deployed receivers, which then record the unique ID code of the transmitter, along with the date and time. By putting these little detection pieces together, researchers can track the movements of each fish as they swim past the deployed receivers and piece together the movement puzzle which explains each fish's movement behaviour through space and time. While the expected battery life of acoustic transmitters can range from three months to 10 years, acoustic telemetry still only collects a snapshot of an animal's movement behaviour over a set period of time, particularly for smaller bodied animals that can only be tagged with smaller acoustic transmitters, which equates to shorter monitoring periods. Natural tags, such as otolith microchemistry, on the other hand, allows researchers to assess the lifetime use of different environments by individual animals. Otolith microchemistry involves investigating the chemical composition of fish otoliths. Otoliths are calcified structures found in the inner ear of fish generally used for hearing and balance. The shape and size of each otolith is unique to each fish species. The otoliths grow incrementally throughout a fish's life (like rings of trees) and as they grow, trace elements in the surrounding water body are incorporated into the otolith. While researchers commonly use otoliths to age fish, the chemical composition in the otoliths also reflects the water chemistry (i.e., freshwater or marine water) in which the fish has lived throughout its lifetime. Combining the two methodologies provides a comprehensive overview of the space used by individual fish overtime, allowing for an assessment of similarities and/or differences among movements and methodologies.

Apart from what is known about mullet spawning at sea and their estuarine dependency, there is a lack of empirical data on their movement patterns and space use within estuaries and connectivity to the marine environment, information required for the development of improved management regulations and spatial planning initiatives. In addition, their abundance and distribution in estuaries are strongly linked to different temperature regimes along the coast. As such, mullet have been identified to be one of the first groups of fish likely to respond to climate change (James et al. 2016), making them excellent indicator species. Therefore, pairing movement information with environmental monitoring allows the prediction of how these species may alter their movements given certain changes in environmental parameters.

Here we **highlight the movement ecology work** that researchers and students from NRF-SAIAB are conducting on **several mullet species in the Kowie Estuary**, Eastern Cape, South Africa, and and why it is necessary to conserve these socio-ecologically important species, as well as the estuaries in which they occur.

SNAPSHOT (SHORT-TERM) MOVEMENTS: ACOUSTIC TELEMETRY

Acoustic telemetry was used to assess the **movement behaviour and habitat use** of four species of mullet (Figure 1) – **flathead** mullet *Mugil cephalus* (n = 21), **striped** mullet *Chelon tricuspidens* (n = 14), **grooved** mullet *Chelon dumerili* (n = 12) and **southern** mullet *Chelon richardsonii* (n = 6) – in the Kowie Estuary, Eastern Cape, South Africa (Figure 2) for a year, between May 2023 and June 2024. Fish were tagged with acoustic transmitters and monitored by an acoustic array comprising 26 acoustic receivers deployed throughout the estuary up to the estuary-riverine interface, covering approximately 21 km on the estuary (Figure 2).

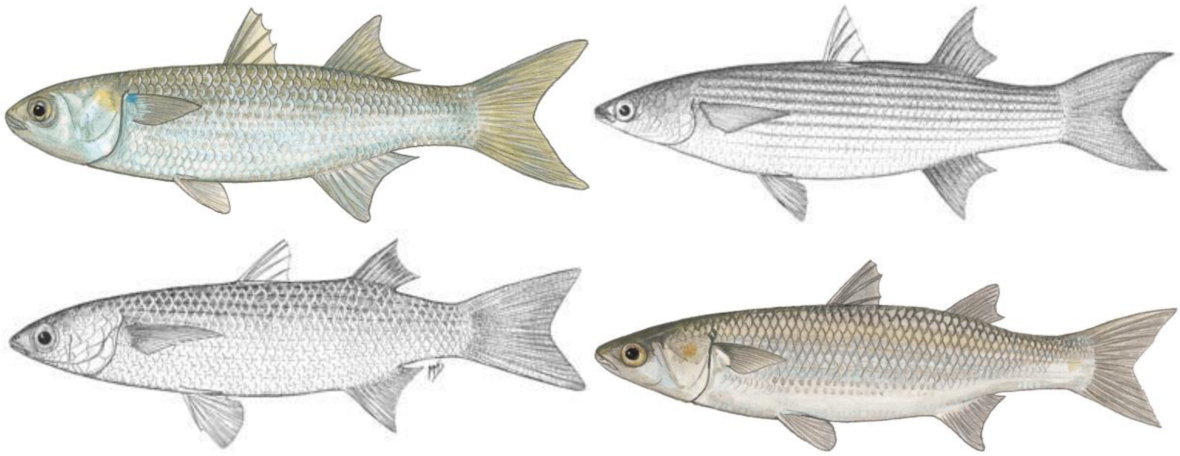

Figure 1: The four mullet species – flathead *Mugil cephalus* (top left), striped *Chelon tricuspidens* (top right), grooved *Chelon dumerili* (bottom left) and southern *Chelon richardsonii* (bottom right) – acoustically tagged in the Kowie Estuary, Eastern Cape and monitored using an extensive acoustic receiver array deployed throughout the system.

All receivers form part of the Acoustic Tracking Array Platform (ATAP), a nationwide network of marine and estuarine acoustic receivers deployed along 2200 km of the South African coastline from St Helena in the west to Santa Maria in southern Mozambique (see https://saiab.ac.za/platforms/acoustic-tracking-array-tracking/) (Figure 2), that provides an infrastructure backbone facilitating the small-, large-scale, long-term monitoring of acoustically-tagged marine animals (Cowley et al. 2017, Murray et al. 2022). The ATAP is one of the NRF-SAIAB's research infrastructure platforms and a briefing note describing this platform and how collected movement data can be incorporated into marine spatial planning efforts is available for distribution.

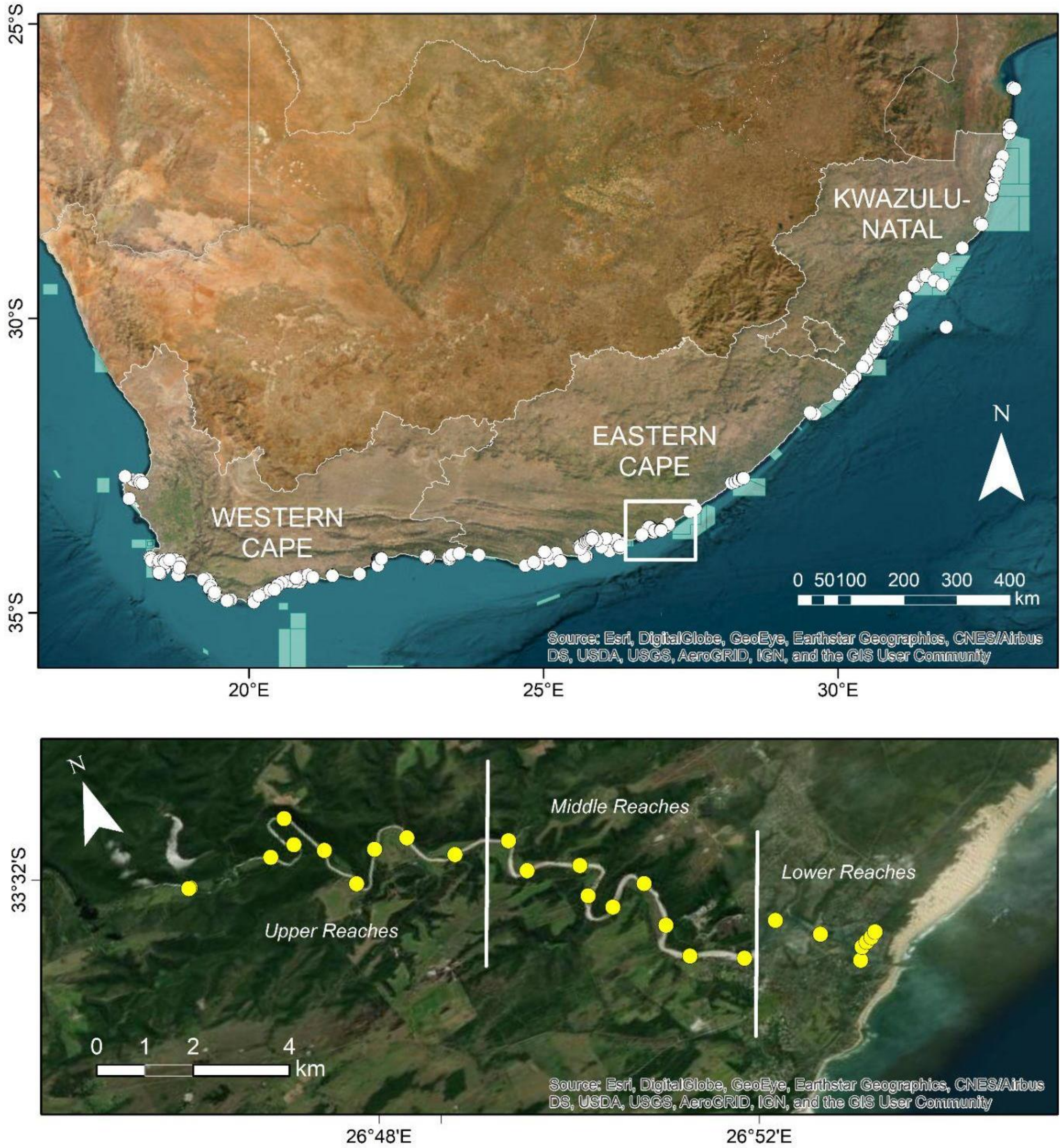

Figure 2: Map of South Africa (top) showing the greater Acoustic Tracking Array Platform, with white dots representing deployed acoustic receivers. The Kowie Estuary receiver array (bottom) is shown in more detail, with yellow dots representing deployed acoustic receivers. This array is still in place, despite the current mullet study coming to an end. This is to allow other researchers to make the most of the available infrastructure.

Mullet, similar to other mobile estuary-dependent species such as the piscivorous (i.e. fish-eating) leervis *Lichia amia* and dusky kob *Argyrosomus japonicus*, appear to move up and down the estuary, linking these **upstream and downstream movements with the incoming and outgoing tides, respectively** (Figure 3). Some interesting space use behaviours were observed, with **each species occupying slightly different reaches of the estuary**: striped mullet made use predominantly of the lower reaches, grooved mullet the middle reaches, and southern mullet the upper and middle reaches. Flathead mullet made extensive use of the entire system, which is unsurprising given their cosmopolitan distribution, occurring in estuarine and marine environments across the globe (Figure 4).

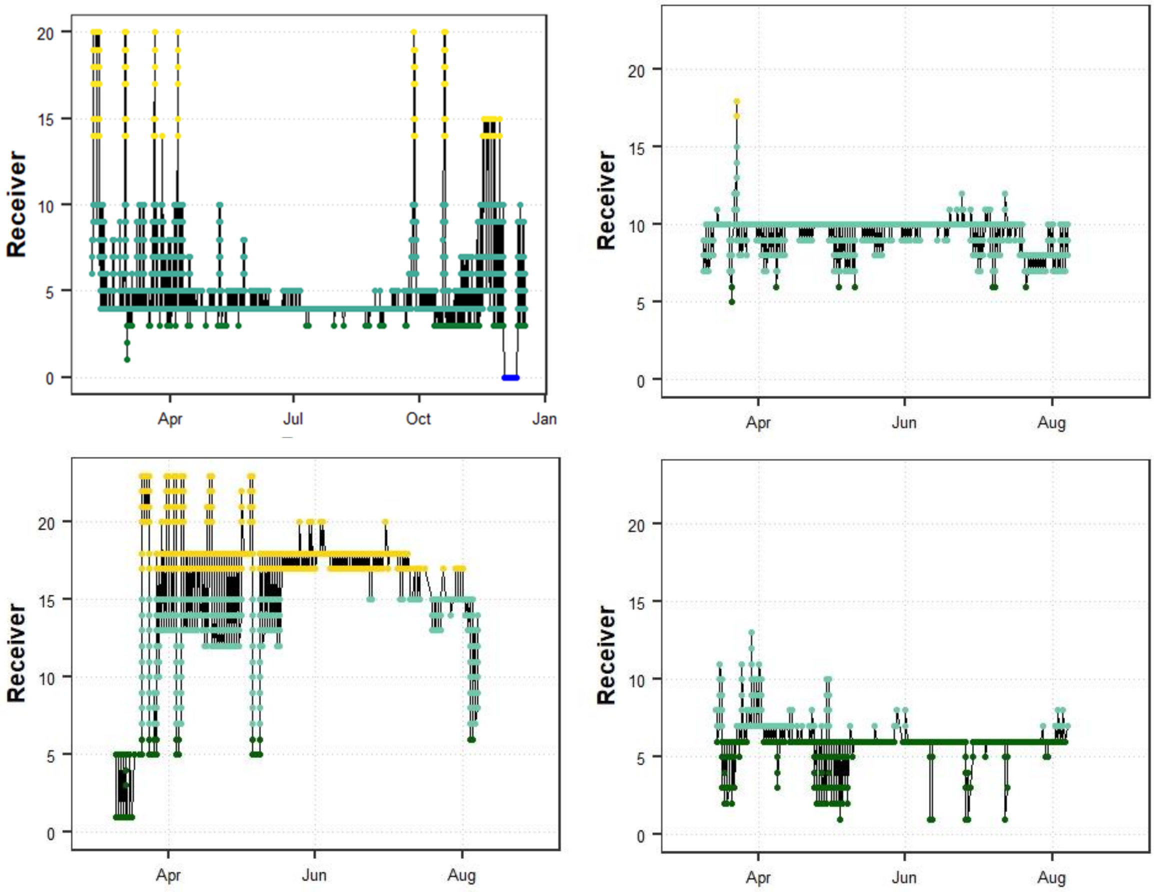

Figure 3: Example of upstream and downstream movements by an individual flathead mullet (top left), grooved mullet (top right), southern mullet (bottom left) and striped mullet (bottom right). Different coloured dots represent different reaches of the estuary, with yellow denoting upper reaches, lighter green the middle reaches, darker green the lower reaches, and blue the sea. The numbers on the y-axis represent distance from the mouth.

Seasonal shifts in movements were also observed within each species and among the different species. While flathead mullet appeared to retract the amount of estuary used during winter, essentially avoiding the colder upper reaches, southern mullet expanded their space use, being recorded in the upper reaches during the cooler winter months. Extent of space use remained somewhat stable for grooved mullet, with striped mullet slightly expanding their use of the Kowie Estuary into the lower to middle reaches during colder winter months (Figure 4).

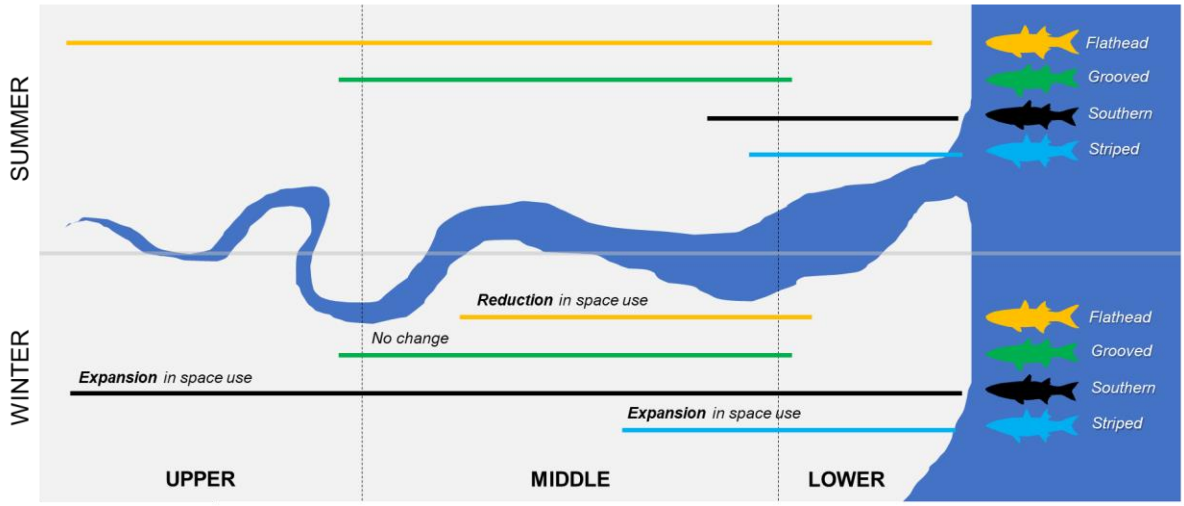

Figure 4: Infographic summarising the habitat use of four mullet species (flathead, grooved, southern, striped) tagged and monitored in the Kowie Estuary, Eastern Cape between May 2023 and June 2024. Different colours represent different species, and bars graphically represent the extent of the estuary used. Please note, this is just a schematic and the estuary pictured is not the Kowie Estuary.

LIFETIME MOVEMENTS: OTOLITH MICROCHEMISTRY

Over the last 30 years, scientists have developed methods that can infer a fish's past movement and migration history by using biological markers. This includes using otoliths (ear bones) (Figure 5a). Otoliths are calcified structures that are composed mainly of calcium carbonate and various trace elements. The amount of trace elements in the otoliths depends on the amount of these elements in the water bodies in which they are found. The fish (and subsequently the otolith) is then exposed to these trace elements during a particular time, which are then embedded/deposited on the otoliths during the process of biomineralization. Because certain habitats or environments contain varying levels of certain trace elements, by analysing the amounts of trace elements accumulated in the otolith at a particular time (using laser inductively coupled plasma mass spectrometry, Figure 5b), one can begin to gain a better understanding of where an individual animal has been throughout its life. For estuaries for example, the two most commonly used trace elements are strontium (Sr) and barium (Ba). A high concentration of Sr is generally representative of high salinity, while conversely, a high Ba concentration is generally representative of low salinity.

This component of the mullet project has been conducted in collaboration with researchers from the Centre national de la recherché scientifique (CNRS) and University of Montpellier, France. Without their expertise and assistance, and an equipment-related travel and training grant from the National Research Foundation, this work would not be possible.

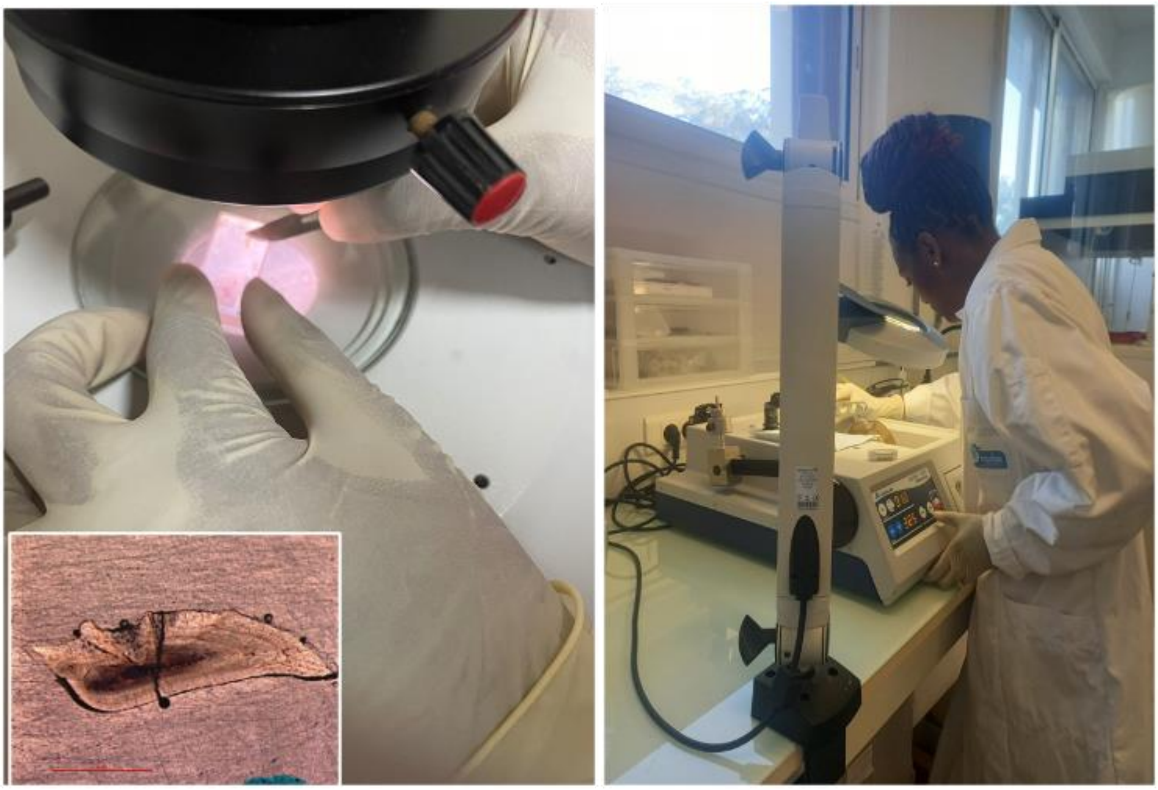

Figure 5: (a) A photograph of an otolith (fish ear bone) mounted on a glass slide prior to laser mass spectrometry; and (b) preparation of the sample for laser mass spectrometry.

Since mullet are estuarine-dependent, using the marine, estuarine and riverine habitats throughout their life cycle, otolith microchemistry was used to **determine the extent of dependency** of flathead and grooved mullet **on these habitats at different life stages**, with the ultimate aim of highlighting areas of high importance within these habitats that may be vulnerable to anthropogenic activities and impacts.

Results have revealed not only several insights into the lifetime use of estuaries by flathead and grooved mullet, but also valuable information for future researchers conducting similar research on mullet or similar species:

1) The **trace element providing the best results for each species differed**, with Sr being most suited for grooved mullet, and Ba more suitable for flathead mullet;
2) Despite the acoustic telemetry results showing extensive use of the estuary as a whole, each species showed clear 'groupings', indicative of **different behavioural contingents**. In other words, some fish displayed the stereotypical life history i.e. born at sea and recruiting into the estuary where they mostly remained with the occasional trip to sea; some fish were predominantly marine, moving occasionally into the estuary; and some fish were almost exclusively estuarine (i.e. residency to only the estuary); and
3) These otolith microchemistry results are touching the surface in terms of what researchers can learn about these and other estuary-dependent species.

A CHANGING CLIMATE: WILL MULLET THRIVE OR TAKE A DIVE?

Learning more about the movement behaviour, both short-term and throughout their lifetime, is only one piece of the ecological puzzle of any species. Understanding the drivers behind those movements, however, is arguably just as, if not more important. Temperature has been identified as the most important variable influencing a fish's internal physiology and behaviour. Due to the abrupt dynamic changes that characterise most estuaries (i.e. changes in temperature, salinity, turbidity, dissolved oxygen, etc.), fish living within them need to adjust their internal physiology or behaviour to cope with these changes. As such, temperature loggers were placed throughout the Kowie Estuary at specific sites to continuously record water temperatures. This information can then be related to the movement behaviour observed using acoustic telemetry.

In order to gain a greater understanding of how temperature influences mullet, two species – **flathead and grooved mullet** – were selected for laboratory trials (Figure 6) to test their thermal tolerance ranges. This was done to understand **the current thermal tolerance** of these fishes as well as to predict the future impacts of anthropogenic climate change on these species' physiology and behaviour, and their ability to adapt to these changes.

Figure 6: Orange dye-tagged grooved mullet (left) and flathead mullet (right) swimming in the experimental tanks (centre) during thermal tolerance trials.

Both flathead and grooved mullet had broad thermal tolerances when compared to other estuarine-associated species; however, **flathead** mullet had a considerably **broader thermal range** relative to grooved mullet and other species. Not only could flathead mullet tolerate cooler water temperatures (3.5 °C, compared to 5.7 °C for grooved mullet), but also warmer water temperatures (37.8 °C, compared to 36.7 °C for grooved mullet). The extremely low critical thermal limit of 3.5 °C for flathead mullet was surprising. However, being a globally distributed species, occurring in many different environments and habitats throughout the world, and exhibiting extensive use of the Kowie Estuary when compared to the other mullet species, these results are understandable and provide some clues for their success. It is important to note that prior to these critical thermal minima and maxima, the fish began displaying signs of stress a couple of degrees (either warmer or cooler) before these limits.

IMPLICATIONS FOR MANAGEMENT

The results of this study highlight the importance of adopting a multimethod approach when answering broader ecological questions. The results from the **acoustic telemetry** component of this study clearly **highlighted habitat partitioning between the four mullet species** (flathead, grooved, southern, striped), where individuals, while coexisting and feeding on similar prey items, used different parts of the estuary on an almost daily basis. **Otolith microchemistry** confirmed the importance of estuaries to two mullet species (flathead, grooved), but interestingly identified **three different types of 'behavioural contingents'**, which each made use of the various environments differently. **Thermal tolerance experiments identified** the thermal range of two mullet species (flathead grooved), clearly identifying **points (i.e. temperatures) at which each species begins to experience severe physiological stress, as well as their critical thermal end points** associated with both an increase and decrease in water temperature.

By studying the movement ecology of multiple mullet species in a single estuarine system, we can begin to identify areas of high importance in terms of space use. In the case of the Kowie Estuary, an extensive seagrass bed in the lower reaches of the estuary was exceptionally important to all species. This is most likely linked to the abundance of food within this habitat for all the mullet species. This highlights the importance of conserving and actively rehabilitating important estuarine habitats, such as seagrass beds, as well as maintaining estuary health as a whole, which will not only benefit the aquatic plant species and subsequent invertebrate communities associated with these habitats, but also the fish species that rely on these habitats for food and shelter.

The main implications for management from this project include:

- Mullet make extensive use of estuaries in which they occur, but display habitat partitioning whereby they use different reaches of the estuary.
- Seasonality influenced the extent of the estuary use for three of the four tagged species, with either expansions or reductions in the estuary use.
- Despite extensive use of the system from lower to upper reaches, the seagrass beds approximately 3 to 4 km from the estuary mouth (lower to middle reaches) were highlighted as important habitats for all tagged species.
- The identification of at least three 'behavioural contingents' indicate scope for resilience, where, should one contingent be significantly impacted in terms of habitat degradation, there is potential for the species to persist.
- Their broad thermal ranges suggest that, despite a changing climate, populations will be able to persist irrespective of a general increase or decrease in water temperature. However, the seasonal movement patterns of certain individuals and species in response to cold riverine waters in winter and warm riverine temperatures in summer suggest that thermal stress may impact some individuals, which may result in habitat squeeze for some fish. In other words, the amount of estuary used by certain individuals or species will reduce. It is also important to be aware that these variables seldom work in isolation, with other environmental variables also playing a major role in the distribution and use of estuaries.
- As such, conserving and rehabilitating important habitats within estuaries will not only conserve smaller bodied fish species making use of these areas, but will also promote resilience to climate change effects.

NATIONAL OR INTERNATIONAL PROCESSES THAT MAY USE THE DATA OR OUTCOMES

- **Estuary Management Plans (EMP):** Estuary-specific information can be shared with the management authority responsible for the development of specific EMPs.
- **National Biodiversity Assessment (NBA):** Movement data can be incorporated into the NBA, contributing particularly to the estuarine and marine components.
- **National Biodiversity Strategies and Action Plans (NBSAPs):** Telemetry data can be used to contribute towards the conservation, management and sustainable use of aquatic species to ensure equitable benefits to the people of South Africa, both currently and in the future. Strategic Objectives 1, 4, 5 and 6 are particularly relevant to the ATAP.
- **Red-listing:** The movement data collected by researchers can be used towards the reassessment of species or provide a local assessment using criteria developed by the International Union for Conservation of Nature's Red List of Threatened Species. Updated information on movements are often missing when evaluating a given species.

KEY PAPERS FOR CONSIDERATION

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AGENCIES THAT SHOULD BE CONTACTED

Department of Forestry, Fisheries and the Environment (DFFE)

Department of Economic Development, Environmental Affairs and Tourism (DEDEAT)

CapeNature

South African National Parks (SANParks)

Eastern Cape Parks and Tourism Agency (ECPTA)

Ezemvelo KZN Wildlife (EKZNW)

South African National Biodiversity Institute (SANBI)

Council for Scientific and Industrial Research (CSIR)

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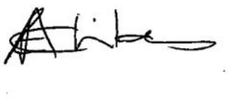

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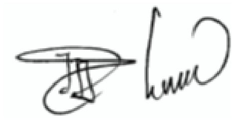

Approved by Prof Albert Chakona

NRF-SAIAB Acting Managing Director