Investigating the entire continuous dataset of a fish's otolith microchemical profile using time-series analysis

Ba [ppm]

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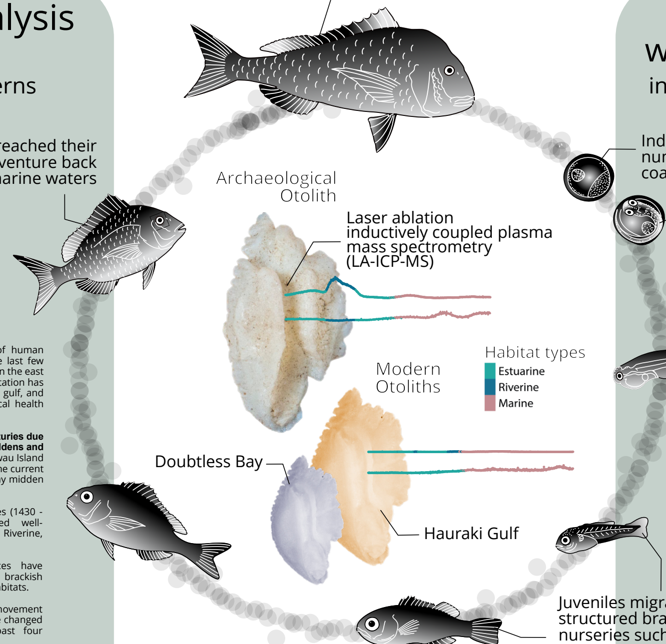
Snapper *Chrysophrys auratus*

is a seabream species and one of the most abundant coastal fishes around New Zealand's North Island



Behavioural Change Point Analysis with k-means clustering

informs us about early life habitat use patterns

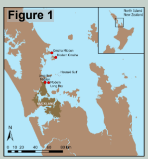
Behavioural Change Point Analysis (BCPA) is a methodology that can be employed to identify hidden shifts of the underlying parameters in the autocorrelation structure of a time-series, an approach which is rooted in the field of movement ecology (Gurarie et al. 2009). When coupled with a k-means clustering algorithm it can be utilised to infer changes in behavioural "states" of an animal's movement (Zhang et al. 2015).

Like a movement trajectory, the time-series of chemical signatures extracted from otolith samples are temporally autocorrelated. This allows us to retrospectively position individual fish in space and time throughout their life and make inferences about nursery habitat use patterns during its ontogeny - **independent of confounding metabolic factors.**

The application of BCPA with k-means clustering to snapper otoliths showed that most fish experienced three distinct "behavioural clusters" during the period represented by the 1010 µm long ablation transects - the minimum readable distance for all samples.

By calculating the mean values within these behavioural clusters, we were able to reconstruct three distinct aquatic habitat types experienced by snapper according to the diverging mean concentrations of Ba and Sr: Riverine, Estuarine, and Marine.

Figure 1



In New Zealand snapper have been fished extensively since the beginning of human colonisation around 1000 years ago (Leach & Davidson 2000). Further, over the last few decades, the natural environment of the Hauraki Gulf, a large coastal embayment on the east coast of New Zealand's North Island, has changed significantly. Increasing sedimentation has had a particularly harmful impact on benthic ecology in the upper reaches of the gulf, and overall, the estuarine coastal environments are deemed to be in poor ecological health (Hauraki Gulf Forum 2020; Drylie 2021).

To test, whether snapper early life movement patterns have changed over the centuries due to anthropogenic pressures, we sampled historic otoliths from archaeological middens and modern-day otoliths from recreational fishers at two sites in the Hauraki Gulf. Kawau Island (2016 AD) served as the closest modern comparison to the Omaha midden, while the current Long Bay marine reserve (2020 AD) provided samples to compare with the Long Bay midden (**Fig. 1**).

Figure 2

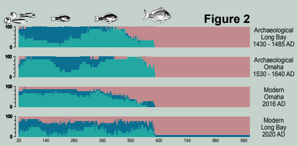


Fig. 2 informs us that over several centuries (1430 - 1640 AD), historical individuals showed well-synchronised movement patterns between Riverine, Estuarine and marine Habitats.

In contrast, modern human disturbances have resulted in snapper spending less time in brackish nurseries and moving chaotically between habitats.

It is therefore evident that early habitat movement patterns of snapper in the Hauraki Gulf have changed dramatically at some stage over the past four centuries.

Temporal comparison of habitat-use patterns through Behavioural Change Point Analysis (BCPA) with k-means clustering proofed to be a powerful tool to evaluate past and present nursery habitat quality.

Dynamic Time Warping with multivariate hierarchical clustering

informs us about inter-stock differences in nursery areas

Dynamic time warping (DTW) is a time series analysis approach that is both efficient and remarkably flexible, capable of matching sequentially structured data sets comparable to otolith micro-chemical information (Mueen and Keogh 2016). More importantly, the approach is capable of comparing sequential data despite temporal offsets that confound other methods (Al-Naymat et al. 2009, Rakthanmanon et al. 2012).

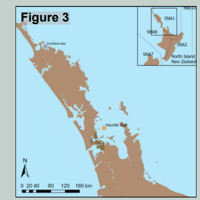
Due to the loss of information through aggregation, standard methods are not able to distinguish the fine-scale chemical movement information of early life stages of fish (Hegg and Kennedy 2021). We employed multivariate hierarchical DTW clustering to compare similarities between continuous otolith elemental Ba values in order to reveal information that will indicate the number of nursery clusters in snappers sampled from two distinct geographic locations **- independent of individual fish catch locations and dates.**

To ensure that we covered early habitat interactions before settlement for all sampled fish, ablation length was set to between 200 and 400 µm.

In New Zealand snapper stocks are managed in relatively large and distinct quota management areas (SNAs). Unfortunately, snapper nurseries are generally under threat from coastal pollution and development, and the population suffers from overexploitation both commercially and recreationally. Hence, more accurate discrimination between nursery areas is needed to ensure appropriate fine-scale management and to guarantee that conservation measures are implemented in order to preserve the full genetic potential of the stock.

To test, whether we can differentiate between nursery areas within a single managed population, we acquired fish of different length from recreational fisheries in the Hauraki Gulf and Doubtless Bay (Upper East Coast of New Zealand's North Island) in 2020 (**Fig. 3**). These two locations are known as snapper spawning aggregation sites and represent heavily and moderately populated coastal regions, respectively.

Figure 3

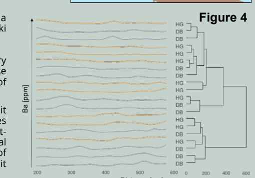


Our preliminary analysis of a subset of samples did not show a clear separation of clusters between the sampling sites Hauraki Gulf [HG] and Doubtless Bay [DB] (**Fig. 4**).

We were therefore unable to identify specific snapper nursery clusters in SNA1. This could be due to the disturbed habitat use patterns we previously identified in the region, where a lack of brackish water nursery signatures was observed.

However, given the preliminary nature of our analysis, it is also likely that attempts to reveal stock structures based on micro-chemical differences in nursery habitat-use will require further investigations and analytical approaches. As it stands, the current management of the snapper population in the SNA1 management unit seems justified.

Figure 4



Preliminary comparison of nursery areas on the basis of Dynamic Time Warping with multivariate hierarchical clustering indicated one single population in the current management unit.

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Literature

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