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Work plan for an Indian Ocean yellowfin tuna close-kin mark-recapture design study

Yellowfin tuna CKMR design study

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Summary

Recent stock assessments for Indian Ocean yellowfin tuna have been compromised by ongoing uncertainty in catch estimates, catch per unit effort indices, conventional tagging data, and reliant on assumptions about the spatial structure and connectivity. Close-kin mark-recapture (CKMR) offers a promising alternative for estimating key population parameters, such as absolute spawning biomass, total mortality, and connectivity. A CKMR design study for Indian Ocean yellowfin tuna was recently funded and will conclude with the delivery of statistically evaluated design for the implementation of a basin-scale CKMR project. This working paper briefly outlines the work plan and specific issues that will be considered in the design study, including the key research questions, population structure, biological parameters, and sampling design. To assist in the development of the design study, the WPM is invited to discuss and provide feedback on the following:

- *Suggest any other priority research questions for Indian Ocean yellowfin tuna to consider in the CKMR design study*
- *Advise on any additional plausible hypotheses of population structure of yellowfin tuna in the Indian Ocean that might be explored alongside the current understanding from recent basin wide stock structure analyses.*
- *Suggest additional evidence-based values for biological parameters and plausible population sizes that could be used at starting values in the population model.*
- *Advise on fisheries and locations where useful quantities of samples could be practicality and efficiently collected, given the population structure hypotheses and likely requirements they would have on possible sampling locations*

Introduction

The yellowfin tuna stock in the Indian Ocean is overfished, and substantial reductions in catch are required to rebuild the stock to target levels (Fu et al. 2018, Kolody and Jumppanen 2019). The sustainability concerns for yellowfin tuna are exacerbated by ongoing issues with data inputs for the stock assessments, which include uncertainty in catch estimates, fisheries-dependent CPUE indices, conventional tagging data, and assumptions about the spatial structure and connectivity for the assessment models (Kolody and Bravington 2019, Matsumoto et al. 2018).

Options for improving the yellowfin assessment data have been debated at IOTC Working Party and Scientific Committee meetings for several years. One of the most promising alternatives identified is the application of close-kin mark-recapture (CKMR), a method that has a proven track record in application to the assessment and management of other tuna populations (e.g. Southern bluefin tuna, Bravington et al. 2016a, Hillary et al. 2020) and which has been identified as a priority research activity for yellowfin tuna in the WPTT Program of Work since 2017 (IOTC 2017).

CKMR uses modern genetics to identify closely related pairs of fish. The number of kin-pairs identified, and how they are distributed in space and time, can be used in a population dynamics model to estimate key population parameters, such as absolute spawning biomass, total mortality, and connectivity (Bravington et al 2016a). CKMR is different to other types of tagging programs in that off-spring 'tag' their parents via their DNA, and half-siblings 'tag' each other and their parents via their shared DNA. CKMR requires collection of tissue samples for DNA extraction and genotyping but these can be sampled from dead fish (i.e., fishery catches) and, in comparison to other mark-recapture programs, there is no requirement to consider tag shedding, tag-induced mortality, or reporting rates of recaptured fish.

Kolody & Bravington (2019) concluded that CKMR should be logistically feasible for Indian Ocean yellowfin tuna, provided that catch samples can be obtained from appropriate locations and fisheries across the Indian Ocean. They recommended that prior to an ocean basin-wide project, a detailed design study be undertaken that attempts to represent the biology more accurately, quantifies expected precision of different population parameter estimates with respect to sampling design, and evaluates the combined costs of catch sampling, DNA extraction, genotyping, close-kin analysis, and population modelling.

Funding for a CKMR yellowfin tuna design study has been provided by the Australian Government Department of Foreign Affairs and Trade. This working paper briefly outlines the work plan for this design study and identifies specific considerations in developing the design study that would benefit from feedback from the WPM.

Work plan

A CKMR design study for Indian Ocean yellowfin tuna was funded in mid-2021 and will conclude with the delivery of statistically evaluated design for the implementation of a basin-scale CKMR project to the IOTC Scientific Committee in 2022. The design study will identify several specific research questions of interest to the IOTC and evaluate the pros and cons of alternative sampling designs to address these questions and the costs and resources required for their implementation in a basin-scale CKMR monitoring program for Indian Ocean yellowfin tuna. The following sections outline a range of considerations for the design study, and the WPM is invited to discuss and provide feedback on the aspects noted by *highlighted* text.

What do we want from CKMR?

CKMR can provide information on a wide range of population parameters, including absolute abundance of adults, total mortality rates, fecundity at age, and connectivity, among others (Bravington et al. 2016a). CKMR can also be applied to provide an instantaneous estimate of these parameters or extended through time to provide a time series of estimates for monitoring. The design of the sampling strategy and population model may differ depending on what questions are to be answered or known constraints. For example, if the primary interest is to obtain a single estimate of absolute adult abundance, then a sampling strategy could be designed to collect a large number of both adults and juveniles (to identify both parent-offspring pairs (POPs) and half-sibling pairs (HSPs)) over a short period to provide a 'snap-shot' estimate of abundance. However, if the *trend* in absolute abundance of adults is of more interest, or a more precise estimate is required, then the sampling strategy could be designed to build the required samples over several years, and to enable the continued collection of samples over time. If estimation of adult mortality is a priority, consideration would be given to an extended period of sampling to detect cross-cohort HSPs which are particularly informative of adult mortality rates (Bravington et al 2016). To address questions on connectivity, the design exercise must consider a spatial sampling program that includes as much available and relevant information as possible to ensure we are able to detect kin pairs (POPs and HSPs) between possible spawning sites and are able to estimate connectivity.

Given the significant issues with current Indian Ocean yellowfin tuna stock assessment, particularly the reduced information available from the standardised CPUE series, we consider having a fishery-independent estimate of the trend in the adult population and adult mortality would present the best value from a CKMR project. The design required to provide this information would also allow estimation of other parameters including connectivity and fecundity-at-age.

We invite the WPM to suggest other priority research questions for Indian Ocean yellowfin tuna to consider in the CKMR design study.

Population model

The design study will develop a CKMR population model – of the same age and spatial structure as the assessment with some potential additional spawning site dynamics - for IOTC yellowfin tuna that gives realistic consideration of achievable precision of key management parameters, such as recent spawning population, spawning population trends, reproductive output at age, total mortality, and population connectivity. In developing the CKMR population model, consideration needs to be given to spatial structure (both migratory and reproductive) and biology of the Indian Ocean yellowfin population.

Spatial considerations

Spatial structure in populations can have important implications for CKMR. Unfortunately, there is no one-case-fits-all approach for dealing with spatial structure in CKMR, so a case-by-case approach is required. Numerous studies have reported varying degrees of structure within the Indian Ocean yellowfin population, from single to multiple stocks. The most recent studies indicate that multiple populations are more likely than a single stock (Davies et al. 2020), which has been the underlying assumption of yellowfin tuna stock assessments to date. The design study will review the existing information on population structure of yellowfin tuna in the Indian Ocean to evaluate the most plausible scenarios and to determine whether these need to be explicitly accounted for in the population model.

The WPM is invited to advise on any additional plausible hypotheses of population structure of yellowfin tuna in the Indian Ocean that might be explored alongside the current understanding from recent basin wide stock structure analyses.

A simple non-spatial CKMR population model should provide reasonable estimates even in the presence of spatial structure, as long as the sampling is sufficiently spread across the fishery. It is important to note that the design of the sampling is key to minimising the potential effects of spatial population structure on CKMR results. A poorly designed sampling scheme would be unable to deliver reliable estimates regardless of modelling efforts and would not provide the information required to determine whether a spatially-explicit population model is necessary (Bravington et al. 2021). A well-designed sampling scheme could not simply sample all fish from a single location but would spread the sampling out spatially across the areas fished. Ultimately, with a well-designed sampling scheme, CKMR itself can provide direct information on spatial population structure because observations of closely-related pairs provide a direct measure of population connectivity.

Biological information

Designing a CKMR study requires some prior information on biological parameters which are used as covariates in the population model. Key biological parameters required for the population model of a design study include age or sex-specific estimates of growth, maturity, fecundity and some estimate of the true population size. For yellowfin tuna, much of this information is available either from biological studies or from inputs/outputs from stock assessments. The design study will undertake a review of the available biological information for yellowfin tuna in the Indian Ocean to identify the most robust biological parameter estimates to use in the population model. Estimates of plausible population sizes will be drawn from past stock assessments (e.g. Fu 2018).

The WPM is invited to suggest additional evidence-based values for biological parameters and plausible population sizes that could be used at starting values in the population model.

CKMR requires information on the age of sampled fish to determine the year of birth and the likely fecundity and maturity of the potential parent at that time. While age estimates do not have to be perfect, increased precision improves the model's ability to estimate abundance and other demographic parameters reliably. Length is generally a poor predictor of age for yellowfin tuna, particularly for larger individuals, given the high variability in size-at-age and the decline in growth rate beyond about five years of age. Some age information for juvenile fish (<3yo) could be derived from length-frequency data but overlaps in length-frequency modes will reduce precision and may introduce bias.

Otoliths provide the most reliable method for obtaining age estimates for yellowfin tuna. Otoliths have been collected in port and by on-board observers in the Indian Ocean during other studies to provide age information for estimating age-specific parameters such as growth (e.g. Dortel et al. 2014). The logistics and quantities required for CKMR across the whole longitudinal range of yellowfin tuna in the Indian Ocean will be examined in the design study.

Application of epigenetics to estimate age is a potential alternative method to obtain age and offers several advantages over large-scale otolith collection and reading. Epigenetic ageing has emerged rapidly in the last couple of years (e.g. Mayne et al. 2021) and can be highly automated thus less expensive than reading otoliths. The DNA collected and extracted from tissue samples for CKMR can be re-used directly for epigenetic ageing, hence no additional sampling is required, and the complex and potentially damaging process of extracting otoliths can be avoided. The application of this technique to other species, including tuna, has shown promising results, and the technique is highly transferrable between species. The potential for epigenetics to provide reliable estimates of age for yellowfin tuna will be evaluated during this design study.

Sampling opportunities

The design study will refine and optimise the sample sizes required to obtain a set precision of the estimates from the CKMR program. The sample size required to obtain relative precise estimates of adult population size of yellowfin tuna are likely to be large. For example, Kolody and Bravington (2019) estimated that 64,000 – 128,000 fish (adults + juveniles) would need to be sampled to provide the required number of kin pairs to estimate adult biomass with a precision of ~15%. As described above, another important consideration is to ensure that the sampling is spread out spatially across the main areas fished, particularly if some population structure is thought to exist. This will require consideration of the size of fish sampled to ensure an adequate number of juveniles and adults are sampled.

This design study will evaluate the fisheries and locations where useful quantities of samples can be practicality and efficiently collected, noting that samples must include approximate capture location and information on fish size. This design study will also explore what existing samples might be available from previous studies to contribute to a CKMR study.

The WPM is invited to advise on fisheries and locations where useful quantities of samples could be practicality and efficiently collected, given the population structure hypotheses and likely requirements they would have on possible sampling locations

Consultation and Collaboration

The success of a CKMR project, particularly a large-scale project such as for Indian Ocean yellowfin tuna, is strongly dependent on developing the necessary stakeholder consultation and collaborative institutional arrangements to move from a design study to basin-scale implementation. Given the value of the yellowfin tuna fishery for IOTC member countries, and the urgency for resolving sustainability concerns for the stock, obtaining cooperation from members for the appropriate level of catch sampling across this widely distributed fishery is unlikely to be problematic. Furthermore, the extensive networks established during recent large-scale collaborative projects (e.g. the Indian Ocean stock structure project; Davies et al. 2020) provide a strong foundation for establishment of an effective project team to facilitate the transition from a design study to implementation of a large basin-scale sampling program across the Indian Ocean.

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