



Australian Government

Australian Fisheries Management Authority

Minutes

Meeting	Shark Resource Assessment Group (SharkRAG)		
Meeting Number	1 out of 3	Date	31 July 2025
Location	Online, Microsoft Teams	Time	13:00 – 17:00
Members	Dr Rik Buckworth (Chair) Dr Robin Thomson (Scientific member) Dr Matias Braccini (Scientific member) Dr Charlie Huveneers (Scientific member) Dr Caleb Gardener (Economic member) Mr Kyriakos Toumazos (Industry member) Mr Anthony Harriss (Industry member) Mr Jamie Papas (Industry member) Dr Lianos Triantafillos (AFMA member) Ms Michelle Henriksen (Executive officer – AFMA)		
Apologies	Ms Anissa Lawrence (Conservation member) Mr Leigh Castle (Industry member)		
Invited Participants	Mr Ross Bromley (SSIA ¹) Dr Pia Bessell-Browne (CSIRO ²) Dr Paul Burch (CSIRO)		
Observers	Mr Kurt Davis (ABARES ³) Mr James Woodhams (ABARES) Mr Anthony Coggan (AFMA) Mr Dan Corrie (AFMA)		

Agenda Item	Title/Topic/Issue	Notes, Action & Recommendations
1.	Preliminaries	1.1 Welcome and apologies The Chair, Dr Rik Buckworth, opened the meeting with an Acknowledgement of Country and welcomed participants. The Chair also facilitated the

¹ Southern Shark Industry Association

² Commonwealth Scientific and Industrial Research Organisation

³ Australian Bureau of Agricultural and Resource Economics and Sciences

		<p>introduction of meeting participants and noted apologies, which is recorded in the table above. Meeting participants were informed that the meeting would be recorded for the purpose of assisting the preparation of meeting minutes.</p> <p>1.2 Declarations of interests</p> <p>The SharkRAG noted, in line with Section 15 of Fisheries Management Paper 1 – Consultative Committees (FMP1), the requirement for all meeting participants to declare relevant interests, not limited to pecuniary gain, regarding all agenda items proposed for SharkRAG. Declared interests are recorded in the register of interest at Attachment B.</p> <p>1.3 Adoption of agenda</p> <p>The agenda was adopted as final (Attachment A).</p> <p>1.4 Minutes of previous meeting</p> <p>AFMA noted that the minutes from SharkRAG meeting held on 31 July 2025 were distributed to SharkRAG members for feedback prior to finalisation and are available on the AFMA website.</p> <p>1.5 Actions arising from previous meetings</p> <p>SharkRAG endorsed the status of all action items from previous meetings, except for the item raised in SharkRAG 1 (2023) regarding improving discard reporting and exploring industry-led options to enhance it. Members requested this issue be revisited, with particular attention to assess the congruence between logbook data and EM for key non-target discard species, ETPs, and other bycatch species A summary of actions and recommendations from SharkRAG are at Attachment C.</p> <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Action 1: AFMA, CSIRO and ABARES to refocus the action item raised in SharkRAG 1 2023 “<i>improve discard reporting and the potential options industry can undertake to improve better discard reporting</i>” to assess the congruence between discards and EM for non-target and bycatch species.</p> </div>
2	Fishery Update	<p>SharkRAG noted updates from AFMA and the RAG memberships regarding current management arrangements and activities in the Commonwealth Shark Fishery.</p> <p>2.1 AFMA Management</p> <ul style="list-style-type: none"> • AFMA is preparing a contract for a desktop study proposed by SSIA to assess the implications of allowing automatic baiting in the Bass Strait. The study will examine potential impacts on economic value, Total Allowable Catches (TACs), bycatch species and benthic habitats. A final report is expected by December 2025. • The Fisheries Research and Development Corporation (FRDC) has agreed to fund the second phase of the multispecies harvest strategy project. This research will develop and test harvest strategies tailored for the Southern and Eastern Scafish and Shark Fishery (SESSF). • The SESSF has been re-accredited as an approved Wildlife Trade Operation (WTO) for a three-year period from 1 July 2025. Key SharkRAG related conditions include: <ul style="list-style-type: none"> ○ a review of the school shark rebuilding strategy to be completed by January 2028.

		<ul style="list-style-type: none"> ○ engage with state jurisdictions to share management responsibility for stocks subject to overfishing and effectively manage all forms of mortality, particularly for school shark. ○ continued implementation of the gillnet dolphin mitigation strategy. <ul style="list-style-type: none"> • Five endemic shark and ray species are under consideration for listing under the <i>Environmental Protection and Biodiversity Conservation Act 1999</i> (EPBC Act). AFMA supports a conservation dependent listing but holds concerns about data limitations and the feasibility of rebuilding targets. Misidentification issues (e.g., whitefin swellshark vs. draughtboard shark) were also highlighted. AFMA is continuing discussion with the Department of Climate Change, Energy, the Environment and Water (DCCEEW) and the Threatened Species Scientific Committee (TSSC) regarding these matters. Final advice from the TSSC is expected in October 2025. <p>2.2 Industry update</p> <ul style="list-style-type: none"> • Gummy shark fishing has been steady and productive, with yearly improvements across South Australia and the Bass Strait. • There is increasing difficulty in avoiding school shark, including in historically low-interaction areas. Observations suggest a significant increase in school shark abundance, with some operators reporting two to three times more interactions than in previous years. • Economic challenges were reported, particularly due to: <ul style="list-style-type: none"> ○ difficulty competing with imported products, specifically with New Zealand imports of school shark and gummy shark, which at \$18-21 /kg are priced significantly lower than Australian products. ○ reduced processing capacity due competing New Zealand market prices and market saturation. • Concerns were raised about the inconsistency in school shark management across jurisdictions, particularly the impact of potential high school shark catches in Western Australia. <p>2.3 Scientific update</p> <ul style="list-style-type: none"> • CSIRO presented a summary of an upcoming research project that aims to complete a spatial analysis to quantify school shark bycatch in the SESSF. Preliminary results will be presented at the next SharkRAG meeting in November 2025, with a final analysis provided at a third meeting due to the scheduled in late 2025/early 2026. The analysis will include: <ul style="list-style-type: none"> ○ spatial and temporal distribution of school shark bycatch. ○ school-to-gummy shark ratios to assess economic implications. ○ discard estimates across sectors. <p>2.4 Economic update</p> <ul style="list-style-type: none"> • No updates were provided by the economics member. <p>2.5 Conservation update</p> <ul style="list-style-type: none"> • No updates were provided by the conservation member.
3	Close-kin Mark-Recapture assessments	<p>An update on the close-kin mark-recapture (CKMR) assessment was provided by Dr Robin Thomson (CSIRO).</p> <ul style="list-style-type: none"> • CKMR is a mark-recapture method used to estimate absolute population abundance and demographic parameters by identifying

		<p>close genetic relationships (e.g., parent-offspring, half-siblings) among sampled individuals.</p> <ul style="list-style-type: none"> • The technique relies on DNA sequencing to detect kin pairs and uses the frequency and temporal distribution of these pairs to infer population size, survival rates, and reproductive output (although for school shark productivity at length is assumed known from biological investigations). • CKMR is particularly useful for species where traditional abundance indices (e.g., CPUE) are unreliable or unavailable. • The CKMR model is being updated with an additional 3000 samples, collected from 2018 to 2022. The addition of these new CKMR samples is expected to reduce overall uncertainty in population trend and further strengthen the robustness of the assessment. • Genetic sequencing and kin pair identification for the new samples brings the total to 8 POPs, 95 FSPs, and 204 HSPs—an increase of 5 POPs, 61 FSPs and 140 HSPs from the 2019 study. • Vertebral ages are available for the original 3,000 samples from 2019 and for 160 newly sampled individuals involved in new kin pairs. • To address the high uncertainty associated with vertebral ageing, a new statistical method has been developed to estimate age within the CKMR framework. This method uses full sibling pairs to calibrate and improve uncertain age measures such as those from vertebral aging and length measurement and will be incorporated into the updated CKMR model. • Industry is working to collect more samples from Western South Australia and Western Bass Strait to feed into the model. <p>SharkRAG discussed the following:</p> <ul style="list-style-type: none"> • Concerns were raised about the spatial structure assumed for school shark populations, with industry members suggesting the existence of regional, resident stocks not being fully captured by CKMR sampling. • Eastern Bass Strait was highlighted as a region with high kin-pair density, prompting discussion on juvenile aggregation. • Industry representatives believe there are differences in shark morphology and behavior across regions. • Concerns about the reliability of ageing were noted, with vertebral ageing showing significant error margins. Efforts to improve age estimation using genetic markers were unsuccessful within the budget and timeframe of this project. • The kin pair data show no evidence for regional clustering of related individuals, with the exception of sibling pairs in EBS. • CSIRO requests skippers to inform them if any tag-and-recaptured individuals are found. It was emphasized that these known age individuals could be very helpful in calibrating ageing methods. • The next CKMR assessment is scheduled to be completed by November 2025 and will be presented to SharkRAG 2.
4	Harvest control rule project update	<p>CSIRO, Dr Pia Bessell-Browne, provided an update on the project exploring the use of Spawning Potential Ratio (SPR) as the basis for harvest control rules (HCRs) with Close Kin Mark Recapture data, particularly where estimates of unfished biomass (B_0) are unavailable.</p>

		<ul style="list-style-type: none"> • Traditional HCRs often rely on estimates of B_0, to determine stock status. • Estimating B_0 accurately is challenging, particularly in dynamic environments where productivity may fluctuate. • The project aimed to develop an HCR for a school shark-like population that can be used without a measure of B_0. • Stock assessments based on CKMR data can accurately estimate absolute abundance from genetic relationships among sampled individuals as well as fishing mortality rate (if known catches are incorporated into the model) SPR (spawners per recruit) is a measure of the expected lifetime reproductive potential of an average fish. SPRR (SPR ratio) is the ratio of SPR in a fished population relative to an unfished one. • Simulation testing was conducted using a school shark-like population model, incorporating close-kin data and age-structured dynamics. • Results showed that SPR-based HCRs produced stable catch recommendations and tracked biomass trends effectively. • The SPR approach may reduce variability in recommended catches compared to traditional HCRs, aligning with harvest strategy performance objectives. • A future project is required to develop HCR parameters tuned for school shark to assess the performance of HCRs under various productivity scenarios. <p>SharkRAG discussed the following:</p> <ul style="list-style-type: none"> • The SPR approach was also tested on an example teleost species, indicating potential for broader use. However, the performance of the method may be limited for fisheries lacking close-kin data or robust age/length sampling. • While SPR-based HCRs are consistent with harvest strategy policy, the conservation-dependent listing of school shark requires continued focus on recovery objectives that are defined relative to B_0 noting that the project developed an alternate estimate of $B_{unfished}$, which is B_0 under current productivity conditions. <p>Full Management Strategy Evaluation (MSE) testing is required to validate the SPR-based approach and ensure that it will not have unexpected consequences. Ideally this work will include consideration of technical interactions with gummy shark and optimisation of reference point parameters.</p>
5	SPR literature review	<p>SharkRAG noted the presentation by AFMA member Dr Lianos Triantafillos on the evidence for a shift in school shark productivity baselines and the use of SPR based assessments and associated HCRs in the SESSF:</p> <ul style="list-style-type: none"> • School shark have been classified as overfished and subject to overfishing in the ABARES fishery status report and have been listed as conservation dependent under the EPBC Act since 2009. • The School Shark Rebuilding Strategy has been in place since 2008 and aims to restore the stock to above 20% of unfished biomass over 3 generations by 2074 (66 years since 2008) using a range of

		<p>management measures to constrain school shark catch. This includes setting a minimum incidental bycatch TAC, gear restrictions, mandatory live release rule, and spatial closures.</p> <ul style="list-style-type: none"> • There are signs that this rebuilding strategy is performing as intended, including: <ul style="list-style-type: none"> ○ an increasing CPUE in the SESSF trawl sector ○ anecdotal reports from industry of high school shark abundance ○ increased state catches and discards in recent years, and ○ changing fleet dynamics to avoid areas of high school shark abundance. • There is evidence that the productivity of school shark has changed since the 1990s, including: <ul style="list-style-type: none"> ○ Punt et al's stock assessment model could not account for the steep decline in catch rates of school shark during the late 1980s – 1990s under a single stock model. The CKMR model could not sustain the high catches of the 1990s given the current low stock abundance. ○ the degradation of critical nursery areas in Tasmania and Victoria in the 1980s and 1990s resulted in a marked decline in the catch rates of pups and juveniles, when these nursery areas were re-sampled in the 1990s. In some areas, pups were no longer present, suggesting that they may no longer function as viable nursery habitats ○ increased juvenile growth rates in less degraded nursery areas, possibly due to reduced competition from lower population density (Stevens and West 1997). • Anthropogenic pressures such as climate change and urbanisation are likely to impede the recovery of the nursery areas, making a return to historical abundance levels highly improbable. • Current management reference points that rely on the assumption that school shark stocks will return to historical abundances in the absence of fishing are no longer applicable. • The CKMR assessment cannot be used to determine the stock status of school shark because it provides an estimate of absolute abundance, without representing population dynamics back to unfished levels, whereas the current harvest strategy policy relies on estimates of abundance relative to B_0. • SPR-reference points are robust to plausible levels of life-history variability under environmental change –supporting the use of SPR as a reliable, adaptable tool, even under changing environmental conditions. • SPR-based HCRs are inherently precautionary, especially when using an SPR of 40% or higher, and there are no policy or guideline barriers to using SPR-based HCR in Commonwealth fisheries. This approach aligns with the CFHSP emphasis on evidence-based, precautionary, and cost-effective management. • The SPR approach is therefore proposed as an alternative method to assess the stock status of school shark and inform a bycatch TAC. • The SPR method indicates a suitable method for species such as school shark with slow growth rates and late maturity stages.
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		<p>SharkRAG discussed the following:</p> <ul style="list-style-type: none"> • There was broad support for the view that school shark productivity has changed, and it is no longer applicable to use reference points that rely on B_0. • More discussion is required to determine how a change in productivity can be quantified in an assessment, and whether the productivity change is a removal of the stock or removal of part of the recruitment capacity. • There was an agreement for AFMA to develop a formal document summarising the evidence of school shark productivity change and SPR justification containing citations. • Industry is not looking for substantial changes to be made to the current school shark measures and support maintaining area closures. Industry instead seeks more operational flexibility to reduce discards and improve the harvesting ability of gummy shark. • There was support to adopt the SPR approach, noting that a process will need to be determined in the interim until the method can be MSE tested. It was noted that this work should be considered at the Southern and Eastern Scalefish and Shark Fishery Resource Assessment Group (SESSFRAG) data meeting in August 2025. <p>SharkRAG provided the following advice and recommendations:</p> <ul style="list-style-type: none"> • Catalogue the evidence for change in school shark productivity into a formal document. • Full MSE testing of the SPR approach to be pursued as a longer-term priority. <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Action 2: The evidence for change in school shark productivity that was presented by Dr Lianos Triantafillos (AFMA) to be released as a formal document.</p> </div> <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Recommendation 1: That a basic SPR approach is used going forward for assessing the stock status and setting the school shark bycatch TAC in the interim until full MSE testing can be completed.</p> </div>
6	Other business	<p>SharkRAG noted the following:</p> <ul style="list-style-type: none"> • SharkRAG to reconvene in November 2025 to review the CKMR assessment results, with possible follow-up meetings in December and/or January to finalise TAC advice. • Research highlighted as key priorities to be considered for funding by SESSFRAG in August 2025 and the AFMA Research Council (ARC) include: <ol style="list-style-type: none"> 1. MSE testing of a novel SPR based approach to determine stock status and set the TAC for school shark. • Additional research highlighted by SharkRAG, although lower in priority include: <ol style="list-style-type: none"> 1. Investigation of discards of logbook reports through a congruence analysis. 2. Understanding the stock structure of school shark

		<p>3. Improving age estimation of school shark (currently part of ongoing updates to the school shark CKMR model).</p> <div style="border: 1px solid black; padding: 5px;"> <p>Recommendation 2: The following research priorities were highlighted as priorities for the next 12 months to be considered by SESSFRAG in August 2025 and the ARC:</p> <ol style="list-style-type: none"> 1. MSE testing of a novel SPR based approach to determine stock status and set the TAC for school shark. </div>
<p>Close of meeting</p>	<p>The Chair closed the meeting at 17:33pm</p>	

Attachment A – Adopted agenda

Time (AEST): 13:00 pm – 16:45 pm

Location: Online, Microsoft Teams

Chair Name: Dr. Rik Buckworth

Time	Item	Purpose	Presenter
13:00 (15 min)	Agenda item 1. Preliminaries		
	1.1 Welcome and apologies	For noting/advice	Chair/Executive officer
	1.2 Declaration of interests		
	1.3 Adoption of agenda		
	1.4 Minutes from previous meeting		
	1.5 Actions arising from previous meetings		
13:15 (30 min)	Agenda item 2. Fishery update		
	2.1 AFMA Management	For noting/advice	AFMA/Members of each group
	2.2 Industry updates		
	2.3 Scientific updates		
	2.3 Economic updates		
	2.3 Conservation updates		
13:45 (60 min)	Agenda item 3. Close-Kin Mark-Recapture assessments		
	3.1 CKMR assessment approach	For noting	Dr Robin Thomson
	3.2 School shark CKMR update		
14:45 (15 min)	Break		
15:00 (45 min)	Agenda item 4. Harvest control rule project update	For noting	Dr Pia Bessell-Browne
15:45 (45 min)	Agenda item 5. SPR literature review	For noting	Dr Lianos Triantafillos
16:30 (15 min)	Agenda Item 6. Other business	For advice	AFMA
16:45	End of Meeting		

Attachment B – Register of interests

Table 1. Members', invited participants' and observers' declarations of interest

Member	Position	Interest declared
Rik Buckworth	Chair	<p>Chair of SharkRAG.</p> <p>Director of Sea Sense Australia Pty Ltd</p> <p>Scientific Member – NPRAG Member – Data Working Group for the GABTF</p> <p>Adjunct Professor – Charles Darwin University Current or anticipated projects with government agencies, CDU and fishing industry for projects in the NT, Qld and Commonwealth fisheries.</p> <p>Researcher involved particularly in stock assessment research. No pecuniary or other interest in the SESSF shark fishery.</p>
Robin Thomson	Scientific Member	<p>CSIRO, Assessment scientist. Acquiring funding for research purposes.</p> <p>PI of AFMA-CSIRO co-funded project 'Ongoing monitoring of school shark abundance and rebuilding in the SESSF using close kin mark recapture'.</p> <p>PI of the AFMA-funded project 2022/0806: "CKMR assessment design for selected key and rebuilding species in the SESSF and development of a CKMR tool for bycatch stocks".</p> <p>Co-investigator on FRDC project to develop harvest strategies for CKMR assessments for school shark and scalefish.</p>
Charlie Huveneers	Scientific Member	Associate Professor and research scientist. Potential interest in funding for research. No pecuniary interest or otherwise.
Matias Braccini	Scientific Member	<p>Employed by WA DPI</p> <p>Senior research scientist for the Shark and Ray Sustainability research group</p> <p>Potential interest in funding for research. No pecuniary interest or otherwise.</p>

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Member	Position	Interest declared
Caleb Gardner	Economic Member	Institute for Marine and Antarctic Studies. Organisation is known to submit research funding applications for consideration by AFMA Committees
Kyriakos Toumazos	Industry Member	Chief Executive Officer (South Australian Northern Zone Rock Lobster Fishermen’s Association Inc.); Director of Southern Sea Eagles Pty Ltd; Director of Southern Fisheries Pty Ltd; Director Health Balance Pharmacies Pty Ltd; Member South Australian Boating Facility Board; Member of Shark Resource Assessment Group (AFMA); Member of South East Management Advisory Committee; Member of AMSA Regional Safety Committee; Director Southern Shark Industry Alliance; Director PACK Investments Pty Ltd; Director Cruickshank’s Corner Developments Pty Ltd; Director Cruickshank’s Corner Commercial Pty Ltd; Director Seafood Industry Australia;
Leigh Castle	Industry Member	Tasmanian shark hook, scalefish hook and tuna minor line fisher. Owns SESSF quota and vessel statutory fishing rights. Has a declared interest in shark hook items and RBC recommendations
Anthony Harriss	Industry Member	Gillnet fisher and SFR holder.
Jamie Papas	Industry Member	Gillnet fisher and SFR holder. Board Director San Remo Fishermen’s Co/Op
Anissa Lawrence	Conservation Member	Director of TierraMar Ltd, registered charity. Independent consultant TierraMar Consulting Pty Ltd Undertakes contracts for a number of Conservation Non-Government Organisations, government departments, non-government agencies and the private sector on a range of fishery related matters. No pecuniary interest. Conservation member on SPFRAG. Conservation member on SEMAC Conservation member on South Australia Rock Lobster MAC and RSC. Conservation member on Spencer Gulf Prawn RSC

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Member	Position	Interest declared
		Director and Chair of Ocean Future Fund Inc
Ross Bromley	Invited Participant	Principal of Girella Fisheries Services. Engaged by SSIA as SIDaC manager. Engaged by SETFIA as western orange roughy project manager. Member of Victorian Rock Lobster RAG. EO of Eastrock (Eastern Zone Rock Lobster Industry Association Inc.). Client representative of various MSC Certificates (none are shark <i>spp.</i>). No interest, pecuniary or otherwise.
Pia Bessell-Browne	Invited Participant	CSIRO assessment scientist. Acquiring funding for research purposes. PI on FRDC project: Developing a harvest control rule to use in situations where depletion can no longer be calculated relative to unfished levels.
Paul Burch	Invited Participant	Employed by CSIRO, assessment scientist. Acquiring funding for research purposes. Principal investigator on the SESSF stock assessment project.
Lianos Triantafillos	AFMA Member	AFMA member, Manager of the Gillnet, Hook and Trap fishery. No interest pecuniary or otherwise.
Michelle Henriksen	Executive Officer	AFMA EO. No interest pecuniary or otherwise.
Kurt Davis	Observer	Employed by ABARES. No interest, pecuniary or otherwise.
James Woodhams	Observer	Employed by ABARES. No interest, pecuniary or otherwise.
Anthony Coggan	Observer	Employed by AFMA. No interest pecuniary or otherwise.
Sally Weekes	Observer	Employed by AFMA. No interest pecuniary or otherwise.

Attachment C - Summary of Actions and Recommendations

Agenda Item	No.	Action	Agency/Person Responsible	Timeframe
1	1	AFMA, CSIRO and ABARES to refocus the action item raised in SharkRAG 1 2023 <i>“improve discard reporting and the potential options industry can undertake to improve better discard reporting”</i> to assess the congruence between discards and EM for quota and ETP species.	AFMA/CSIRO/ABARES	SharkRAG 1 2026
5	2	The evidence for change in school shark productivity that was presented by Dr Lianos Triantafillos (AFMA) to be released as a formal document	AFMA	SharkRAG 2 2025
Agenda Item	No.	Recommendation	Agency/Person Responsible	Timeframe
5	1	That a basic SPR approach is used going forward for assessing the stock status and setting the school shark bycatch TAC in the interim until full MSE testing can be completed.	AFMA/CSIRO	SharkRAG 2 2025
6	2	The following research priorities were highlighted as priorities for the next 12 months to be considered by SESSFRAG in August 2025 and the ARC: 1. MSE testing of novel SPR based approaches	AFMA	SESSFRAG data meeting 2025

Evidence for Ecosystem Productivity Decline in School Shark (*Galeorhinus galeus*): Implications for Stock Assessment Reference Points.

Abstract

Stock assessments for school shark (*Galeorhinus galeus*) have traditionally employed reference points based on historical unfished biomass (B_0) estimates derived from 1927 baseline conditions. However, accumulating evidence suggests fundamental changes in ecosystem productivity that may invalidate these historical baselines.

Multi-decadal datasets were analysed, including systematic nursery habitat surveys, commercial fishery data, population genetic analysis, and regional oceanographic records. Systematic surveys demonstrated 60-90% declines in nursery habitat productivity between 1947-1956 and 1991-1997 periods, with complete functional loss documented in formerly critical areas. Sea surface temperatures in southeastern Australia have experienced significant warming over the past 80 years (Hobday and Pecl, 2014). Sea surface temperatures have increased by up to $\sim 2^\circ\text{C}$ at locations such as Maria Island in Tasmania, coinciding with documented regime shifts in marine ecosystem productivity.

Close-Kin Mark-Recapture (CKMR) analysis revealed fundamental inconsistencies between historical catch levels and genetic data under single-stock assumptions. Density-dependent responses (increases in juvenile growth rates) provided biological evidence for population decline below habitat carrying capacity.

Convergent evidence from habitat degradation, climate-driven regime shifts, and population structure complexity indicates that current ecosystem conditions cannot support historical productivity levels. Reference points based on 1927 B_0 estimates are scientifically inappropriate and should be replaced with approaches reflecting demonstrated ecosystem carrying capacity constraints.

Keywords: *Galeorhinus galeus*, stock assessment, reference points, regime shift, nursery habitat, productivity decline, CKMR

1. Introduction

Stock assessment reference points form the foundation of science-based fisheries management, providing quantitative targets and thresholds for sustainable harvest strategies (Hilborn and Walters, 1992). Traditional approaches assume that populations can recover to historical unfished biomass levels (B_0) in the absence of fishing mortality, with reference points typically expressed as percentages of estimated virgin biomass (Punt and Smith, 2001). This assumption underpins harvest control rules and recovery planning across most contemporary fisheries management frameworks, including the Commonwealth Fisheries Harvest Strategy Policy, which guides all Commonwealth fisheries in Australia (DAFF, 2018).

However, accumulating evidence suggests that rapid environmental change may invalidate historical baselines for some species, particularly those dependent on specific habitat requirements or operating in ecosystems experiencing climate-driven regime shifts (Brander, 2007; King et al., 2015; Free et al., 2019). Climate-driven changes in marine ecosystems have resulted in widespread range shifts, with marine species moving poleward at average rates of 72.0 ± 13.5 km per decade (Poloczanska et al., 2013). These changes necessitate ecosystem-based approaches to fisheries management that account for environmental variability and long-term ecosystem trends (Hare et al., 2016; Hollowed et al., 2013).

School shark represent a critical case study for evaluating reference point validity under changing environmental conditions. This temperate shark species supports important commercial fisheries across multiple jurisdictions within the Southern and Eastern Scalefish and Shark Fishery (SESSF), primarily through the Gillnet, Hook and Trap (GHAT) sector. Current stock status is not known but the last time they were accurately estimated they were only 12% of original biomass, with the population having crashed by ~90% from historical levels (Thomson and Punt, 2009; AFMA, 2023).

School sharks exhibit complex life histories with distinct ontogenetic habitat requirements. Adults migrate widely across southern Australian waters, mixing on offshore feeding and spawning grounds (Stevens and West, 1997). Reproductive success depends on access to specific inshore nursery areas—shallow, protected bays and inlets with seagrass beds that provide optimal environmental conditions. These nursery habitats supply essential prey resources and predator refuge for juveniles during their first 1-2 years of life.

The commercial exploitation of school shark in Australia began in the early 20th century and peaked during the 1960s. Since then, the population has suffered significant decline, with current catches stabilised at <10% of historical peaks despite two decades of stringent management measures (Walker, 1998; Punt et al., 2000). While these measures have successfully stabilised catches, they have not yet produced clear evidence of population recovery to target levels.

Recent developments in population assessment methodology, particularly CKMR approaches, have provided new insights while revealing inconsistencies with traditional stock assessment assumptions (Thomson et al., 2020; Bravington et al., 2016). CKMR methods utilise genetic markers to identify kinship relationships within samples, providing absolute abundance estimates that are independent of fishing behaviour and therefore particularly valuable for heavily exploited species.

This study evaluates scientific evidence for ecosystem productivity decline in the school shark population and assesses implications for stock assessment reference point validity. We test the hypothesis that current ecosystem conditions cannot support historical productivity levels, rendering traditional B_0 -based reference points scientifically inappropriate for management application.

2. Methods

2.1 Study System and Species

School shark are a temperate shark species exhibiting viviparous reproduction, with females producing small litters (~28 pups) following 12-month gestation. Sexual maturity occurs at 8-10 years for males and 12-15 years for females, with maximum lifespans of 40-50 years (Walker, 2007). Reproductive success is critically dependent on access to specific shallow coastal nursery areas. This life history creates inherent vulnerability to overexploitation due to limited reproductive output and slow population growth rates (Stevens and West, 1997).

Commercial catch data were obtained from the Australian Fisheries Management Authority (AFMA) databases covering the GHAT sector of the SESSF from 1969 to 2024, including annual catch totals, effort measures, and spatial distribution information.

2.2 Nursery Habitat Productivity Assessment

Nursery habitat productivity was assessed using catch-per-unit-effort (CPUE) data from three distinct survey periods: 1947-1956 (Olsen, 1954), 1991-1997 (Stevens and West, 1997), and 2012-2014 (McAllister et al., 2018). Although survey methodologies varied between periods, all studies employed consistent gear types (longlines and gillnets) deployed at standardised locations within each nursery area to enable temporal comparisons. Age-0+ individuals (young-of-year) were used as the primary indicator of nursery habitat functionality, as recruitment success reflects recent reproductive output and habitat suitability (Beck et al., 2001).

2.3 Population Structure Analysis

Population structure was evaluated using two approaches: (1) multi-stock population modelling; and (2) CKMR genetic analysis. Multi-stock modelling tested single-stock versus two-stock (eastern/western) hypotheses, examining regional differences in catch decline patterns during the 1980s-1990s as described in Punt et al. (2000).

CKMR genetic analysis followed methods described in Thomson et al. (2020) and Bravington et al. (2016). Genetic samples were collected from commercial catches and research surveys, with kinship analysis identifying parent-offspring pairs (POPs) and half-sibling pairs (HSPs). Adult abundance estimates were derived from kinship encounter rates. Model validation tested whether genetic data could reconcile with historical catches exceeding 2,000 tonnes annually, including scenarios with optimistic biological parameters (100% annual female reproduction and 100% pup survival) to assess maximum plausible exploitation levels under single-stock assumptions.

3. Results

3.1 Historical Catch Patterns

The school shark fishery peaked in 1969 at 2,543 tonnes, followed by sharp decline to ~700 tonnes by 1973 due to mercury content concerns. Catches rebounded to approximately 2,000 tonnes by 1986, representing nearly 80% of the historical peak. This resurgence may have indicated either a genuine population recovery or unsustainable exploitation of the remaining biomass. The sustained decline in catches through the late 1980s and 1990s, reaching ~500 tonnes by 2000, supports the latter interpretation.

Spatially disaggregated data revealed steeper declines in western regions (South Australia, western Victoria) during the late 1980s-1990s compared to eastern areas, despite uniform management measures, suggesting underlying biological or environmental differences (Punt et al., 2000). Catches have stabilised at ~200 tonnes, over the last two decades, representing <10% of the historical peak. This coincides with the introduction of stringent management measures under the School Shark Rebuilding Strategy, first implemented in 2009 (AFMA 2015).

3.2 Nursery Habitat Productivity Decline

Comprehensive surveys by Olsen between 1947 and 1956 established baseline conditions for school shark nursery areas across southern Australia. In Tasmania, areas such as Port Sorrell, Georges Bay, Upper Pittwater, and the D'Entrecasteaux Channel supported dense age-0+ populations with consistent annual recruitment. Nursery areas in Victoria such as Western Port, Port Phillip Bay (western side), and Swan Bay were similarly highly productive.

Follow-up surveys by Stevens and West (1991-97) revealed dramatic declines relative to these historical baselines. CPUE dropped by 60-90% across most previously productive nursery areas, with pups entirely absent in Georges Bay and the D'Entrecasteaux Channel. Widespread habitat degradation, particularly in Victorian waters, contributed to these declines. Western Port Bay lost 17,800 hectares of seagrass habitat between the 1970s and 1980s, representing an 85% decline from 25,000 to 7,200 hectares (Tanner et al., 2014). This loss has been recognized internationally as an ecological disaster (Waycott et al., 2009). Port Phillip Bay experienced variable seagrass changes, with some areas showing severe losses of up to 91% between 1998 and 2006, particularly in channels affected by altered freshwater flows and industrial pollution (Ball et al. 2014).

Biological responses included accelerated growth in juveniles (above historical levels) and shifts in age structure toward older juveniles, suggesting reduced recruitment and density-dependent effects. Adult growth rates remained unchanged, indicating effects were confined to nursery habitats rather than adult feeding grounds (Stevens and West, 1997).

McAllister et al. (2018) reported stable or slightly increased young-of-year abundance in Upper Pittwater and nearby Frederick Henry Bay. While these two nursery areas show limited signs of recovery, the documented loss of multiple historically productive nursery sites has reduced the overall nursery habitat capacity, constraining population recovery potential (McAllister et al., 2018; Stevens and West, 1997).

3.3 Population Structure Evidence

Single-stock assessment models could not satisfactorily account for the regional differences in catch decline patterns during the 1980s-1990s (Punt et al., 2000). While a two-stock approach with separate eastern and western components improved the model performance, Punt et al. (2000) noted that the true population structure probably involved additional complexity beyond this basic east-west division.

This complexity was further confirmed by CKMR analysis (Thomson et al., 2020), which revealed fundamental inconsistencies between historical catch levels and contemporary

genetic data. Even when assuming extremely optimistic biological parameters—including 100% annual female reproduction and 100% pup survival—single-stock models could not reconcile observed kinship patterns with the historical catches that regularly exceeded 2,000 tonnes annually.

The CKMR-derived abundance estimates were substantially lower than what would be required to sustain such historical exploitation levels. This discrepancy provides quantitative evidence for either severe population depletion or a complex population structure involving multiple semi-independent breeding populations that collectively supported the historical fishery.

3.4 Climate-Driven Ecosystem Change

Sea surface temperatures in southeastern Australia have undergone significant warming over the past 80 years (Hobday and Pecl, 2014). Independent monitoring data shows temperature increases up to ~2°C at locations such as Maria Island in Tasmania, with this warming affecting coastal regions that include key school shark nursery areas and coincides with broader declines in marine ecosystem productivity.

The impacts of such environmental changes on fisheries productivity are already recognised in Australian fisheries management. The eastern stock of jackass morwong (*Nemadactylus macropterus*) provides a relevant precedent, having experienced persistent recruitment failure despite reduced fishing pressure. In response, AFMA formally recognised a shift in the productivity regime and revised management reference points and updated estimates of unfished recruitment (R_0) to reflect lower productivity under current environmental conditions (AFMA, 2019).

While species-specific thermal tolerance studies for school shark are limited, research on related shark species provides strong indication of likely physiological impacts. Studies on tropical sharks such as epaulette sharks (*Hemiscyllium ocellatum*) demonstrate that elevated temperatures significantly reduce embryonic survival rates, with survival dropping from 82% under current conditions to only 11% under high warming scenarios (Wheeler et al., 2024)

Warming patterns exhibit pronounced spatial heterogeneity across the southeastern Australian region, creating a complex mosaic of thermal conditions across different nursery areas. Some locations have experienced temperature increases exceeding 2.5°C, while others show more modest warming of 1-1.5°C. This spatial variability in thermal stress may explain the observed differential patterns in recruitment success and population recovery potential among geographically separated nursery areas, with more severely warmed locations showing greater declines in juvenile abundance.

Temperature increases compound other environmental changes affecting school shark nursery habitat suitability. Altered precipitation patterns and coastal development have modified freshwater discharge regimes, leading to elevated salinity levels in critical nursery areas including Port Phillip Bay and Western Port. School shark pups demonstrate sensitivity to salinity levels above species-optimal ranges, with elevated salinity reducing habitat suitability during early development phases. The combination of thermal stress

and salinity changes creates synergistic impacts that exceed the effects of either stressor alone.

The implications of these environmental changes are particularly severe for school sharks due to their limited adaptive capacity. Strong natal site fidelity means individuals return to specific nursery areas for reproduction, preventing rapid geographic adaptation to changing conditions.

Combined with extremely slow reproductive rates (12-15 year maturation period, 12-month gestation, small litter sizes), these life history constraints severely limit the species' ability to adapt to rapidly changing environmental conditions. Consequently, environmental degradation of specific nursery areas creates long-term bottlenecks that constrain population recovery potential regardless of fishing pressure reductions.

4. Discussion

4.1 Convergent Evidence for Productivity Decline

Multiple independent lines of evidence support fundamental decline in school shark productivity. Nursery habitat surveys provide the strongest evidence for irreversible productivity decline, including complete functional loss in productive sites like Georges Bay and D'Entrecasteaux Channel.

Western Port's loss of 17,800 hectares of seagrass habitat represents permanent reduction in ecosystem carrying capacity that cannot be reversed through fishing pressure reduction alone. Seagrass ecosystems require 10-50 years for recovery even under optimal conditions (Orth et al., 2006), and many areas have transitioned to alternative stable states dominated by algal mats and bare sediment. These changes represent a permanent reduction in ecosystem carrying capacity.

CKMR analysis provides quantitative validation that current ecosystem conditions cannot support historical exploitation levels. The statistical impossibility of reconciling genetic data with historical catches under single-stock assumptions constitutes the strongest evidence for fundamental productivity decline.

Documented regime shifts in related species (jackass morwong) and AFMA's precedent for reference point revision provide institutional framework for acknowledging productivity decline.

4.2 Mechanisms of Irreversible Decline

Habitat degradation in key nursery areas appears irreversible due to three key mechanisms:

1. **Seagrass Ecosystem Collapse:** Seagrass beds provide essential ecosystem services, including prey availability, predator protection and thermal buffering. Loss of seagrass beds eliminates these services, increasing juvenile mortality and thermal stress. Once degraded, seagrass bed recovery is extremely slow due to altered sediment dynamics, changed light availability, extreme weather events, and loss of seed banks (van Katwijk et al., 2016). Alternative stable states such as

algal mats and bare sediment resist restoration efforts, with successful restoration occurring in only 37% of attempts globally (Bayraktarov et al., 2016).

2. **Hydrological Modifications:** Coastal development permanently altered estuarine conditions through changed freshwater inflow, salinity regimes, and nutrient loading. These modifications make habitats unsuitable for school shark pups even if seagrass coverage recovers.
3. **Connectivity Loss:** Coastal infrastructure disrupts physical connections between nursery and adult habitats, impeding recruitment even where habitat quality improves. Port developments, marina construction, and dredging activities have fragmented continuous seagrass meadows into isolated patches below minimum viable habitat size.
4. **Climate Change Acceleration:** Climate change exacerbates existing stressors and reduces nursery habitat recovery likelihood. Projections of 1-3°C additional warming by 2050-2100 may exceed physiological tolerance limits for juvenile school shark during critical developmental stages. Synergistic effects with ocean acidification and declining dissolved oxygen suggest some systems have crossed ecological thresholds beyond which recovery of nursery habitats is no longer feasible.

Stevens and West (1997) concluded that remaining nursery areas are insufficient to sustain historical population levels, as spatial distribution of nursery areas is as important as total area for demographic resilience.

4.3 Implications for Reference Point Validity

Current reference points rely on assumptions that populations can recover to historical unfished biomass levels, presuming unchanged environmental carrying capacity. This assumption is contradicted by extensive evidence of irreversible habitat degradation and climate-driven productivity shifts. Recovery targets based on 1927 B_0 levels are no longer scientifically defensible, given current ecosystem capacity constraints.

CKMR-based assessments provide absolute abundance estimates that are incompatible with traditional reference points defined as percentages of B_0 . This necessitates development of new decision criteria tailored to CKMR outputs and current productivity conditions.

AFMA's jackass morwong reference point revision demonstrates institutional capacity for acknowledging regime shifts and updating management frameworks. This precedent provides pathway for similar adaptations in school shark management.

4.5 Alternative Framework Requirements

Recognition of long-term productivity decline requires fundamental revision of management frameworks for school shark. Key components should include:

1. **Multi-Stock Assessment:** Population structure complexity necessitates multi-stock approaches acknowledging semi-independent breeding aggregations and differential productivity trends across regions.
2. **Climate-Adjusted Productivity:** Reference points should incorporate environmental constraints on recruitment success.

3. **Habitat-Based Targets:** Management objectives should ensure the protection and restoration of remaining functional nursery areas.
 4. **Adaptive Management:** Regular review and adjustment of reference points based on updated environmental baselines, incorporating comprehensive monitoring of habitat quality, climate variables, and recruitment dynamics to ensure management responses align with changing environmental conditions.
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5. Conclusions

Multiple lines of convergent evidence demonstrate fundamental decline in school shark productivity, invalidating historical unfished biomass reference points. Current conditions cannot support historical productivity levels, making recovery to traditional benchmarks scientifically implausible regardless of fishing pressure.

Key Findings:

1. Nursery habitat productivity declined by 60-90% since 1950s baselines, with 17,800 hectares of critical seagrass habitat permanently lost
2. CKMR analysis provides definitive evidence that current population structure cannot support historical catch levels
3. Climate-driven warming is likely to exceed species tolerance thresholds in many historical nursery areas
4. Institutional precedent exists for reference point revision through AFMA's jackass morwong management adaptation.

The school shark case provides strong justification for adopting alternative reference point frameworks that acknowledge environmental change and carrying capacity constraints, with precedent existing through AFMA's jackass morwong regime shift responses.

School shark exemplify challenges facing long-lived marine species in rapidly changing environments, requiring management paradigms that evolve beyond historical baselines to remain effective and ecologically relevant. This case study provides a template for evaluating reference point validity for other climate-impacted species and demonstrates the need for adaptive management frameworks incorporating ecosystem change.

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