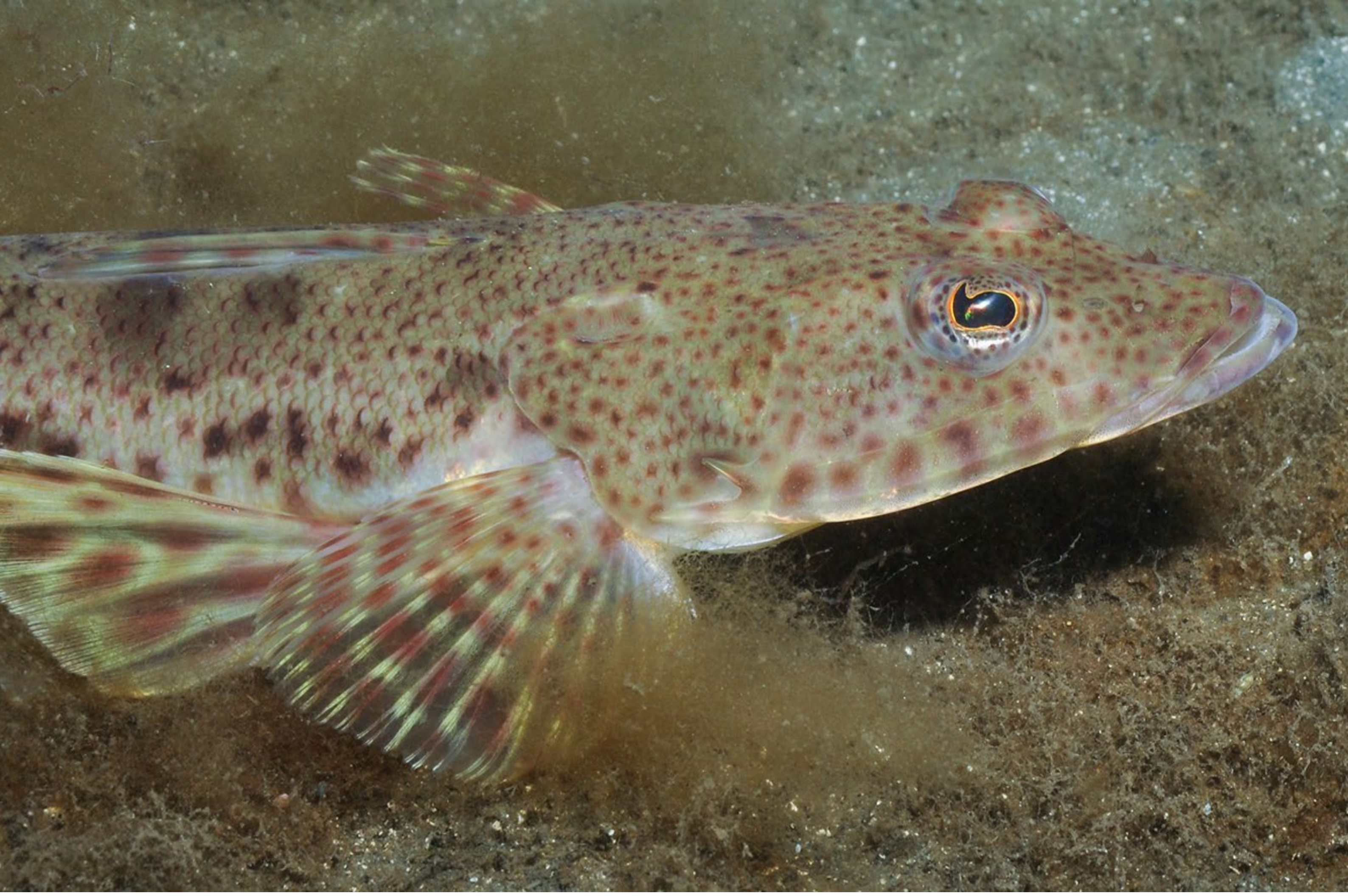

Developing a cost-effective monitoring regime and stock assessment for Sand Flathead in Tasmania

FRDC Project 2020-005
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Acknowledgment of Country

We acknowledge the Pakana and Palawa people of lutruwita, the traditional owners of the land upon which we live and work.

We pay respects to Elders past and present as the knowledge holders and sharers. We honour their strong culture and knowledges as vital to the self-determination, wellbeing and resilience of their communities.

We stand for a future that profoundly respects and acknowledges Aboriginal perspectives, culture, language and history.

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Ethics Statement

This research was conducted under University of Tasmania Animal Ethics projects #24232 and #30505 and Department of Natural Resources and Environment Tasmania Wild Fisheries Management Branch Scientific Research Permit #25075.

Abbreviations

AIC — Akaike Information Criterion

ANCOVA — Analysis of Covariance

ANOVA — Analysis of Variance

B_0 — Unfished biomass

BP — Bridport

CI — Confidence Interval

CPUE — Catch Per Unit Effort

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DEFF — Design Effect

EC — East Coast

ECDF — Empirical Cumulative Distribution Function

F — Fishing mortality

F/M — Relative fishing mortality

FH–NB — Frederick Henry and Norfolk Bays

FI — Flinders Island

FRDC — Fisheries Research and Development Corporation

FY — Financial Year

GLM — Generalised Linear Model

GOB — Great Oyster Bay

GSI — Gonadosomatic Index

ICC — Intraclass Correlation Coefficient

IMAS — Institute for Marine and Antarctic Studies

KS — Kolmogorov–Smirnov (test)

k — Growth coefficient (von Bertalanffy growth function)

LA-ICP-MS — Laser Ablation Inductively Coupled Plasma Mass Spectrometry

LBSPR — Length-Based Spawning Potential Ratio

LDFA — Linear Discriminant Function Analysis

LF — Length Frequency

L_∞ — Asymptotic length (von Bertalanffy growth function)

LRT — Likelihood Ratio Test

M — Natural mortality

MSE — Management Strategy Evaluation

MSL — Minimum Size Limit

NEC — North-East Coast

NRE — Natural Resources and Environment Tasmania

NWC — North-West Coast

PCA — Principal Components Analysis

SEC — South-East Coast

SE — Standard Error

SPR — Spawning Potential Ratio

SPR_0 — Unfished spawning potential

SPR/SPR_0 — Relative spawning potential

t_0 — Theoretical age at zero length

TL — Total Length

UTAS — University of Tasmania

W_1 — Wasserstein distance (first-order)

WC — West Coast

Z — Total mortality

1 Executive Summary

This report presents the most comprehensive biological assessment undertaken of Sand Flathead in Tasmania, the state's most important recreational scalefish fishery. Led by researchers from the Institute for Marine and Antarctic Studies, University of Tasmania, the project was undertaken to determine whether long-standing concerns about declining catch rates, fewer large fish, and regional stock decline reflected real biological change, and to identify practical pathways for rebuilding the fishery.

Using historical records, statewide fishery-independent surveys, fishery-dependent sampling, biological studies, movement and connectivity analyses, and quantitative stock assessment, the report concludes that Sand Flathead are depleted across most regions assessed but remain recoverable. The most severe impacts occur in south-eastern Tasmania, where fishing pressure has been highest and stock productivity is most reduced. Importantly, these findings align closely with outcomes of a complementary recent human dimensions study, which documented widespread fisher concern regarding declining stock condition and support for credible rebuilding measures. Together, these studies provide Tasmania with both the biological evidence and social context needed to guide evidence-based recovery of this iconic fishery.

Background

Sand Flathead are Tasmania's most culturally important and accessible fish species. They are central to family fishing experiences, community participation, coastal tourism, and regional expenditure on boats, tackle, fuel, accommodation, and travel. For many Tasmanians, catching Sand Flathead is their first and most frequent fishing experience, making the species socially significant well beyond its direct harvest value.

Historically, the species was considered highly abundant, including in south-eastern waters close to major population centres. Over time, however, fishers reported a decline in the quality of the fishing experience through smaller average fish size, fewer large fish, lower catch rates, and the need to fish further offshore or for longer periods to achieve previous results. These concerns became particularly strong in the D'Entrecasteaux Channel and the Frederick Henry–Norfolk Bay region, where long-term fishing pressure has been greatest.

Management responses were constrained by the nature of the fishery. Recreational harvest dominates total removals, but unlike larger commercial fisheries, there has been limited continuous catch and effort datasets suitable for conventional stock assessment approaches. Furthermore, catch rates in recreational fisheries are influenced by technology, fisher behaviour, changing expectations, local targeting, and situations where catches can remain acceptable even as stock abundance declines particularly over generational time scales where previous abundance and demographic structure become forgotten.

This project aimed to provide a comprehensive scientific of Sand Flathead in Tasmania, improve the evidence base for management, and establish a framework capable of tracking recovery into the future.

Aims/objectives

The project was designed around seven core objectives intended to address key knowledge gaps and provide a practical pathway to improved management.

These objectives were to:

- review and collate available biological and fishery data on Sand Flathead in Tasmanian waters;
- determine the spatial and temporal variability of key life-history characteristics and population structure;
- design, implement, and assess fishery-dependent and fishery-independent biological sampling methods;
- update reproductive biology at multiple Tasmanian regions;
- investigate movement and connectivity within Tasmania;
- develop a quantitative region-age-sex structured fishery assessment model; and
- identify management scenarios capable of rebuilding depleted areas with a focus on supporting long-term sustainability and maximising value of the fishery to the Tasmanian community.

Methodology

The study used multiple independent lines of evidence representing data collected over several years, allowing findings from one component of the project to be tested and supported by others. Historical records, archived datasets, and previous monitoring programs were reviewed to reconstruct long-term changes in the fishery, historical fish size, and legacy management settings. This historical information provided important context for understanding whether current conditions reflect natural variability or a sustained decline through time.

A statewide fishery-independent survey program was analysed and refinements proposed. This standardised scientific sampling method conducted across multiple Tasmanian regions allowed direct comparison of size structure, and demographic condition independent of fisher behaviour or changes in fishing technology through time.

Fishery-dependent biological data were also collected through a recreational fish frame donation program. These data helped identify the size composition of fish being harvested under current regulations and whether harvested fish are reflective of the broader population structure.

Biological studies examined length, age, growth, sex ratios, maturity and timing of spawning. Movement and connectivity were investigated using conventional tagging and otolith chemistry. In combination, these data and resulting information were used to develop a quantitative equilibrium-based stock assessment framework parameterised according to regional life history traits and size structure.

Results

The project found clear and persistent evidence that Sand Flathead stocks have been depleted by long-term fishing pressure across Tasmania, with the most severe depletion occurring in south-eastern regions, particularly the D’Entrecasteaux Channel and Frederick Henry–Norfolk Bay. Assuming Flinders Island to provide growth parameters representative of near-unfished conditions, all assessed regions other than Flinders Island exhibited a spawning potential below biological reference points for sustainability, with the southeast coast populations showing the most severe depletion in spawning potential estimated at approximately 6% of unfished levels (SPR/SPR_0 = 0.06; 95% CI 0.05–0.07), which is well below the commonly applied limit reference point of 20%. Independent biologically assessed mortality estimates reinforce this significant overfishing has been occurring, with relative fishing mortality (F/M) estimated at approximately 4.81 (95% CI: 3.85–5.77), far exceeding the commonly accepted sustainability threshold of F/M ≈ 1.

Stock depletion is reflected in strong, stable differences among the size structure across regions, with consistently larger flathead on the north and east coasts of Tasmania compared to the southeast. Age structure shows a consistent pattern, with very limited representation of fish older than 10 years in the southeast, compared with northern regions where individuals reach up to 20 years of age, indicating sustained high mortality on older age classes in the south.

Alternative model formulations using southeast-derived growth parameters produced less severe estimates of stock depletion (SPR/SPR_0 ≈ 0.22; 95% CI 0.20–0.25); however, this scenario assumed no historical change in demographic structure and associated impact on growth parameter estimates. This assumption is inconsistent with empirical evidence from independent historical comparisons, which demonstrate under even conservative assumptions, mean flathead length declined by 4.7% (1.5 cm) in Norfolk Bay and 6.0% (1.8 cm) in the D'Entrecasteaux Channel since the 1990s, confirming a long-term shift in population structure rather than short-term natural variability. Further evidence of population depletion and change in size structure is provided by historical creel survey comparisons. Restricting the comparison to fish above the historical legal minimum size limit (30 cm), mean Sand Flathead lengths were significantly larger among fish retained by anglers in historical creel surveys (1997/98 and 2000/01) than in the 2024/25 fishery-independent survey in nearly all regions available for comparison. Mean lengths have declined by 5% (1.7 cm) in Norfolk and Frederick Henry Bays and 7% (2.3 cm) in Derwent/D'Entrecasteaux regions of southeast Tasmania, 6.4% (2.2 cm) in the northwest, 10% (3.7 cm) at Bridport in the northeast, and on the east coast 3.2% (1.1 cm) at Swansea/Coles Bay and 4.4% (1.5 cm) at St Helens. These comparisons demonstrate that comparable shifts toward smaller size structure of Sand Flathead have occurred around Tasmania in recent decades.

These biological findings strongly align with a complementary human dimensions study, in which most fishers who responded to the survey identified the south-east as the area of greatest decline, reporting reduced catch rates, and general fishing experience and expressing concern regarding fewer large fish than in the past. The agreement between independent biological and social evidence provides strong confidence that the observed patterns are real and widely recognised.

The historical review component of the project also identified evidence from earlier reports and surveys suggesting notable non-compliance with regulations during previous decades, including a high proportion of undersized fish retained by fishers in historical creel surveys, with 41% of retained flathead in 1997/98 under the regulated minimum size. This is relevant because realised fishing mortality may have exceeded that implied by formal regulations for extended periods, contributing to stronger depletion than would otherwise have been expected. Similar concerns regarding compliance were also raised in the complementary human dimensions work, indicating that enforcement and education remain important considerations for future rebuilding.

Although the stock is not facing imminent collapse, because at this stage a degree of recruitment is still occurring, however, recruitment alone is not sufficient evidence of stock health. It is not currently possible to determine with confidence whether recruitment has been substantially impaired relative to historical unfished or lightly fished conditions because no reliable long-term recruitment baseline exists. In the absence of this information, recognised fisheries management approaches based on spawning potential, fishing mortality, and limit reference points provide the most appropriate basis for stock status classification.

Multiple independent lines of evidence indicate that prolonged size-selective harvest and excessive fishing mortality have altered the stock from its historical condition. Widespread loss of larger, older fish, reduced female biomass in heavily exploited regions, and persistent truncation of length and to a lesser extent age structures suggest the stock is now likely far below former or near-virgin biomass levels. This is a critical management consideration, because current catches may appear acceptable when judged only against recent experience while still representing a substantially depleted stock.

The project found that larger Sand Flathead are disproportionately female which contribute strongly to egg production and future stock productivity. This means rebuilding cannot focus on fish numbers alone. Recovery also requires restoration of large size classes and the protection of large breeding females. This biological conclusion also aligns with fisher preferences identified in the complementary human dimensions study, where many fishers placed high value on catching larger quality fish rather than simply maximising numbers retained.

Given the strong regional differences found in growth, size structure, age composition, reproductive output, and depletion status, Sand Flathead in Tasmania should not be managed as a single homogeneous statewide stock. Statewide averages risk masking serious depletion in some areas while overstating decline in others. This regional perspective was similarly reflected in the human dimensions study, which showed differing perceptions and tolerance for management action depending on location and local stock condition.

Movement studies showed that adult fish often remain relatively localised although there is a likelihood that a limited degree of regional-scale adult movement and larval dispersal may provide some connectivity across the state. This means depleted south-eastern regions are unlikely to be rapidly rebuilt by immigration from stronger northern areas. Recovery will therefore depend largely on rebuilding local spawning biomass and reducing local fishing mortality.

Fishery-dependent sampling also provided an important behavioural insight. Recreational fishers were generally harvesting fish of similar legal size to those observed in fishery-independent surveys once minimum size limits were considered. However, fishery-independent surveys clearly revealed the broader underlying population structure, including the large proportion of sub-legal fish and the scarcity of larger adults in depleted areas.

A major positive outcome of the project is confirmation that the fishery-independent survey is an effective monitoring framework capable of tracking stock status and rebuilding progress over time. The study also found that sampling more independent sites within each region will improve survey precision more than simply catching more fish or spending more time at the same locations.

Implications for relevant stakeholders

Industry
Sand Flathead underpin major fishing-related expenditure and livelihood value in Tasmania across both the recreational sector and, historically, to a smaller degree the commercial scalefish sector. While the fishery is currently closed to commercial harvest statewide, Sand Flathead previously formed an important component of income for some commercial operators. Short-term rebuilding measures in the recreational fishery may affect some businesses and participation, particularly in regions where stronger management responses are required.

However, successful rebuilding would support stronger long-term outcomes, including better catch rates, larger fish, more stable participation, and increased demand for tackle, boating, tourism, charter services, and the potential for future commercial opportunity should stock condition improve sufficiently to support access under sustainable settings. For commercial fishers who historically relied on Sand Flathead as part of a broader portfolio, rebuilding would improve future options and economic resilience, although any future access would need to be carefully considered within a precautionary management framework.

More broadly, diversification of fishing activity toward other sustainable species may provide an important opportunity during the rebuilding period and beyond. For the recreational sector, reducing concentrated pressure on Sand Flathead could assist stock recovery while also supporting industry through sales of alternative tackle, vessels, electronics, bait, and specialised equipment suited to Tasmania's wider range of fish species. For commercial scalefish licence holders, diversification across available target species may also help maintain business viability while Sand Flathead rebuilding progresses. Realising these opportunities is likely to require education, upskilling, promotion, and market development, with the tackle, boating, seafood, charter, and broader fishing sectors well placed to help lead and promote that transition.

Communities
Sand Flathead are deeply embedded in Tasmanian coastal culture and family recreation. Their accessibility and popularity mean they are important to many households across the state. Rebuilding the stock would protect family fishing

traditions, improve future fishing experiences, and maintain an affordable outdoor activity valued by many Tasmanians. Long-term recovery would also support community wellbeing and regional visitation.

Managers and policy makers
Tasmania now has the evidence base required for decisive action. The strongest priority is reducing fishing mortality, particularly in south-eastern Tasmania where depletion is most acute.

Management should be regionally structured, adaptive, and regularly reviewed against monitoring results. This fishery can now be managed using biologically meaningful indicators such as spawning potential, size structure, and rebuilding trajectory in the absence of sparce catch trends alone. The alignment between biological findings and fisher perceptions also provides confidence that many issues are already recognised by the community.

Recreational fishers
The complementary human dimensions study indicates many fishers already recognise stock decline, particularly in the south-east. There is broad support for management intervention when it is fair, transparent, evidence-based, and clearly linked to measurable recovery outcomes. This suggests that fishers can be important partners in rebuilding if management settings are credible, simple, and communicated clearly, and there is a recognition of the role of recreational fishing in terms of the depletion but also the recovery. This would be best achieved by strong stewardship from within the sector and clear education and communication from the government, research and the sector themselves.

Recommendations
A substantial and sustained reduction in effective fishing mortality is required, with the strongest actions focused on south-eastern Tasmania. This is the most important recommendation arising from the stock assessment.

Fishery-independent monitoring should continue annually or near-annually, particularly in depleted priority regions, so rebuilding progress can be measured objectively through time.

Size-based regulations should be maintained but carefully refined in light of the results of this study. Current evidence indicates that the minimum legal size remains well above size at maturity, the present harvest slot exposes predominantly female fish to harvest because of sexual dimorphism in growth and maximum size, and the current maximum size provides only limited protection in depleted regions where few fish now survive into that upper size range. Future review of slot limits should therefore seek to better balance protection of mature spawning fish, retention of larger breeding females, and harvest yield within constrained catch limits. Getting these settings right is likely to be a critical component of reversing the long-term demographic shifts identified in this study, particularly reduced average size and loss of older fish, and will be most effective when combined with substantial reductions in overall fishing mortality. Management should also be regionally structured, recognising the strong differences in stock condition, productivity, and need for rebuilding across Tasmania.

Areas currently less affected by long-term historical fishing pressure, particularly in northern and north-eastern Tasmania including Flinders Island, should be managed under precautionary settings to maintain their comparatively stronger stock condition and avoid the pattern of serial depletion observed elsewhere in the state. The intent in these areas would not be unnecessary over-restriction, but rather to retain healthy biomass, broader size structure, and higher reproductive capacity while recognising the possibility of effort displacement from more tightly managed regions. If fishing pressure shifts toward these less depleted areas, proactive management will be needed to prevent repetition of the long-term declines documented in south-eastern Tasmania. An appropriately calibrated slot limit is likely to be one of the most effective tools for managing this risk, helping to constrain size-selective depletion, protect larger breeding fish, and maintain more natural demographic structure while still allowing reasonable harvesting opportunities.

Diversification toward other sustainable fisheries should be encouraged where appropriate, helping to maintain participation, reduce concentrated pressure on Sand Flathead, and support associated recreational and commercial industries during the rebuilding period and beyond. At the same time, continued investment in next-generation assessment capability will be important. This should include development of dynamic stock assessment and management strategy evaluation models capable of testing rebuilding timelines, alternative harvest strategies, fisher behaviour, effort redistribution, compliance responses, and the performance of regionally structured management under uncertainty. Ongoing biological research into connectivity, reproductive output, life-history change, and climate-related influences would further strengthen Tasmania's ability to adaptively manage and secure long-term recovery of Sand Flathead.

Closing statement

This project identifies that Sand Flathead rebuilding is achievable. Tasmania now has the scientific evidence, monitoring capability, and management tools required to restore the long-term sustainability, resilience, and quality of its most valued recreational fishery.

The priority ahead is sustained implementation of decisive management, particularly in south-eastern Tasmania where recovery need is greatest. With evidence-based management and continued community support, the fishery can recover and continue to provide social, economic, and cultural benefits for future generations.

Keywords

Sand Flathead (*Platycephalus bassensis*) · fisheries stock assessment · fishery-independent monitoring · recreational fisheries management · size structure and age truncation · spawning biomass · reproductive potential · spatial stock structure · regional variability · size-selective fishing impacts · management strategy evaluation · harvest strategy · stock rebuilding · sustainable fisheries management.

2 Introduction

Southern Sand Flathead (*Platycephalus bassensis*; hereafter Sand Flathead) is a benthic species inhabiting sandy or muddy bottoms of sheltered, shallow (< ~50 m) inlet, estuarine and coastal waters in southern Australia, from Western Australia to northern New South Wales, including waters around Tasmania (Kailola et al., 1993, Edgar, 2008, Gomon et al., 2008). Sand Flathead is the most frequently caught species in Tasmania's recreational fishery, accounting for more than half of the total catch by number. Prior to the 2017/18 survey, catch reports did not differentiate between flathead species: total recreational flathead estimates were 361 tons in 2000/01, 292 tons in 2007/08, and 235.9 tons in 2012/13 (Lyle, 2005, Lyle et al., 2009, Lyle et al., 2014), although it is assumed that the vast majority were Sand Flathead based on subsequent surveys. In 2017/18, Sand Flathead catches were estimated at 184.4 tons (96% of all flathead caught), and 126 ton for the 2022/2023 season (Lyle et al., 2019, Tracey et al., 2024). In contrast, commercial catches have historically been relatively small, and only 1.6 t was recorded in 2022/23 prior to the commercial fishery closure in November 2023 (Sharples et al., 2024). The species exhibits sexually dimorphic growth, with females attaining faster growth rates and larger sizes at age than males (Jordan, 1998, Coulson et al., 2022), making size-selective fishing particularly impactful on the spawning biomass and recruitment (Fraser et al., 2021).

The population structure of Sand Flathead is poorly resolved, and stocks are assessed at the state level (except for Port Phillip Bay in Victoria; SAFS 2023). Studies of growth, reproduction and movement suggest significant regional variability, with individuals exhibiting high site fidelity and limited home ranges despite some spawning-related movements (Bani and Moltschaniwskyj, 2008, Tracey et al., 2020). Such variation indicates the likelihood of population differentiation at finer spatial scales. Consequently, determining the appropriate spatial resolution for stock assessments and management remained a key knowledge gap.

Sustained high fishing pressure, dominated by the recreational sector, has led to stock depletion in all Tasmanian regions except Flinders Island (Krueck et al., 2023, Krueck et al., 2025). The first stock assessment in 2014/15 classified Sand Flathead as depleting (Emery et al., 2016), and subsequent assessment confirmed the stock was depleted in 2023, with fishing mortality considered unsustainable and spawning biomass below the limit reference point (Krueck et al., 2025). In response, management changes in 2023 included a statewide possession limit of 10 fish, reduced bag limits of two in heavily fished regions, and an increase in the minimum legal size to 35 cm along with the introduction of a 40 cm maximum size in most areas.

Because recreational catch exceeds commercial catch by more than 20-fold, trends in commercial catch and effort provide limited insight into stock status. Reliance on the recreational fishery has created challenges for monitoring and assessment, necessitating fishery-independent surveys and novel approaches. Since 2012, IMAS has undertaken annual fishery-independent surveys in three south-eastern regions (Ewing et al., 2014), expanding to nine regions in 2021 and to Flinders Island in 2023 with FRDC funding provided for this project (Coulson et al., 2022, Krueck et al., 2025).

Given the significance of the species, its current depleted status, and the substantial skew to recreational fisheries as the dominant extractive sector with an absence of reliable catch rates through time, there is a clear need for a spatially explicit, cost-effective monitoring and stock assessment framework. This project addressed that need by expanding fishery-independent data collections across Tasmania, collating historical biological and fishery data, quantifying spatial variation in population dynamics, and informing the development of a regional stock assessment to help guide the recovery of Tasmania's important Sand Flathead fishery.

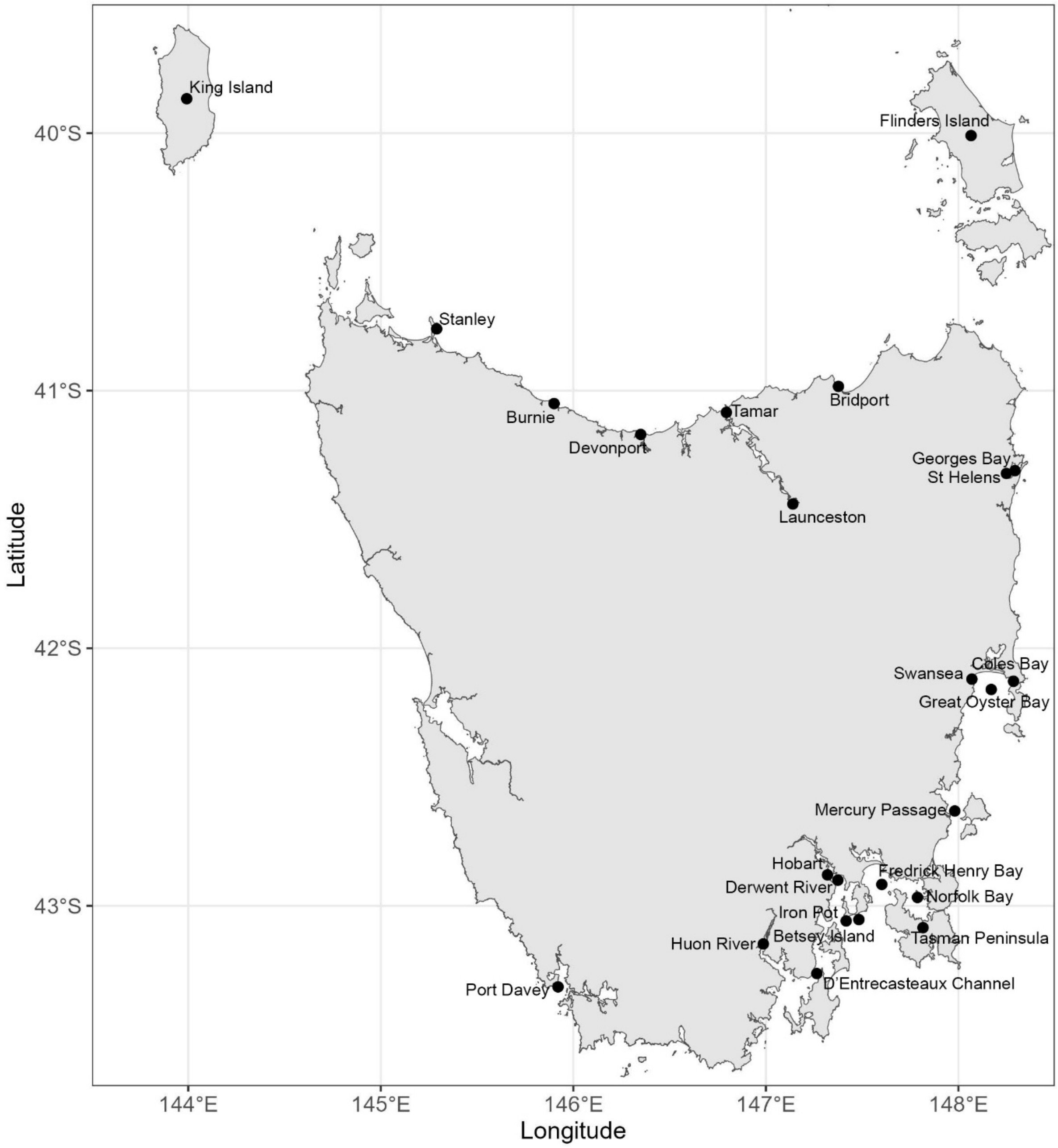


Figure 1. Study location map. Specific sampling locations are highlighted in Figure 15.

3 Objectives

- Review and collate available biological and fishery data collected on Sand Flathead within Tasmanian waters.
- Determine the spatial and temporal variability of key life history characteristics and population structures of Sand Flathead.
- Design, implement and assess the effectiveness of fishery dependent and fishery independent biological sample collection techniques for Sand Flathead.
- Update the reproductive biology of Sand Flathead at three regions around Tasmania.
- Investigate movement and connectivity of Sand Flathead within Tasmania.
- Develop a quantitative region-age-sex structured fishery assessment model for Sand Flathead.
- Identify management scenarios for consideration.

4 Objective 1: Review and collate available biological and fishery data collected on Sand Flathead within Tasmanian waters

4.1 A historical description of the Sand Flathead fishery in Tasmania over the past two centuries[1]

4.1.1 Introduction

Fisheries represent an important source of livelihood for many coastal communities globally. In Australia, commercial fisheries contribute approximately $3 billion annually (Butler et al., 2023). Recreational fisheries engage about one in five Australians, with a nationwide participation of 4.2 million anglers, contributing around $11 billion to the economy (Butler et al., 2023, Moore et al., 2023). Despite the economic and cultural significance of both commercial and recreational fishing, long-term systematic monitoring and catch data for most species do not extend prior to the 1950s (Swartz et al., 2010). This absence of historical perspectives on ecosystem and species population changes can obscure our understanding of the current state of species and environments, a phenomenon known as the shifting baseline (Pauly, 1995). Generational amnesia from excluding the long-term understanding of past ecosystem conditions and their drivers can lead to underestimating the scale of management efforts and recovery targets needed for exploited species.

To address the lack of long-term fisheries data, researchers have turned to other sources, such as historical archives, to investigate changes in species population trends (Thurstan et al., 2018, Chong-Montenegro et al., 2022). These include newspaper articles, fishing logbooks, magazines, historical charts, and oral histories (McClenachan et al., 2024). By integrating quantitative and qualitative methods, scientists can extract valuable insights into historical population dynamics and gain a deeper understanding of long-term changes in marine ecosystems and their social–ecological drivers.

Sand Flathead is a good case study to assess long term human – environment interactions and potential shifting baselines. In Tasmania, this species accounts for 68% of the total recreational catch and is the most popular recreational fishery target species (Tracey and Stark, 2024). The most recent Tasmanian scalefish stock assessment report identified Sand Flathead as depleted, with less than 20% of spawning biomass remaining, and presented strong evidence of growth overfishing and demographic truncation, with increasing risk of recruitment overfishing in the most depleted regions (Krueck et al., 2025). In response, the Tasmanian Government implemented new management rules to recover the Sand Flathead fishery in November 2023. These included a ban on commercial harvesting, and for the recreational sector a reduction in bag limits (Table 1), and an increase in the minimum size limit (from 32 cm to 35 cm). In addition, a maximum size limit (40cm) was introduced for all regions except Flinders and King Islands (Table 1).

[1] Chong-Montenegro, C., Marshell, A., Audzijonyte, A., Frijlink S., Tracey, S.R. (*In Review*). A historical description of the Sand Flathead fishery in Tasmania over the past two centuries. Marine and Freshwater Research.

While the recent assessment (Krueck et al., 2025) provided valuable insights about the current status of the Sand Flathead population, the long-term exploitation history, catches and abundance trends remain unclear. Species-specific commercial landing reports for Sand Flathead only commenced in 2007–2008 in Tasmania, whereas data before 2007 aggregated all flathead species, including the targeted Tiger Flathead (*Platycephalus richardsoni*). While Tiger Flathead is predominantly caught by the commercial fishing sector and is currently assessed as sustainable, Sand Flathead is more commonly targeted by the recreational fishing sector. For example, in the 2017/18 season, 98% of the estimated total catch of Sand Flathead was attributed to recreational fishing. Clearly, the inability to disaggregate commercial landings by species over time is likely to lead to biases in stock estimates and mask the true population trajectory. Annual fishery independent surveys of Sand Flathead started in 2012 and already revealed a low relative abundance of legal-sized fish, particularly in south-eastern Tasmania, where populations are subject to heavy fishing pressure.

The combined results from the recent stock assessments and state-wide recreational fishing reports show clear evidence that the Sand Flathead population has experienced unsustainable levels of fishing pressure in recent years (Tracey and Stark, 2024, Krueck et al., 2025). However, it remains unclear how long the Sand Flathead population status might have been depleting and what the realistic baselines for the Tasmanian populations might be. In addition, long-term fisheries references can help fill gaps in knowledge by improving our understanding of ecological processes which can help minimise the shifting baseline syndrome (Pauly, 1995).

This study presents a historical account on the development of the Sand Flathead fishery in Tasmania, tracing the origins of both commercial and recreational fisheries. Using archival reports and newspapers articles, we identify critical historical turning points, including shifts in fishing technologies and market dynamics, changes in societal perspective towards the fishery, and reflect on the challenges of working with archival datasets. By examining the fishery within a broader socio-ecological framework, we aim to contribute to ongoing discussions about how historical legacies and cultural values shape present-day marine resource use and management.

The authors acknowledge the Aboriginal Peoples of lutruwita Tasmania and their long history of fishing practices. We note that no written or oral records specific to Indigenous fishing of flathead were found in the sampled sources, and therefore Aboriginal fishing was not included in this study.

Table 1. Historical and contemporary fisheries regulations for Sand Flathead in the state of Tasmania, Australia.

Historical Management Changes

	Size Limit	Recreational	Commercial
1998	Min 300mm (all species)	No Limit	No Limit
2001		Bag Limit: 30 (combined all species)	
2015	Min 320mm (sand and tiger)	Bag Limit: 20 (combined sand and tiger)	
April 2023		Bag Limit: 10 (sand flathead)	No commercial take in Frederick Henry and Norfolk Bays
Nov 2023	Min 350mm Max 400mm (excluding King and Flinders Islands	**South:** Bag Limit 2 **East:** Bag Limit 5 **Other regions:** Bag Limit 10	No commercial take Statewide
2024		On-water possession limit equal to bag limit applies	

** Catch data prior to 2007 are estimated by back-calculating using an average species proportional split across the fishery.*

Wild Fisheries Management Branch
Department of Natural Resources and Environment Tasmania

Tasmanian Government

4.1.2 Methods

Historical Sand Flathead fisheries data were sourced from two major archival sources, the Tasmania State library and TROVE, a digital repository of all major newspapers in Australia from 1803 to 1954. The following combination of keywords were used to extract fisheries information: “flathead”, “fish”, “market” and “club”. Archival sources from the Tasmania State Library included government reports and minutes, and angling reports. From TROVE, flathead fishing catches were sourced from newspaper reports. These articles were reviewed in chronological order to avoid potential double counts. Due to the large quantities of relevant articles issued per year, a stratified random sampling approach was implemented to maximize temporal coverage (Chong-Montenegro et al., 2022). This approach consisted of sampling all newspaper articles covering even years between 1826 and 1954 inclusive.

From each sampled article, quantitative and qualitative fisheries data was extracted including the number of flathead caught, total weight of the catch, location fished, number of fishers, hours fished, and qualitative descriptions about the fishery (e.g., name of the vessel). These data were recorded on a metadata file for further analysis. Data were standardised to account for changes in reporting units over time. The main standardisation was required for catch weights, because most archival records reported catches in dozens of fish caught, without providing specific weights.

Reporting units for flathead landings varied throughout the sampling period. In the first half of the 20th century, total landings were typically reported in dozens of fish sold, whereas in the second half, landings were reported in pounds (lbs), and by the end of the century in kilograms. Therefore, to convert numbers of fish caught into approximate catch weights, we assumed an average individual flathead weight of 0.26 kg, based on estimates from the recreational fishing sector (Lyle et al., 2019). This value was used based on two assumptions: first, while this weight estimate comes from the recreational sector, it is the best available information for Sand Flathead; second, given the current stock depletion this value is likely an underestimated historical weight, providing an overall conservative reconstruction of total flathead landings until recent times.

4.1.3 Results and Discussion

4.1.3.1 Archival sources

A total of 1,957 articles were sampled and reviewed from the online digital repository (Trove) for flathead fisheries data. These articles spanned 125 years from 1826 to 1954 and of these, 146 provided relevant quantitative and/or qualitative information about flathead fishing. The most quantitative information was collected from The Mercury, a Tasmanian newspaper, which provided 70% of all data analysed. In addition, a total of 61 documents from 1830 and 1984 were reviewed from the Tasmania State Library archives, including government reports and meeting minutes.

Among all sampled articles, the earliest record of flathead sold for commercial purposes was published in 1826 in The Tasmanian Almanack for the Year of Our Lord. This article provided a list of prices for commercially important fish species sold in Tasmania, including flathead.

4.1.3.2 Development of the Sand Flathead commercial fishery

Following the decline in whaling and sealing fisheries in Tasmania in the early 19th century, scalefish fishing became an increasingly important economic activity in the latter part of the century (Novaglio et al., 2018). By the late 19th century, commercial fishing was centred in southern Tasmania with 63% of the commercial fishing fleet based in the state capital Hobart, although some commercial fishing also occurred in northern population centres such as Launceston (Tasmania, 1882). Fishing activities were carried out around the upper and lower parts of the Derwent and Huon River estuaries and extending southwards towards Port Davey at the turn of the 20th century. Given the importance of the Hobart Fish Market in providing fish to the local population, catch returns (i.e., numbers of fish caught) were commonly published in local newspapers (e.g., The Mercury, Tasmanian News). From 1889 to 1904, fish market returns were published sporadically monthly, while annual returns were published from 1905 to 1939. The publication of these records highlighted the important role of keeping the public informed about the current trends in local fisheries and economics in Hobart.

From 1888 to 1935 commercial fishing grounds were categorised and managed according to their distance from shore. These categories included the home grounds, middle grounds, and outer or open sea fishing grounds (Tasmania, 1882). Sand

Flathead fishing was primarily carried out in the middle grounds, at approximately 10 meters, and around the mouth of estuaries. Graball nets (a type of gillnet) and hook and line were the most used fishing gears to target flathead.

Catch records were usually reported as 'groups' of closely related species (e.g., 'flatheads') making it unclear what proportion of the catch consisted of Sand Flathead. Despite this, it is likely that landings from the 1880s to the mid-1930s primarily consisted of Sand Flathead, as this is the most common 'flathead' species found in shallower waters (<10 m). However, there is evidence that Tiger Flathead, which is now typically found in deeper water, was previously more abundant in shallow waters (Frank et al., 2018). Another flathead species in Tasmania is the Blue Spotted Flathead (*Platycephalus speculator*) which is mainly found in northern Tasmania. While this species, is extending its range south due to climate warming, it is unlikely that Blue Spotted Flathead were caught outside northern Tasmania in the late 19th and early 20th century.

Given concerns about overfishing and the sustainability of local fish stocks, the Tasmanian Government undertook a Royal Commission on the Fisheries of Tasmania (Tasmania, 1882). The Commission was the first formal record of overfishing concerns for species such as striped trumpeter (*Latris lineata*) and jackass morwong (locally called perch, *Nemodactylus macropterus*), linked to their scarcity in more "accessible grounds" (i.e., nearshore areas) (Tasmania, 1882). Despite these concerns, there was no evidence for concerns for Sand Flathead, with reports stating that the species group was "found everywhere around our coasts, in estuaries and around wharves, all year round". The reports described flatheads as "rather repulsive-looking fishes" and "scavengers of our shallow waters", although they did acknowledge it as a "good edible fish" (Tasmania, 1882). Minutes from a meeting of Fisheries Commissioners dated April 14th, 1882, also highlight the abundance of Sand Flathead and its importance for the Hobart Fish Market, quoting: "the common flathead (*Platycephalus bassensis*) are brought in great number to market, because they are most abundant". In 1888 alone, Sand Flathead ranked among the top ten most sold species in the Hobart Fish Market, with 2,241 dozen (or 26,892 individuals) flatheads sold (Tasmania News, 23 June 1888, Figure 2).

Fish Sold in Hobart Market.
Year 1888.
In order of greatest value.

	Quantity.	No. per cent.	Value.
	No. Doz.		£.
1. Barracouta ...	2,410		964
2. Bastard trumpeter	3,477		858
3. *Real trumpeter*	447		788
4. Perch	8 629		736
5. Flounders ...	1126		281
6. Garfish ...	10,229	98·6	256
7. Rock cod ...	2,158		216
8. Mullet	3,202		160
9 Flathead ...	2,241		112
10. Native salmon...	2,358		79
11. Conger	70		39
12. Carp	103		21
13. Gurnet	111		17
14. Trevally ...	75		15
15. Ling	21		7
16. Bream	9		4
17. Horse mackerel	18		3
18. Kingfish ...	75		2
19. Whiting ...	16		1
20. Red perch ...	3		1
	81,753		4540

Figure 2. Newspaper article from the Tasmanian News, published on June 23, 1888, showing a list of the most commonly sold fish species in the Hobart Market.

However, by the 1910s flathead landings at the Hobart Fish Market declined which was apparently related to a broader growing scarcity of fish, as reported by local newspapers. On July 20, 1914, The Mercury published: "Flathead are generally plentiful in Tasmanian waters, but the quantities [from returns] of more sought-after fish coming into the market are said to show an alarming decrease". Through the 1910s reports and comments about fish scarcity, particularly in areas around the Derwent River continued to be published. On July 22, 1916, The Mercury reported comments from the Tasmanian Government Statistician, Mr. Robert M. Johnston, about this scarcity: "depletion, if it existed, was much less than was described" and attributed the perceived fish declines to an increase in both marine traffic (steamers vessels) and numbers of fishing boats (sail-powered) with growing fishing capacity. Despite the fish shortage, it appears that the relatively low catches of Sand Flathead between 1916 and 1919 were attributed to a particular supply-demand market dynamic, rather than declining population abundance. For example, The Mercury, 22 July 1916, reported: “The fishermen, with more industry and better systems, could catch many more fish than they did. Instead of being taken to market, flathead were thrown overboard. It was easy to catch 200 dozen flathead a day and the price obtainable for them was 2s 6d per dozen.” Given the low market price, fishers might not have considered it worth the effort to market the fish, and consequently, these catches were not reflected in the yearly fish market returns.

From the mid-1930s to the 1940s declining inshore catches and technological advances sparked an interest in the adoption of new fishing gears, such as the Danish seine to exploit new fishing grounds. The Danish seine is a large semi-circular net to enclose fish near the seafloor and was deployed from a diesel-powered boat at depths from 10 to 90 meters. The Danish seine has been used in the North Sea since the 1850s (Poulsen et al., 2007) and in New Zealand since the 1930s (Meyer, 2022). Given the considerable fishing success of this technology and the interest of Tasmanian commercial fishers "to exploit possible beds more distant from the coast than those now worked" to "supply larger and cheaper fish" (The Mercury 26 November 1936), the adoption of Danish seine technology followed soon after.

Following the introduction of the Danish seine fishing, flathead (mixed species) catches increased rapidly, averaging 119.9 tons (± 29 SD) from 1936 to 1952, while the average catch from 1888 to 1935, was 17.8 tons (± 12 SD) (Figure 3). During this period of fishing in deeper waters, catch reports did not disaggregate flathead species, combining Sand and Tiger Flathead under one common name. Therefore, it is likely that the commercial catches reported from the 1930s through the 2000s were dominated by Tiger Flathead (Figure 3).

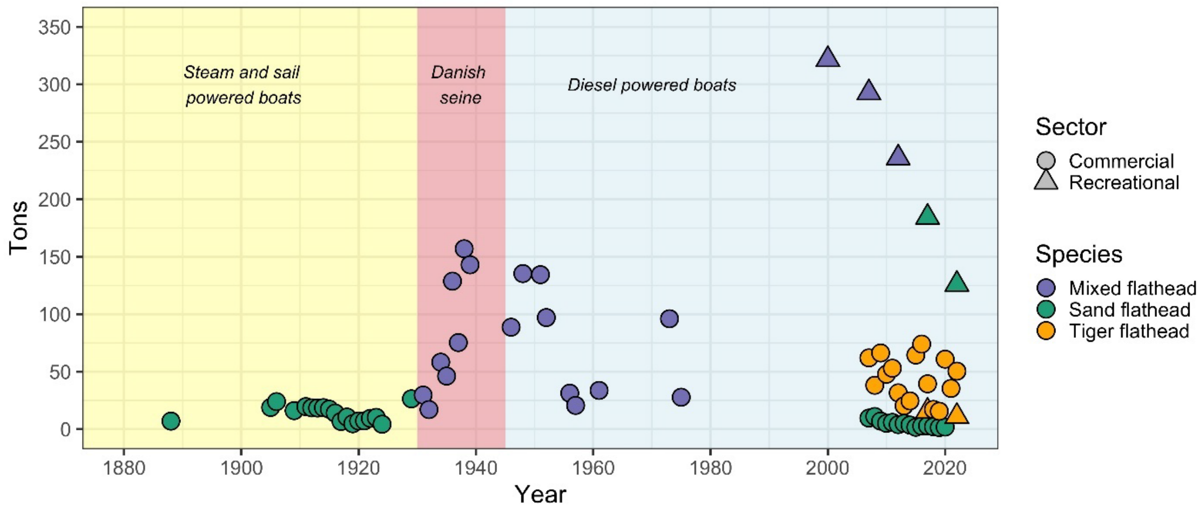


Figure 3. Reconstruction of flathead catches from 1888 to 2022. Green circles show annual catches of *flathead*, most likely Sand Flathead (*Platycephalus bassensis*), purple circles show total catches of aggregated flathead species, yellow circles show annual catches of Tiger Flathead (*Platycephalus richardsoni)*. Circles represent catches from the commercial sector, and triangles represent catches from the recreational sector. Yellow section represents the period when fishing was primarily conducted using steam- and sail-powered boats. The red section indicates the transition period during which the Danish Seine was introduced as a new fishing gear. The blue section shows the period when diesel-powered boats were most commonly used.

Soon after WWII flathead catches began to decline. Increasing concerns about the viability of Tiger Flathead precipitated a stock assessment (Fairbridge, 1952) which revealed large quantities of undersized fish caught in Danish seiners. As a result, the first minimum mesh size regulations were implemented in early 1950s, which seem to have led to stock recovery during the 1960s and 1970s (Klaer, 2010). Unfortunately, we found little data about Sand Flathead assessments or species-specific catch quantities in the earlier period of these decades.

By the late 1970s, the commercial flathead fishery on Tasmania's east coast had become more spatially defined and quantitatively described, particularly within inshore fishing blocks. Production from this region between 1977 and 1982 ranged from approximately 37 to 197 tonnes annually, with a cumulative catch of ~450 tonnes over that period, indicating its importance as a regional production centre (Last and Wolfe, 1983).

Fishing effort during this period was relatively low and episodic, typically involving only two vessels operating consistently, with up to three additional vessels fishing intermittently. Despite this limited effort, Danish seining proved highly efficient, with catch rates ranging from approximately 95 to 570 kg hr^{-1} (mean ~233 kg hr^{-1}), substantially exceeding trawl-based catch rates of only ~7–36 kg per shot (Last and Wolfe, 1983).

Catch distribution was strongly depth-dependent, with the highest commercial flathead densities occurring between 25 and 75 m, although fish were taken across a broader depth range from <25 m to ~125 m. Seasonal patterns in catch rates were weak, but fishing effort varied irregularly through time, with some periods of little or no activity (Last and Wolfe, 1983).

Commercial catches during this period were dominated by Tiger Flathead, reflecting offshore fishing depths and gear selectivity, whereas Sand Flathead remained more prominent in inshore and recreational fisheries. Commercial logbooks did not distinguish between species, but available evidence suggests Sand Flathead were a minor component of commercial landings and were sometimes discarded due to market preferences and minimum size requirements (Last and Wolfe, 1983).

Sand Flathead commercial catch data were first disaggregated in 2007/8. Annual commercial catch of Sand Flathead from 2007 to 2020 averaged 4.52 tons (± 2.97 SD, Figure 3) (Fraser et al., 2020). Assuming flathead landings from 1888 to 1935 mainly comprised of Sand Flathead, a decline of approximately 75% is evident between the two time periods analysed. However, this comparison should be interpreted with caution, as fishing gears and methods used during the early period differed from those used more recently, and technological advances can significantly influence catch efficiency.

The inability to disaggregate flathead species from catch data prior to 2007 is primarily due to challenges and limitations associated with archival sources. However, when examining the development of the fishery through a historical lens, it is possible to assume which species were represented in considerable quantities at a given time. Secondly, catch data availability varied across the reporting fisheries agencies (Figure 4). Depending on the agency, catch data were sourced from correspondences (e.g., letters between the Superintendent of Fisheries Sydney, NSW and the Secretary for Agriculture in Hobart, Tasmania 1949) or from published annual reports (e.g., Report of the Board for the Years 1926–1929 by The Sea Fisheries Board Tasmania). The lack of fisheries agency continuity and availability made data retrieval challenging, as these data were scattered across various archival series at the State Library archives. Despite the challenges associated with the archival sources, it was possible to reconstruct 153 years of flathead fishing history in Tasmania.

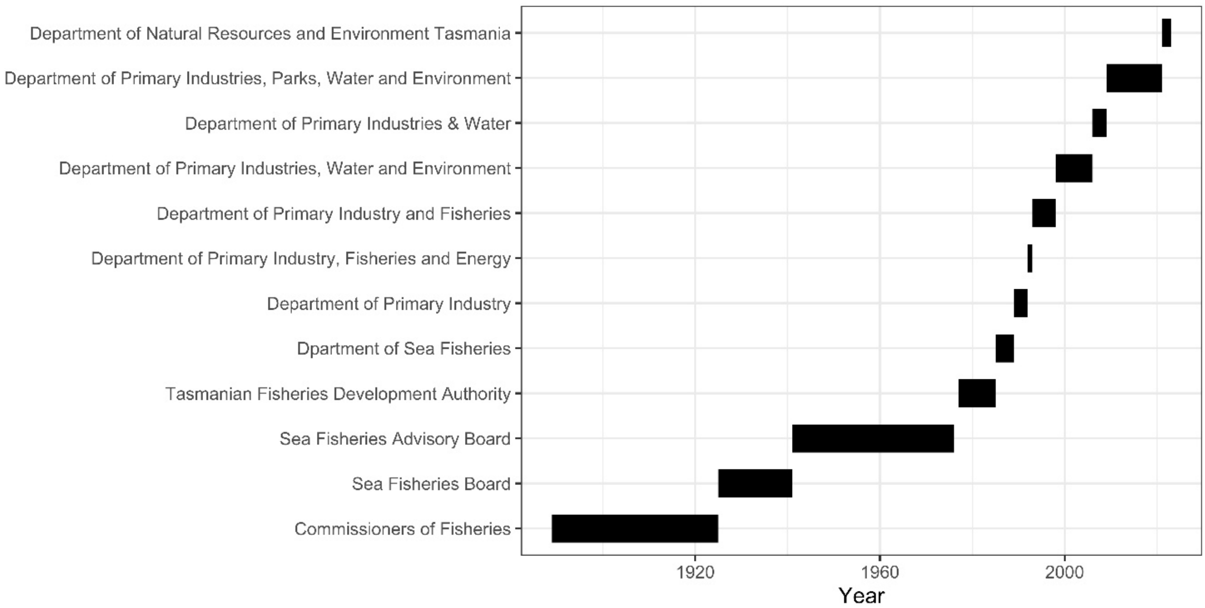


Figure 4. Fisheries management agencies, including Tasmania-specific agencies and Australia-wide agencies, from which Sand Flathead fisheries data were extracted for the period 1888–2022.

4.1.3.3 The recreational Sand Flathead fishery

Of the sampled articles, the earliest record found about recreational fishing was published by The Mercury on January 27, 1872, and described an outing in Adventure Bay: "Captain Clinch has consented to provide room for half-a-dozen small ferry boats for the use of such of the sons of Old Izaak who may leave the ship's side and moor themselves to the kelp, while they drop the tempting bait amongst the trumpeter, perch, bream, flathead and other unsuspecting fishes of Adventure Bay".

From articles reviewed, two types of recreational fishing were identified: fishing charters and shore-based recreational fishing. A total of 21 articles, published between 1872 and 1916, described fishing charter excursions, and 22 articles, published between 1884 to 1932, described shore-based recreational fishing.

In the late 19th century and the first decades of the 20th century, charter fishing was a popular leisure activity. Chartered vessels were typically large steamer boats that carried 150 to 300 people on board. Leaving Hobart (Franklin Wharf), the steamers would visit areas on the southern and eastern coast, including Iron Pot, Betsy Island, and the Tasman Peninsula. Fishing was carried out using baited lines though the steamers would tow small boats which customers could use for net fishing or to explore nearby land. For example, on April 27, 1886, The Mercury reported: "... the excursionists were glad to get once again on board. They discovered that a few who remained on the steamer [S.S. Southern Cross] had obtained large catches of flathead."

From the articles reviewed, it was not possible to determine the total number of charter boats operating in Tasmania from the 1880s to the 1920s. However, the most common charter boats to operate from Hobart and its surroundings were the

Monarch, Josephine, Taranana, Enterprise, S.S. Seabird, Broene, Thistle, S. S. Houn, Nubeena, Panifore, and S.S. Southern Cross. While other species were caught during these fishing outings, including jackass morwong (perch), Australian salmon and rock cod, flathead was often the most caught fish. For example, on February 25, 1902, the Mercury reported: "The boat... proceeded to the inner water of South Arm, off Chipman's. Having hove-to, all had their lines over the side quickly, with the hope of catching some flathead". Given the reported fishing locations, it is likely that the flathead catches from the steamer boats consisted mainly of Sand Flathead.

Out of the 21 fishing charter articles, five reported total flathead catches, eight reported numbers of anglers, and the rest provided qualitative flathead fishing descriptions. Given the incomplete quantitative fishing information in the articles, and the common use of 'flathead' to describe the catch rather than specify the species, catch rate reconstruction was not possible. From the articles that reported quantities, flathead landings varied from 500 to 2,400 fish per fishing trip. The largest flathead total catch was reported on March 9, 1916, in The Mercury: "The boat [Broene] came to a jetty and landed those wished to go ashore. Then fishing began. The take was 200 dozen [2,400 individuals] flathead and a gurnet". The lowest of reported catches came from an article published on February 25, 1902 in the Mercury: "The anchor having been lowered [at Bellerive Point], and the lines again cast all around the deck [S.S. Seabird], it was soon found that a bank of flathead had been struck...there were nearly 500 catches, two fish being occasionally hooked at a time. The largest individual catch was 31 flathead". It is not possible to estimate catch rates due to a lack of quantitative data including the number of fishers involved.

Analyses of shore-based fishing reports are also challenged by the incompleteness of catch reports which typically lack details such hours fished, number of fishers, fish sizes. Compared to historical recreational fishing club reports from Queensland and New South Wales, where catch rates could be reconstructed (e.g., number of fish per fisher^{-1} h^{-1}, kg of fish fisher $^{-1}$ h^{-1}) (Gartside et al., 1999, Chong-Montenegro et al., 2022), fishing records in Tasmania reported results of outings in less detail.

From the 1930s onwards, newspaper reports on recreational flathead fishing were scarce, possibly attributed to an editorial refocus to other news. Another possible explanation may be a hesitancy by fishers' to share information to avoid competition and overcrowding of fishing grounds.

By the late 1970s and early 1980s, more structured information on the recreational flathead fishery became available through targeted surveys. Recreational fishing was dominated by line fishing (“lining”) from boats, with additional effort from shore-based anglers, surveys were conducted in areas such as Great Oyster Bay and Mercury Passage. Effort was concentrated in relatively shallow, nearshore waters, contrasting strongly with the deeper offshore grounds exploited by commercial vessels (Last and Wolfe, 1983).

Quantitative survey data from this period indicate that recreational catches were dominated by Sand Flathead. Creel survey data suggested that Sand Flathead were caught at substantially higher rates than Tiger Flathead, with an approximate ratio of seven Sand Flathead to every Tiger Flathead captured. This reflects the nearshore distribution of Sand Flathead and their accessibility to line fishers. Despite this information the available data from this period were spatially limited and based on modest sample sizes, highlighting early recognition of the need for more comprehensive monitoring of recreational fishing effort and harvest (Last and Wolfe, 1983).

Standardised state-wide recreational fishing surveys commenced in Tasmania in 2000/1. Since then, surveys have been conducted every five years (Lyle, 2005, Lyle et al., 2009, Lyle et al., 2014, Lyle et al., 2019, Tracey et al., 2024). Prior to the 2019 survey, catch reports did not differentiate between flathead species: total recreational flathead estimates were 361 tons in 2000/01, 292 tons in 2007/08, and 235.9 tons in 2012/13 (Lyle, 2005, Lyle et al., 2009, Lyle et al., 2014). However, for the recreational fishing report in 2017/18, Sand Flathead catches were estimated at 184.4 tons, and 126 ton for the 2022/2023 season (Lyle et al., 2019, Tracey and Stark, 2024).

Over a span of 133 years, recreational Sand Flathead catches far exceed those of commercial fishing harvests (Figure 3). The highest recorded commercial catch of flathead (grouped species) was 158 tons in 1938—still 27 tons lower than the comparatively modest estimated recreational catch of Sand Flathead in 2017–2018.

4.1.3.4 The importance and challenges of using archival data in fisheries research

Historical reconstructions of exploited species can shed light on changes in perceptions and societal behaviour toward nature (Chong-Montenegro et al., 2022, Thurstan, 2022). For the Sand Flathead fishery in Tasmania, we observed a shift in societal attitudes, from viewing Sand Flathead as a disregarded fish to recognising it as an important exploited species and, eventually, a significant target for recreational fishing. This evolution in human-nature interactions illustrates the complexity of fisheries as intricate social-ecological systems (Hunt et al., 2013).

The historical development of the Sand Flathead fishery reveals its inherent complexity. Changes in socio-cultural values, technological advancements, and challenges in species-level reporting significantly influenced the fishery's development. For instance, advancements in fishing technology, such as the Danish seine, facilitated the expansion of commercial fisheries into deeper offshore waters. Despite these improvements, catch reporting did not improve and species-specific data remained inconsistent. This period highlighted the taxonomic uncertainty that has long characterised multispecies fisheries (Blasco et al., 2020), as catch reports from the 1930s to the 1950s aggregated landings of Tiger Flathead and Sand Flathead, complicating efforts to reconstruct species-specific historical baselines.

Despite these limitations, the archival sources examined in this study provide valuable insights into the evolving dynamics of the fishery and highlight the colonial legacy on fisheries management. Notably, no records of indigenous flathead fisheries were found, which may illustrate the impact of colonisation on the land and its people.

Lastly, the trajectory of the currently depleted Sand Flathead population results from a complex interplay of social and ecological factors that have influenced the population over the past two centuries. These long-term historical perspectives demonstrate how cumulative human pressures continue to reshape marine ecosystems, emphasizing the importance of retrospective reconstructions in understanding the long-term ecological impacts on vulnerable fish populations.

4.2 Historical biological data collection review

4.2.1 Introduction

Understanding how fish size structure changes through time is fundamental to evaluating stock condition, productivity, resilience, and rebuilding potential in exploited fisheries (Beverton and Holt, 1957, Hixon et al., 2014). The size and age composition of a fish population strongly influence reproductive output, recruitment stability, ecological function, and the capacity of stocks to withstand environmental variability and fishing pressure. Large and older individuals often contribute disproportionately to egg production, spawning timing diversity, offspring quality, and buffering against poor recruitment years, meaning that changes in size structure can have consequences beyond those captured by biomass estimates alone (Berkeley et al., 2004b, Hixon et al., 2014). For this reason, reductions in the abundance of larger fish are widely recognised as among the earliest and most informative indicators of sustained exploitation, particularly where harvest selectively removes larger individuals (Law, 2000).

Selective removal of larger fish can lead to demographic truncation, whereby populations become dominated by smaller, younger age classes and lose the broader age and size diversity that underpins resilience. Such changes may manifest as reduced spawning potential, altered growth trajectories, increased variability in recruitment, and greater sensitivity to environmental fluctuations (Hsieh et al., 2006, Anderson et al., 2008). Where size-selective harvest persists over long periods, there is also potential for fisheries-induced evolution, with selection favouring earlier maturation, slower growth to large size, or reduced size-at-age. Although disentangling plastic and evolutionary responses is challenging in wild populations, the possibility of harvest-driven life-history change further emphasises the importance of long-term monitoring of size structure (Uusi-Heikkilä et al., Olsen et al., 2004, Heino and Dieckmann, 2009).

Historical comparisons are especially valuable in long-utilised coastal fisheries such as Sand Flathead in Tasmania, where formal fishery-independent monitoring programs are relatively recent, but exploitation has occurred for many decades. In the absence of historical perspective, contemporary populations risk being assessed against already depleted reference points. This phenomenon, widely termed shifting baselines, occurs when each generation accepts the stock condition encountered early in their own experience as normal, even if substantial decline had already occurred previously (Pauly, 1995). Related to this is generational loss of perspective, whereby successive cohorts of fishers, managers, and communities progressively lose awareness of former fish abundance, average size, and ecosystem condition because those states are no longer directly experienced or socially transmitted (Sáenz-Arroyo et al., 2005, Papworth et al., 2009, Jones et al., 2020). Together, these processes can mask long-term decline, normalise reduced stock condition, and lead to underestimation of the scale of rebuilding required.

These issues are particularly relevant for Sand Flathead, a culturally, socially, and historically important Tasmanian coastal species that has supported recreational and commercial fisheries for generations. Contemporary evidence from fisheries-independent surveys and other recent data sources has raised concerns regarding reductions in mean size, loss of larger individuals, and regional demographic contraction, particularly in south-eastern Tasmania. However, robust evaluation of whether current stock structure is significantly different from earlier decades requires comparison with historical biological datasets collected prior to recent depletion signals. Historical data sources, while often imperfect and methodologically heterogeneous, can provide critical insight when carefully screened, standardised, and interpreted alongside contemporary surveys.

This chapter therefore collates available historical datasets containing Sand Flathead length information from Tasmania, evaluates their suitability for temporal comparison, and integrates selected datasets with contemporary IMAS fisheries-independent monitoring data. Reconstructing and analysing changes in size composition across regions from the early 1990s to the present, provides important long-term context for understanding stock trajectories, distinguishing between recent and historical conditions, evaluating current stock status, and informing realistic rebuilding objectives. More broadly, the chapter seeks to ensure that management decisions are grounded not only in present-day observations, but also in an evidence-based appreciation of what the Sand Flathead stock looked like previously and what levels of recovery may be achievable.

4.2.2 Method

4.2.2.1 Screening and selection of historical datasets

Historical datasets sampled prior to the fisheries independent surveys (2011/12 for long term sites and 2020/21 for expanded sites, see Table 2) that included length data were screened to identify those suitable for comparisons with contemporary fishery-independent survey data. Given that some of the published resources share underlying datasets, ten candidate datasets providing pre-IMAS survey individual-level length data for Sand Flathead were identified (Table 2: 2–16). Candidate datasets were evaluated against several criteria:

- Sampling gear comparable to the fisheries independent survey hook and line gear (i.e., typical recreational angling size 3/0 baited hooks; see Section 5.1.2). Where gears differed, datasets were prioritised if sufficient methodological detail was available to examine gear selectivity.

- Given the effect of spatial clustering of Sand Flathead length data identified in Section 6.1.3, sufficient spatial information to assess fine-scale overlap with fisheries independent survey regions and ideally, sites within regions.

- Sufficient overlap with the seasonal window of the IMAS fisheries independent survey (January–March) to minimise biases arising from seasonal variation in Sand Flathead size structure.

Several data sources (Table 2 reference numbers 2, 6–8, 11) were collected with Danish Seine or Beam Trawls with poor size selectivity relative to hook-and-line gear, sometimes to target juvenile flathead (e.g., refs. 6–8) for which it was not possible to address gear selectivity biases. Reference 10 had insufficient resolution of lengths to recreate length frequencies (i.e., to the nearest 1 cm) and references 11 and 16 had insufficient spatial information to assess overlap with modern IMAS survey regions.

Four datasets were collected using comparable fishing gear with suitable spatial and seasonal overlap and sample sizes were retained for comparison with recent IMAS fisheries independent survey length data (references 3, 4–5, 9, and 13–15): the CSIRO Nursery Project (Stevens and West, 1993), TAFI Creel Surveys (Lyle and Campbell, 1999, Lyle et al., 2002), and Life history sampling from 2001–2003 (Bani, 2005). These datasets allowed for multiple regional comparisons to flathead lengths in the early 1990s and 2000s.

As the requirements for robust analysis of length differences varied with the details of each historical dataset, data preparation, validation and statistical methods used are explained for each included dataset in turn.

Table 2. Historical datasets that provide Sand Flathead (*Platycephalus bassensis*) size, age, and/or reproductive data, by decade.

Decade	Study	Data available: Size	Age	Repro.
1980s	1. Last, P.R. and Wolfe D.C. (1983) A situation report on the recreational and commercial flathead fisheries off the east coast of Tasmania.	N	N	N
	2. CSIRO Danish Seine sampling (F/V *Allanwood*) of Frederick Henry Bay, June 1983–May 1984 (unpublished)	Y	N	N
1990s	3. Lyle, J.M., and Campbell, D.A. (1999). Species and size composition of recreational catches with particular reference to licenced fishing methods. Final report to the Marine Recreational Fishery Advisory Committee.	Y	N	N
	Flathead bycatch measured as part of the following CSIRO/FRDC projects: 4. Stevens, J.D. & West, G.J. 1993. *Investigation of school and gummy shark nursery areas in south-eastern Australia*. *FRDC*. Final Report: Project 93/061. https://www.frdc.com.au/sites/default/files/products/1993-061-DLD.pdf	Y	N	N
	5. Reproductive biology, early life-history, and settlement distribution of Sand Flathead in Tasmania collected in the early 1990s (Jordan, 1998b, Jordan, 2001b).	Y	Y	Y
	6. Size and age structure of coastal Sand Flathead populations on the Tasmanian continental shelf and Storm Bay collected from demersal trawl sampling operations in the early 1990s (Jordan, 1997).	Y	Y	N
	7. Size and age structure from shallow inshore soft bottom habitats and early life history from inshore juvenile and plankton sampling in the late 1990s (Jordan et al., 1998).	Y	Y	Y
2000s	8. Lyle, J., Forward, J., and Morton, A. (2002). Species and size composition of recreational catches based on 2000/2001 creel surveys. Internal Report. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania. December 2002	Y	N	N
2000s	9. Reproductive strategy and spawning activity of Sand Flathead, *Platycephalus bassensis* (Platycephalidae) (Bani et al., 2009)	Y	Y	Y
	10. Temporal and spatial variability of the life history characteristics of Sand Flathead, *Platycephalus bassensis* (Bani, 2005)	Y	Y	Y

	11. Spatio-temporal variability in reproductive ecology of Sand Flathead, *Platycephalus bassensis*, in three Tasmanian inshore habitats: Potential implications for management. (Bani and Moltschaniwskyj, 2008b).	Y	Y	Y
	12. Flathead catches from the Tasmanian coast for fisheries and gear technology educational projects at the Australian Maritime College from 2006 to 2018.	Y	Y	N
2010s	13. Catchability, seasonal activity, and movement in SE Tasmania (Stehfest et al., 2014).	Y	N	N
	14. Flathead catches from the Tasmanian coast for fisheries and gear technology educational projects at the Australian Maritime College from 2010 to 2018.	Y	Y	N
	IMAS fishery-independent surveys from 2012:	Y	Y	N
	15. Ewing, G. and J. M. Lyle (2014). "Developing a low-cost monitoring regime to assess relative abundance and population characteristics of Sand Flathead." Fishwise Technical Report, Institute for Marine and Antarctic Studies, Hobart.			
	16. Ewing, G. and J. M. Lyle (2015). "Low-cost monitoring regime to assess relative abundance and population characteristics of Sand Flathead." Technical Report, Institute for Marine and Antarctic Studies, Hobart.			
	17. Ewing, G. and J. M. Lyle (2018). "Low-cost monitoring regime to assess relative abundance and population characteristics of Sand Flathead - 2018 Update." Technical Report, Institute for Marine and Antarctic Studies, Hobart.			
2020s	18. Relic, L. (2021) Variations in Life-History Characteristics of Four Co-Existing Species of Platycephalids from Northern Tasmania. UTAS Honours thesis. 70 pages. (data from 2006–2008 and 2015–2018)	Y	Y	Y
	19. Coulson P., Ewing G.P. & Marshell, A. 2022. *Fishery-independent monitoring of Sand Flathead population dynamics*. University of Tasmania, Institute for Marine and Antarctic Studies. https://www.utas.edu.au/__data/assets/pdf_file/0007/1671136/IMASSandFlatheadIndepSurveys_2022.pdf.	Y	Y	N

4.2.3 Results

4.2.3.1 CSIRO Nursery Project (1992–1997)

The historical dataset that most closely met the inclusion criteria was the CSIRO Nursery Project (1992–1997), which examined shark nursery areas around Tasmania (Stevens and West, 1993; Table 2). Raw data was accessed via the AODN[2]. Sample-level data were cleaned and standardised, then filtered to include only Sand Flathead records. This resulted in 10,014 catch records, of which 8,376 included length measurements. A total of 7,417 records were collected during the January–March period, aligning with the IMAS fisheries-independent survey window, with most data originating from the 1992/93 to 1995/96 financial years.

The CSIRO Nursery Project data, which were collected from embayments and inshore coastal areas around Tasmania, were assessed for spatial overlap with the IMAS fisheries-independent survey. Norfolk Bay showed the greatest overlap and represented approximately half of the long-term IMAS survey region 'Frederick Henry–Norfolk Bay', which has been surveyed annually since 2010/11. The overlapping CSIRO subset comprised 2,474 Sand Flathead length records from 1993/94 and 1994/95. A second overlapping subset was identified in the D'Entrecasteaux Channel with 1,512 length samples from 1992/93 and 1993/94. These two subsets were selected and harmonised with the IMAS fisheries-independent survey dataset to examine temporal trends in length structure.

Although the Nursery Project used a combination of longline and gillnet sampling in other regions, all Sand Flathead length samples from Norfolk Bay were collected using gillnets with 2-, 3-, and 4-inch mesh sizes. As these gears differ from the hook-and-line methods used in the historical CSIRO and contemporary IMAS surveys, the potential effects of gillnet size selectivity and relative fishing power were evaluated to assess their influence on observed temporal trends in length structure.

Assessing gillnet size selectivity of sand flathead

To support comparisons of fishing power and size selectivity among mesh sizes, fishing effort in Norfolk Bay was first estimated from catch data, as metadata on net deployments (including zero-catch sets) were unavailable. Effort was approximated by counting unique location–date–mesh combinations across all species records, assuming most net sets captured at least one fish. This yielded 97, 95, and 79 unique sets for 2-, 3-, and 4-inch mesh sizes, respectively. These similar deployment numbers indicate that nets were set in series at each location, enabling direct comparison of mesh-specific fishing power and efficiency.

Relative fishing power and size selectivity were then assessed by summarising Sand Flathead length-frequency distributions by mesh size, both within Norfolk Bay and across all regions. Comparisons were also made between gillnet and non-gillnet gears. Non-gillnet gears were primarily longlines using size 5/0 hooks, with some larger Japanese tuna hooks (Stevens and West 1997).

[2] Investigation of School and Gummy Shark Nursery Areas in South East Tasmania and South East Australia

Table 3. Summary of CSIRO Nursery Project Sand Flathead data by gillnet mesh size. Summary statistics refer to Sand Flathead total lengths (mm) and *n* refers to total sample sizes. Length data were not recorded for the 20 longline-sampled Sand Flathead in Norfolk Bay.

Mesh size (inch)	**All sites**			**Norfolk Bay**		
	Median	**Mean**	***n***	**Median**	**Mean**	***n***
2	302	306.0	6,483	302	304.2	2,369
3	358	349.2	1,366	343	335.7	493
4	315	324.5	240	301	305.1	108
Non-gillnet	321	322.5	824	-	-	20

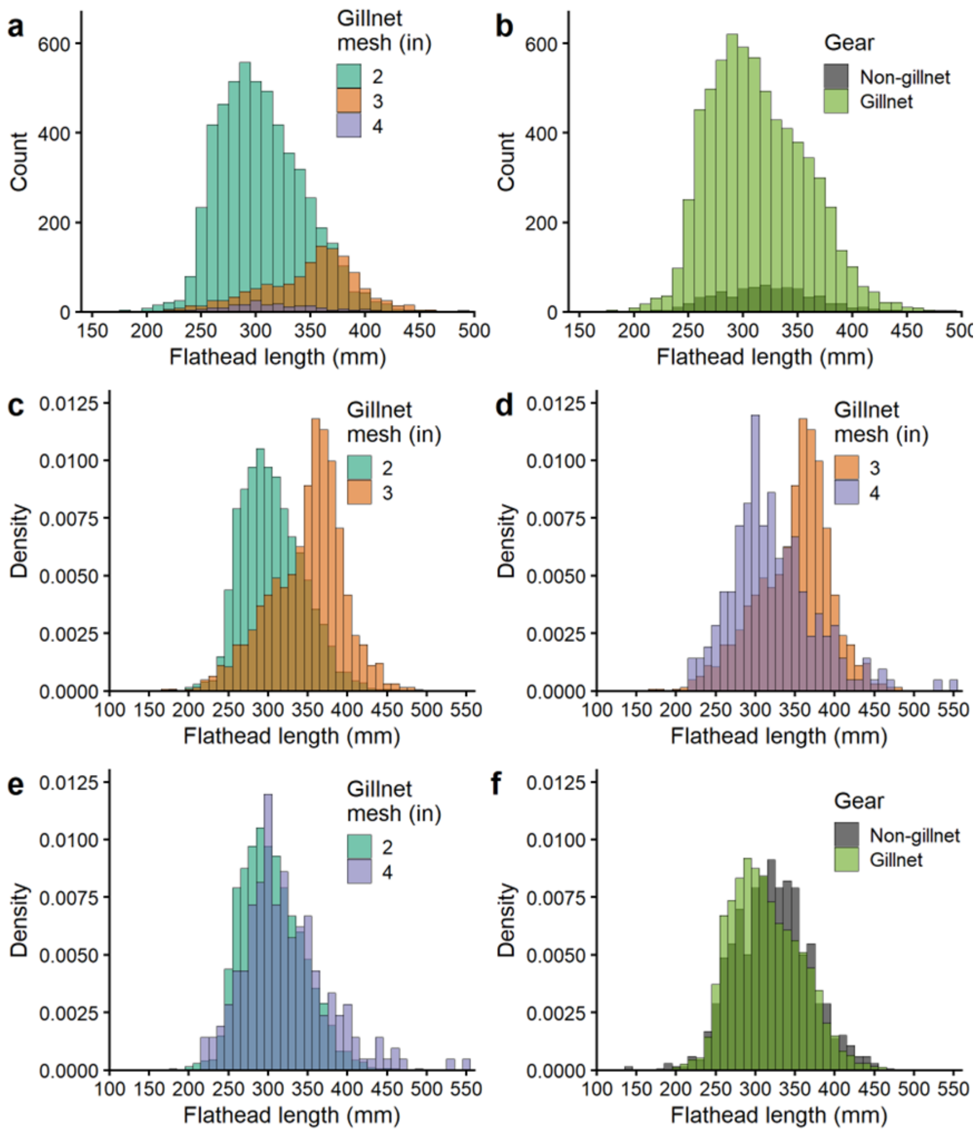


Figure 5. Sand Flathead gear size selectivity for Sand Flathead from CSIRO Nursery project data, across all sites. a) Length frequencies of Sand Flathead by gillnet mesh size (inch). b) Length frequencies of Gillnet vs non-gillnet gear, which were almost entirely longline-based gears with 5/0 sized hooks. Pairwise combinations of meshes scaled to unit density (bars for each category add to 1) are displayed in panels c-f for selectivity comparison.

Sand flathead fishing power declined markedly with increasing gillnet mesh size, with an approximate 80% reduction for each additional inch of mesh (Table 3; Figure 5a, Figure 6a). The very low fishing power of the 4-inch mesh likely explains the slightly lower number of estimated sets for this mesh size, as some deployments may not have retained any Sand Flathead. This supports the assumption of broadly comparable sampling effort among mesh sizes in Norfolk Bay.

Clear size selectivity was evident among gillnet mesh sizes, with consistent patterns across all sites (Figure 5) and within Norfolk Bay (Figure 6). The 3-inch mesh selected for larger Sand Flathead than the 2-inch mesh in both cases (Figure 5b; Figure 6c). In contrast, the 4-inch mesh did not shift the modal length further upward, instead selecting a similar modal size to the 2-inch mesh (Figure 5d; Figure 6e), although with a thin right tail indicating occasional capture of the largest individuals.

This pattern likely reflects differences in capture mechanisms. The 2- and 3-inch meshes presumably capture fish predominantly by gilling or wedging, where retention depends on body girth matching mesh size. In contrast, the 4-inch mesh would only gill or wedge the largest individuals and is more likely to retain fish through snagging or entanglement.

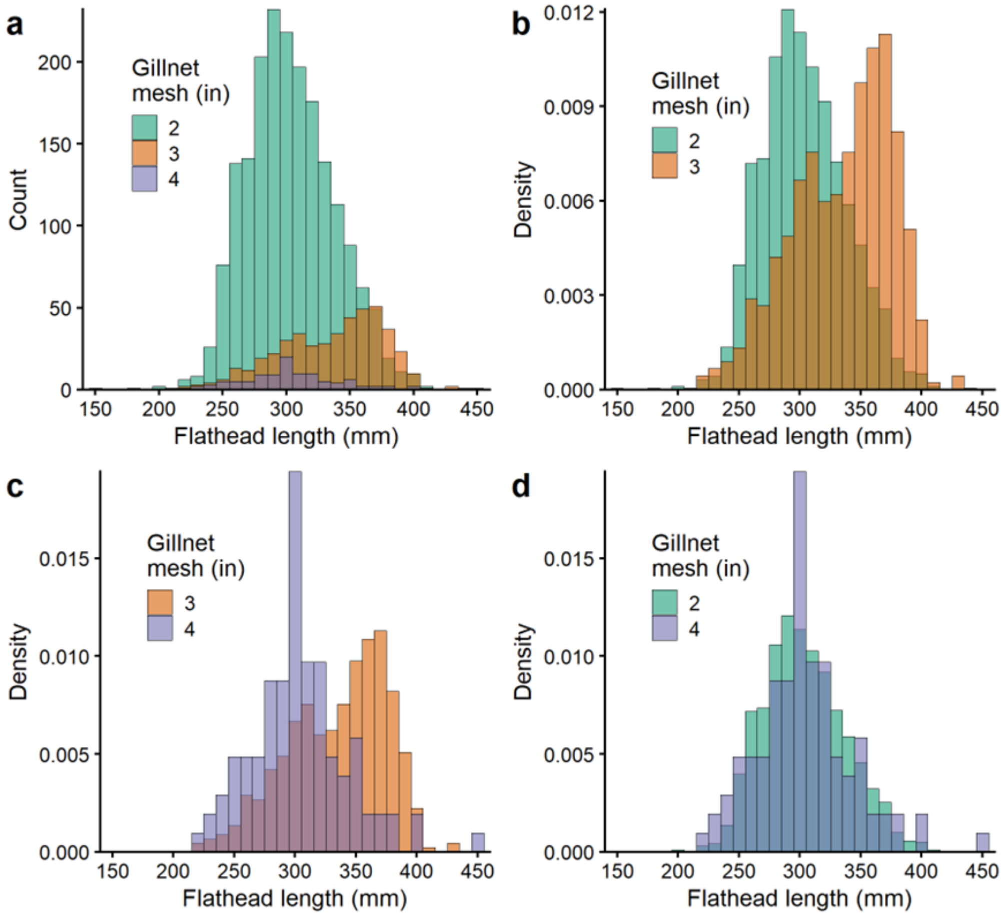


Figure 6. Gillnet mesh size selectivity for Sand Flathead from the CSIRO Nursery project data conducted in Norfolk Bay. a) Length Frequencies of Sand Flathead by gillnet mesh size (inch). b–d) Combinations of meshes seen scaled to unit density (i.e., bars add to 1 for each category) for comparison.

The primary differences between Sand Flathead length frequencies from 2-inch and 3-inch gillnets were evident in their opposing skewness. The 2-inch mesh produced a right-skewed distribution, whereas the 3-inch mesh was strongly left-skewed, corresponding to median lengths of 302 mm and 343 mm, respectively, in Norfolk Bay.

Together with the low fishing power of the 4-inch mesh, these results suggest that the range of mesh sizes used in the project provided adequate coverage of the length structure observed in the fisheries-independent survey, particularly across the upper size range.

However, comparison of the lower tail of the length distributions revealed general agreement between gillnet catches and those obtained using 5/0 longline hooks (Figure 5f). Given that hook size influences selectivity, and that the fisheries-independent survey used smaller 3/0 hooks, these would be expected to retain smaller individuals more effectively than 5/0 hooks. This indicates that the gillnet survey may under-represent the smallest Sand Flathead relative to the fisheries-independent survey, an effect that was accounted for in subsequent trend analyses.

Matching historical sampling to IMAS fisheries independent survey sites

To compare Sand Flathead length distributions between the 1990s (CSIRO) and the contemporary IMAS survey in Norfolk Bay, the IMAS fisheries-independent dataset was subset to sites within Norfolk Bay (Frederick Henry–Norfolk Bay region, site numbers 22–28 and 32–35). CSIRO Nursery Project sampling locations were distributed throughout Norfolk Bay across a range of depths, including areas proximal to IMAS survey sites (Figure 7), allowing the spatial structure of sampling within the bay to be appropriately represented.

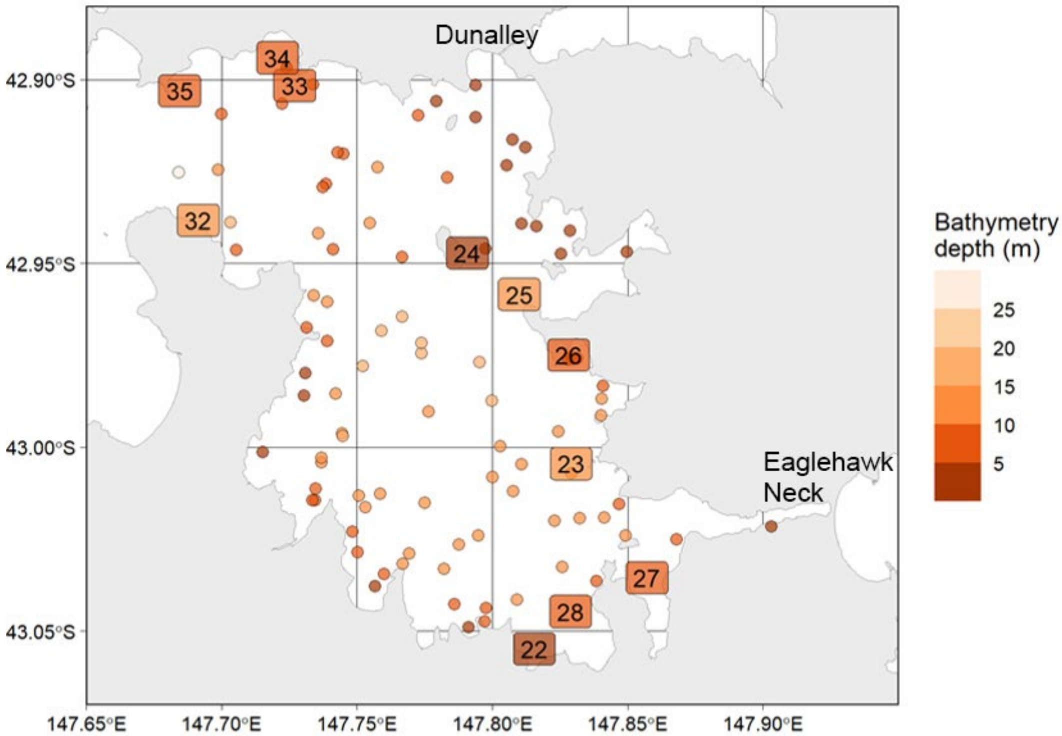


Figure 7. IMAS fisheries independent survey sites (rounded squares, numerals indicate Frederick Henry-Norfolk Bay survey region site code #) and CSIRO Nursery Project gillnet sampling locations (round markers) that yielded Sand Flathead lengths. Refer to Figure 14 to identify region within Tasmania.

To integrate historical CSIRO samples with the IMAS fishery independent survey, CSIRO sampling locations in Norfolk Bay were matched to the nearest independent-survey sites based on depth and geographic distance. This was performed using multivariate nearest-neighbour matching in principal components space, derived from scaled longitude and latitude along with bathymetric depth (down-weighted to 1/3 to reduce its influence relative to horizontal distance). Matches were retained only where Euclidean distance in PCA space was ≤ 1 standard deviation, supporting spatial and habitat comparability between matched CSIRO sampling locations and independent survey sites (Figure 8). Of 2,474 flathead lengths sampled in the CSIRO project from Norfolk Bay, 1,363 were retained after the site matching process (Figure 8).

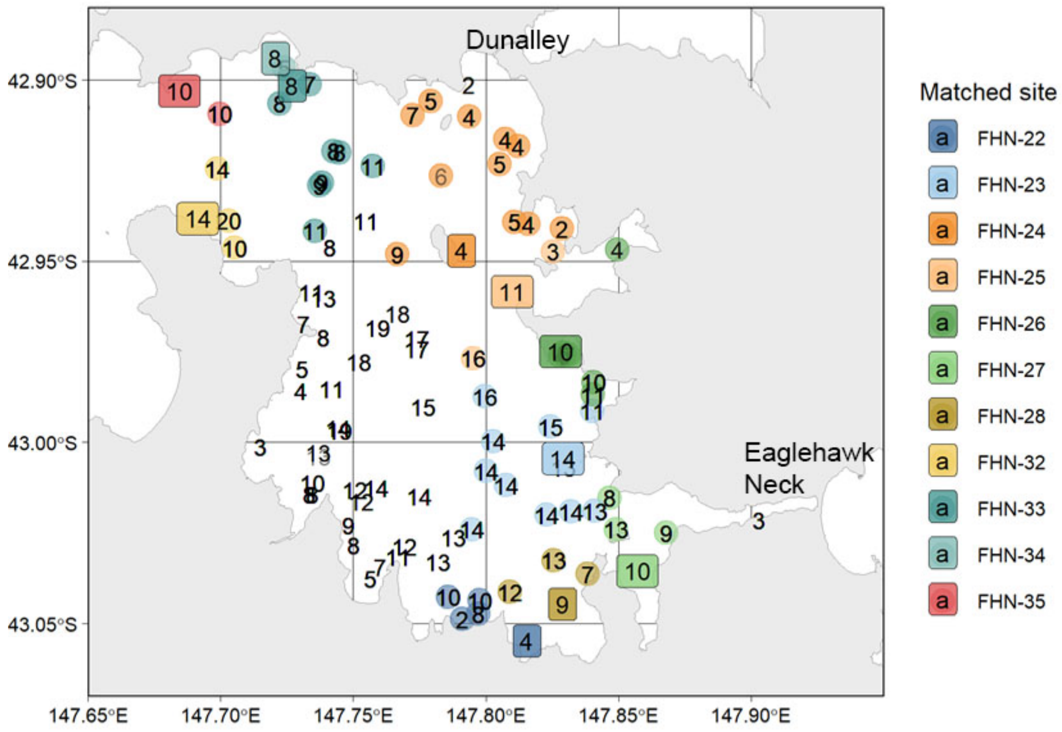


Figure 8. CSIRO gillnet sampling locations with recorded Sand Flathead catch from the 1990s Nursery project (round markers, with depth in metres indicated) matched to IMAS fisheries independent annual survey sites (squared markers, with site numbers indicated) in Norfolk Bay. Pairing was undertaken using nearest-neighbour matching in principal components (PC) space calculated from scaled latitude and longitude and bathymetric depth with 1/3 of the weight of coordinate variables. CSIRO gillnet samples matched to each IMAS survey site are indicated with colour coded markers, and those that were farther than 1 PC standard deviations from an IMAS survey site were excluded, shown as depth labels without coloured markers. Refer to Figure 15 to identify region within Tasmania.

The same procedure was used to match the spatial structure of historical CSIRO sampling and IMAS survey sites in the D'Entrecasteaux Channel, but due to the greater geographical extent, depth was down weighted to ¼ of the coordinate variables after scaling in the PCA, and a maximum 0.5 PC standard deviations distance threshold was used for selecting CSIRO sampling locations near IMAS survey sites. After matching, four IMAS sites (Channel sites 2, 3, 12 and 16) with matching CSIRO samples were retained, with another two matched sites (8 and 15) excluded as less than 10 historical length samples matched in total (Figure 9). A total of 990 historical CSIRO and 893 contemporary IMAS flathead length samples were retained for analysis.

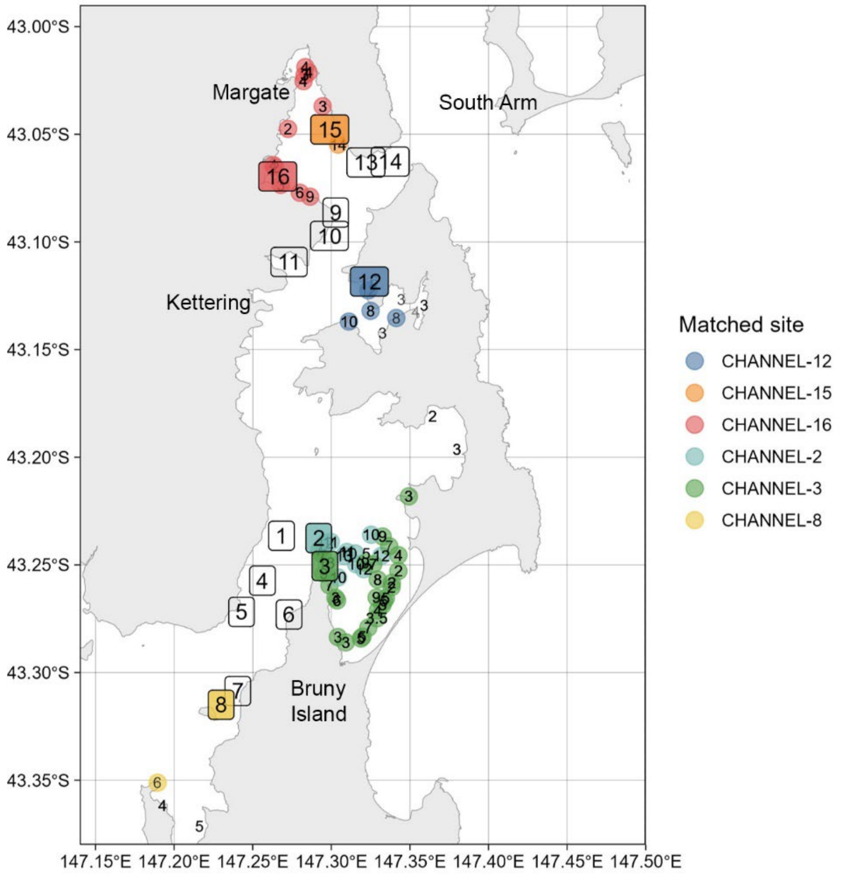


Figure 9. CSIRO gillnet sampling locations with recorded Sand Flathead catch from the 1990s Nursery project (round markers, with depth in metres indicated) matched to IMAS fisheries independent annual survey sites (squared markers, with site numbers indicated) in the D'Entrecasteaux Channel. Unfilled labels indicate IMAS survey sites with no paired historical data. Pairing was undertaken using nearest-neighbour matching in principal components (PC) space calculated from scaled latitude and longitude and bathymetric depth with 1/4 of the weight of coordinate variables. CSIRO gillnet samples matched to each IMAS survey site are indicated with colour coded markers, and those that were farther than 0.5 PC standard deviations from an IMAS survey site were excluded, shown as depth labels without coloured markers. Sites 8 and 15 were also excluded from analysis as less than 10 historical samples in total were matched to either site. Refer to Figure 15 to identify region within Tasmania.

Analysis of Sand Flathead length differences

Matched CSIRO and fisheries-independent survey samples were combined to analyse temporal trends in Sand Flathead length across financial years (FY). Differences in length over time were assessed using linear mixed-effects models fitted with *lmer* from the *lme4* package. Fish length was specified as the response variable, FY as a categorical fixed effect, and site was included as a random intercept to account for spatial variation among sampling locations (see Section 6.1.3).

Models were fitted to (i) the IMAS subsets of the harmonised data, and (ii) the combined historical (CSIRO) and contemporary (IMAS fisheries-independent survey) dataset. For the IMAS data, FY was also modelled as a continuous covariate to test for a linear temporal trend. Differences in mean Sand Flathead length between historical and contemporary periods were assessed using three sets of contrasts: (i) a single omnibus contrast between pooled historical FYs (two present in each regional subset) against the pooled contemporary IMAS survey FYs (2011/12–2024/25); (ii) each historical

FY against the pooled contemporary FYs; (iii) Dunnett-style multiple comparisons were used to compare each contemporary FY individually against each historical FY for the two harmonised regional subsets.

For both of the harmonised regional data subsets, differences in mean Sand Flathead length between historical and contemporary periods were assessed using three sets of contrasts: (i) an omnibus comparison between pooled historical financial years (1993/94 and 1994/95 for Norfolk Bay, 1992/93 and 1993/94 for the Channel) and pooled contemporary IMAS survey years (2011/12–2024/25); (ii) comparisons of each historical year against the pooled contemporary period; and (iii) Dunnett-style multiple comparisons, in which each contemporary year was compared individually against each historical year.

To evaluate the influence of gillnet size selectivity in the historical data on estimated trends, analyses were repeated under three alternative data treatments: (i) restricting historical data to 2-inch mesh gillnet samples to minimise bias towards larger fish; (ii) applying a left truncation at 260 mm to account for reduced selectivity of gillnets for smaller individuals relative to 3/0 hook sampling used in the IMAS survey; and (iii) combining both approaches by restricting historical data to 2-inch mesh samples and excluding lengths below 260 mm.

Evidence of greater average flathead lengths in the 1990s

Norfolk Bay

Consistent with the broader Frederick Henry–Norfolk Bay region (see Section 5.6.6), no significant linear trend was detected when FY was treated as a continuous variable (Type III ANOVA, $p = 0.66$), so it was treated as a categorical predictor, with significant interannual variation was observed ($p < 0.001$). The omnibus contrast (historic vs modern survey years both pooled) revealed that in Norfolk Bay, the mean length of Sand Flathead in the 1990s was 29.2 mm greater than in the recent pooled fisheries independent survey from 2011–2025 (95% CI 26.1–32.4 mm; $t = 18.1$, $p < 0.0001$). This is equivalent to a relative decline of 9.5% (95% CI 8.4% – 10.6%) from the 1990s mean of 308 mm (95% CI 303–314 mm) to the recent mean of 279 mm (95% CI 274–284 mm). This difference was greater in 1993/94 than 1994/95, at 35.5 mm (30.0–41.0 mm; $t = 14.4$, $p < 0.0001$) and 23.0 mm (19.4–26.4 mm; $t = 14.7$, $p < 0.0001$).

This result was robust after subsetting data to control for potential effects of gear selectivity. Restricting the historical data to 2-inch mesh gillnets yielded a mean length in the 1990s that was 25.3 mm greater than the contemporary survey (95% CI: 22.0–28.6 mm; $t = 15.05$, $p < 0.001$). When data were left-truncated at 260 mm to account for reduced selectivity for smaller individuals, the difference remained 18.4 mm (95% CI: 15.6–21.2 mm; $t = 12.88$, $p < 0.001$). Under the most conservative subset (2-inch mesh only and lengths ≥ 260 mm), the historical mean was still significantly greater by 14.8 mm (estimate = 14.8 mm, 95% CI: 11.9–17.6 mm; $t = 10.15$, $p < 0.001$), equivalent to a relative decline of 4.7% (95% CI 3.8%–5.7%) from 312 mm (95% CI 308–315 mm) in the 1990s mean and 297 mm (95% CI 293–300 mm) in the recent mean.

Contrasts comparing individual contemporary survey years to the pooled historical period showed that all 14 survey financial years (2011/12–2024/25) had significantly smaller mean lengths than the historical baseline ($p < 0.001$ for all comparisons). The largest difference occurred in 2012/13, where the historical mean exceeded the contemporary mean by 46.0 mm (estimate = 46.0 mm, 95% CI: 37.2–54.8 mm; $t = 15.19$), while the smallest difference was observed in 2011/12 (estimate = 14.7 mm, 95% CI: 5.3–24.0 mm; $t = 4.60$).

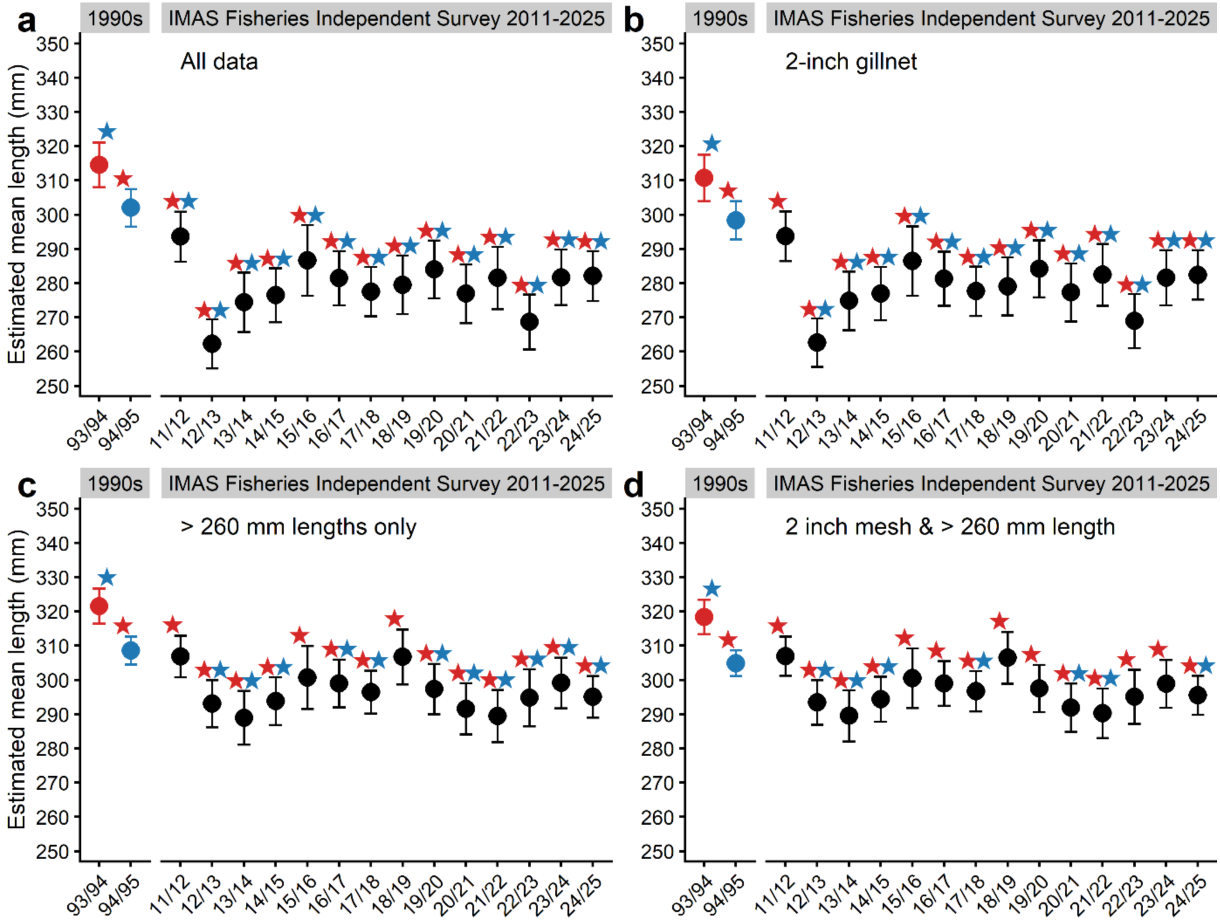


Figure 10. Estimated marginal mean Sand Flathead length in Norfolk Bay by financial year. The 1990s data are from the CSIRO Nursery Project, collected by gillnet while the recent data are from the IMAS fisheries-independent survey. a) model results with all data; b) gillnet samples limited to 2-inch mesh catches; c) censoring all samples > 260 mm length; d) limiting gillnet samples to 2-inch mesh and censoring > 260 mm. Stars above each FY indicate significant differences between the individual survey year mean lengths and the Nursery Project mean lengths in 1993/94 (red star, shifted left) and/or 1994/95 (blue star, shifted right).

These patterns remained largely consistent after accounting for potential gear selectivity. When restricting historical data to 2-inch mesh gillnets ($p < 0.001$) or applying a left truncation at 260 mm ($p = 0.032$), all contemporary survey years continued to exhibit significantly smaller mean lengths than the 1990s. Under the most conservative treatment (2-inch mesh only and lengths ≥ 260 mm), 12 of the 14 contemporary years remained significantly smaller, with the exceptions of 2011/12 and 2018/19.

Estimated annual mean flathead lengths along with results of contrasts between historical and contemporary survey years are presented in Figure 10. All contemporary

IMAS fisheries-independent surveys (2011/12–2024/25) differed significantly from both historical years (1993/94 and 1994/95; $p \leq 0.008$; Figure 10a), and the two historical years also differed significantly from one another.

After accounting for potential gear selectivity, all contemporary years remained significantly smaller than 1993/94 across all data treatments. In contrast, relative to 1994/95, an increasing number of contemporary years were no longer significantly different as selectivity controls were applied: one year when restricting historical data to 2-inch mesh (Figure 10b), three years when truncating lengths below 260 mm (Figure 10c), and six years when applying both filters simultaneously (Figure 10d).

D'Entrecasteaux Channel

While there was not a significant trend in mean flathead lengths in the overall Channel IMAS survey region over the 2011/12–2024/25 extent of the survey (see Section 6.1.3), among the subset of four sites matched in harmonised data there was a significant decline of -0.86 mm per year (95% CI −1.51 to −0.20 mm yr^{-1}; $t = -2.569$; $p = 0.01$) over this period. With the historical surveys in 1992/93 and 1993/94 included, there was a significant negative trend of −1.60 mm yr^{-1} (95% CI −1.77 to −1.44 mm yr^{-1}; $t = -19.275$; $p < 0.0001$) estimated. However, under the most conservative gear selectivity subset (gillnet catches 2 inch meshes only, lengths truncated to ≥ 260 mm) mean length showed a similar rate of decline as occurred in the contemporary IMAS period, of −0.771 mm yr^{-1} (95% CI −0.928 to −0.613 mm yr^{-1}; $t = -9.648$, $p < 0.0001$).

Contrasts of models with FY treated as a categorical predictor indicate flathead were longer in the pooled early 1990s than in the pooled recent 2011/12 to 2024/25 surveys by 38.8 mm (95% CI 34.4–43.3; $t = 17.18$, $p < 0.0001$), a relative decrease in mean size of 12.4% (95% CI 10.4%–14.3%) from 314 mm (95% CI 308–320 mm) in the early 1990s to 275 mm (95% CI 270–281 mm) recently. Year-specific contrasts vs pooled recent survey yielded differences of 33.8 mm in 1992/93 (27.7–39.9; $t = 12.44$) and 43.8 mm in 1993/94 (38.2–49.4; $t = 17.53$). This difference was robust to subsetting data to control for gear selectivity, the pooled contrast of the data under the most conservative subset (≥260 mm lengths and 2-inch mesh gillnet catches) indicated that mean length in the early 1990s was still 18.6 mm greater than in the recent pooled fisheries-independent survey (95% CI 14.4–22.8 mm; $t = 8.76$, $p < 0.0001$), a 6.0% relative decrease (95% CI 4.0%–8.0%) from an estimated mean of 311 mm (95% CI 306–317 mm) in the early 1990s to 293 mm (95% CI 288–297 mm) recently.

Contrasted with the pooled historical years, all contemporary survey years were significantly smaller, by between 21.6 and 49.2 mm (all $p < 0.05$). Under the most conservative gear selectivity control data subsetting (≥260 mm and 2-inch mesh), 12 of 14 IMAS survey years were significantly different from the pooled historical years (all but 2013/14 and 14/15). Pairwise contrasts of each historical year vs each modern year displayed in Figure 11 demonstrate contemporary surveys were different from both historical survey years, except for the (2013/14)–(1992/93) comparison for the non-subset model ($p = 0.1$) or 2-inch gillnet subset model ($p = 0.18$). Under the 260 mm truncated model, 25 of 28 possible pairwise year comparison were significantly different and under the most-conservative ≥260 mm and 2-inch mesh subset, 18/28 pairwise contrasts were significantly different.

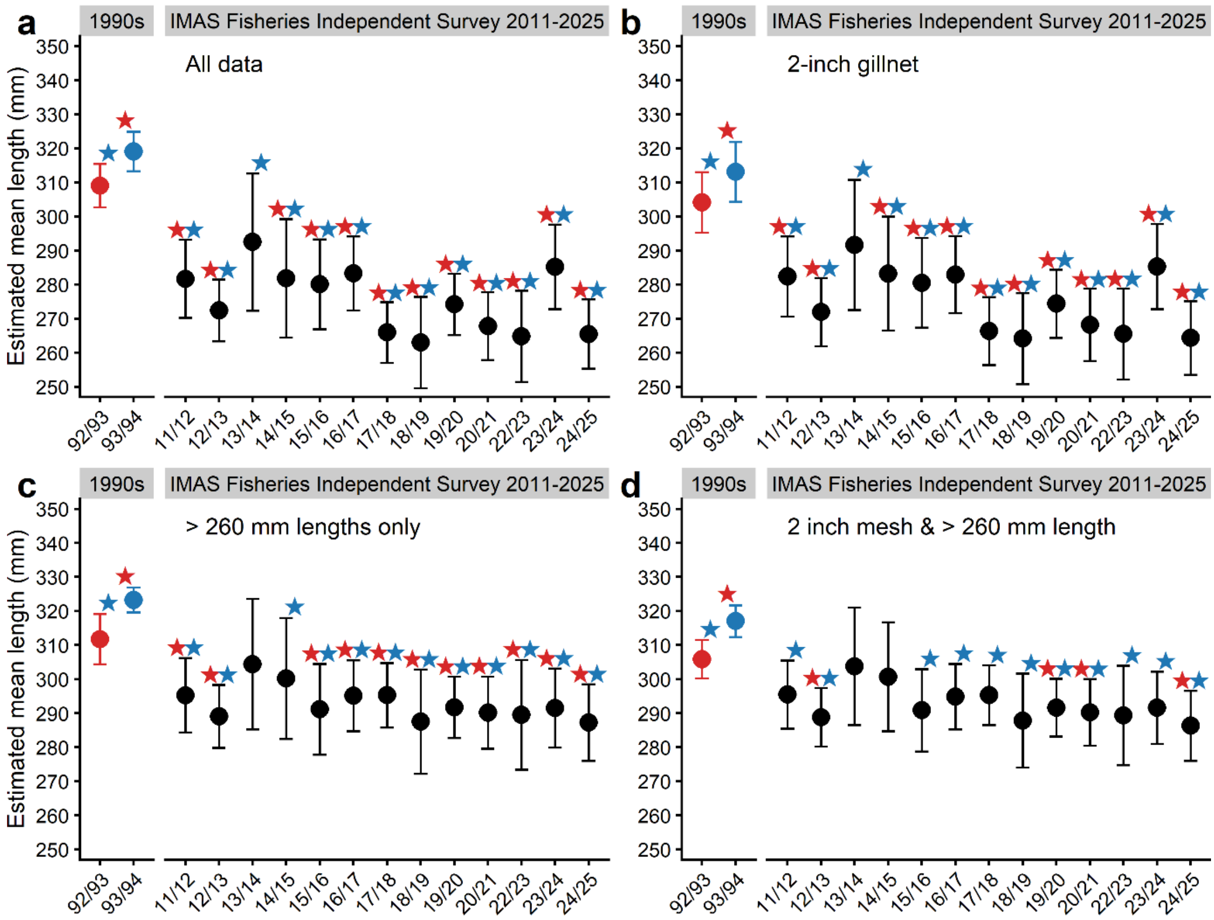


Figure 11. Estimated marginal mean Sand Flathead length in the D'Entrecasteaux Channel by financial year. The 1990s data are from the CSIRO Nursery Project, collected by gillnet while the recent data are from the IMAS fisheries-independent survey. a) model results with all data; b) gillnet samples limited to 2-inch mesh catches; c) censoring all samples > 260 mm length; d) limiting gillnet samples to 2-inch mesh and censoring > 260 mm. Stars above each FY indicate significant differences between the individual survey year mean lengths and the Nursery Project mean lengths in 1992/93 (red star, shifted left) and/or 1993/94 (blue star, shifted right).

4.2.3.2 TAFI Creel Surveys (1997/98 and 2000/01) and Life History Sampling (2001–2003)

Historical data from TAFI-conducted creel surveys provided a complementary line of evidence, including one survey conducted over December – April in 1997/98 (i.e., peak recreational fishing season in Tasmania and overlapping with the IMAS fishery-independent survey season) and a second that formed the on-site component of the National Recreational Fishing Survey 2000/01 (Lyle et al., 2002) which were compared against results from the most recent available (2024/25) IMAS fishery-independent survey. During the 2000/01 creel survey, Sand Flathead accounted for 70.5% of retained recreational line catches examined by creel agents.

Historic data were extracted with the flathead extractor https://recfish.pelagic-movement.cloud.edu.au/shiny/extractor/ web app from length frequency plots included in Lyle and Campbell (1999) and Lyle et al. (2002), and total sample sizes included on the figure allowed validating the extraction.

Spatial harmonisation was achieved by mapping modern sampling sites to regional strata used in the Lyle and Campbell (1999) and Lyle et al. (2002) report as follows: Bridport – Bridport; Swansea/Coles Bay – GOB; St Helens – St Helens-Inside and St Helens-Outside; Northwest – Stanley and Tamar-outside; East – St Helens-outside and Mercury Passage; Derwent/D'Entrecasteaux – The Channel. Modern measurements were converted to centimetres and rounded down to the nearest whole for consistency with the protocol used for measurements in these reports.

Length-frequency distributions were analysed using a linear model incorporating an interaction between region and financial year (FY). There was a high percentage of non-compliance to the 30 cm minimum legal-size limit reported in both historical creel surveys with 41% and 28.9% of fish landed and measured as part of the survey below this size in 1997/98 and 2000/01 respectively. All data were filtered to lengths ≥ 30 cm for subsequent analysis as there was still presumably some influence of the size limit or angler preferences for larger fish on retention of smaller flathead. Estimated marginal mean contrasts and associated confidence intervals were calculated to assess the significance of size shifts within each region.

Table 4. Mean and standard error of length of flathead (cm, rounded down, with lengths < 30 cm excluded) between surveys by region (following Lyle and Campbell 1999). % change is the percent change of mean size since the historical survey. "Difference" represents the mean difference in length (< 30 cm omitted) between the 2024/25 IMAS fishery-independent survey and the TAFI 1997/98 creel survey (negative values indicate a decline in length since the historical survey). Percent change and mean differences are presented with 95% confidence intervals in parentheses.

Region	Mean length (cm) ± SE		% change	Difference (cm)
	1997/98	2024/25		
Bridport	36.8 ± 0.2	33.1 ± 0.5	-9.9% (-13.0–-6.9%)	-3.7 (-4. 8 – -2.5)
St Helens	34.7 ± 0.3	33.1 ± 0.7	-4.4% (-8.7–-0.1%)	-1.5 (-3.0 – -0.0)
Swansea/Coles Bay	33.9 ± 0.2	32.8 ± 0.4	-3.2% (-5.7–-0.7%)	-1.1 (-1.9 – -0.2)

Table 5. Mean and standard error of length of flathead (cm, rounded down, with lengths < 30 cm excluded) between surveys by region (following Lyle et al., 2002). % change is the percent change of mean size since the historical survey. "Difference" represents the mean difference in length (< 30 cm omitted) between the 2024/25 IMAS fishery-independent survey and the TAFI 2000/01 creel survey (negative values indicate a decline in length since the historical survey). Percent change and mean differences are presented with 95% confidence intervals in parentheses.

	Mean length (cm) ± SE			
Region	2000/01	2024/25	% change	Difference (cm)
North West	34.6 ± 0.3	32.4 ± 0.2	-6.3% (-8.2–-4.5%)	-2.2 (-2.9–-1.5);
East	34.1 ± 0.2	32.8 ± 0.2	-3.9% (-5.6–-2.3%)	-1.3 (-1.9–-0.8);
Great Oyster Bay	32.8 ± 0.1	32.8 ± 0.3	0.0% (-2.0–2.0%)	0.0 (-0.6–0.7);
Norfolk/Frederick Henry Bay	33.4 ± 0.1	31.7 ± 0.3	-5.0% (-6.8–-3.3%)	-1.7 (-2.3–-1.1);
Derwent River/D'Entrecasteaux Channel	33.8 ± 0.2	31.5 ± 0.4	-6.9% (-9.4–-4.4%)	-2.3 (-3.2–-1.5);

Regional length frequencies from historic creel surveys and contemporary fishery-independent surveys are displayed in Figure 12 and Figure 13. Length frequencies for each region are scaled to unit density for the portion of lengths ≥ 30 cm for to allow for direct visual comparisons between surveys among this segment of length frequencies (i.e., on which means were compared).

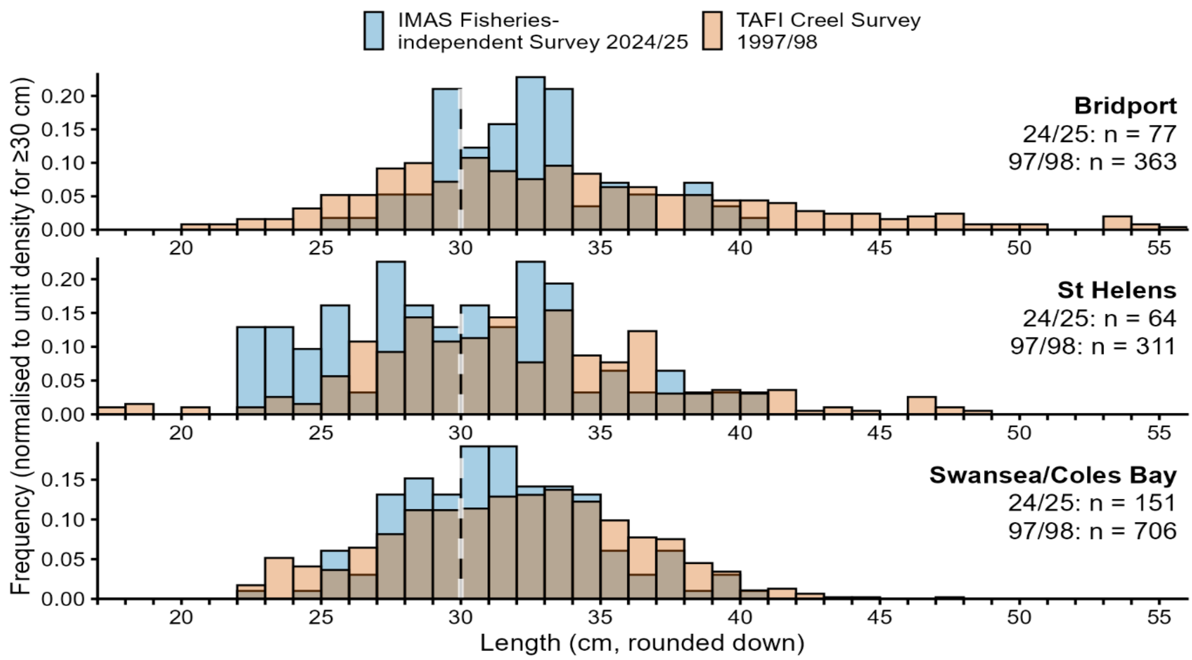


Figure 12. Comparison of Sand Flathead length-frequency distributions between the 1997/98 TAFI Creel Survey (Lyle and Campbell 1999) and the 2024/25 IMAS fishery-independent survey. Histograms are scaled to unit density for bins ≥ 30 cm, the regulated minimum size limit for Sand Flathead at the time of the 1997/98 survey (indicated by the dashed white line). Regional strata are those used by Lyle and Campbell (1999). The IMAS survey regions mapped to each are as follows: Bridport: Bridport; St Helens: St Helens-inside and St Helens-outside; Swansea/Coles Bay: GOB. Total sample sizes by survey are indicated by '*n*'.

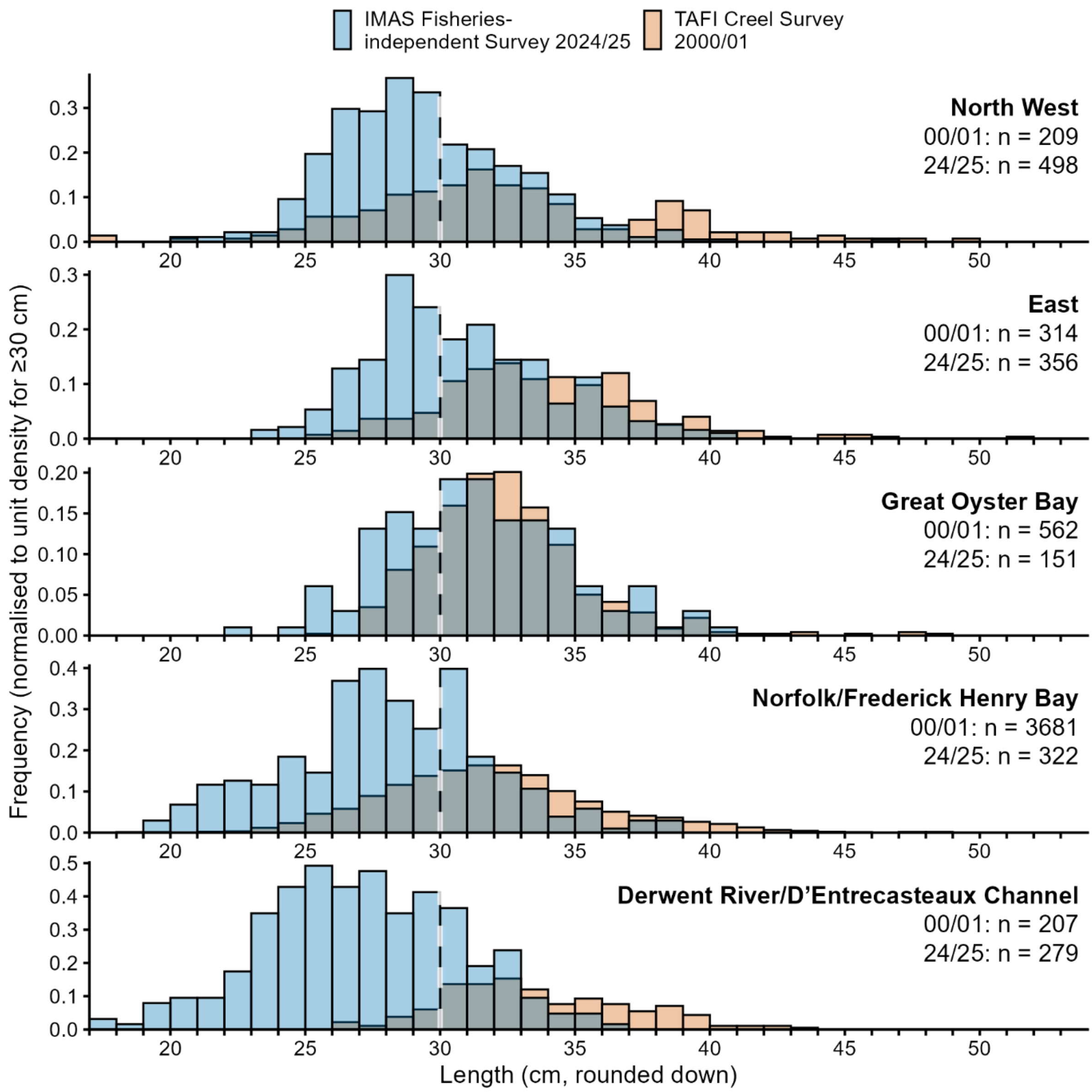


Figure 13. Comparison of Sand Flathead length-frequency distributions between the 2000/01 TAFI Creel Survey and the 2024/25 IMAS fisheries-independent survey. Histograms are scaled to unit density for bins ≥ 30 cm, the regulated minimum size limit for Sand Flathead at the time of the 2000/01 survey (indicated by the dashed white line). Regional strata are those used by Lyle et al. (2002). The IMAS survey regions mapped to each (other than those with the same names, see Figure 16) are as follows: Northwest: Stanley and Tamar-outside; East: St Helens-outside and Mercury Passage; Derwent/D'Entrecasteaux: The Channel. Total sample sizes by survey are indicated by '*n*'.

Contrasts of means reveals Sand Flathead greater than 30 cm were larger on average in all regions across both surveys except Great Oyster Bay from 2000/01 vs 2024/25, where there was little evidence of a difference in means (Table 4). However, the similar comparison of 'Swansea/Coles Bay' in 1997/98 vs the GOB IMAS survey in 2024/25 revealed a 10 mm greater mean length in the historical creel survey (95% CI: 0.2–1.9 cm).

Comparisons between these 1997/98 and 2000/01 TAFI Creel Surveys and the 2024/25 IMAS fishery-independent survey should be interpreted with several limitations in mind. The 2000/01 creel survey was conducted between September 2000 and April 2001, spanning a greater number of months than the January to March IMAS survey period. Finer scale spatial information was not available to fully assess overlap with modern sampling sites. Release rates for Sand Flathead during the creel survey were high (e.g., 48% in the 2000/01 survey), released fish were likely disproportionately smaller individuals; however, restricting analyses to fish ≥30 cm is expected to reduce some of this bias. Gear would have been similar for both surveys, but non-standardised angler behaviour is likely to have favoured the selective targeting and retention of larger fish. It follows that after 30 cm truncation of the data; the historical creel surveys are likely to over-represent larger fish to some degree. Finally, fine-scale location information was not available for the 2000/01 data so actual overlap with IMAS sampling sites could not be assessed nor spatial clustering accounted for (see section 6.2.3.2).

Comparison to Coles Bay 2001–2003 life history sampling length data

A final historical comparison was possible with flathead length data that was collected for life history studies (Bani 2005, Bani et al., 2009). Sampling in this project was conducted in several inshore areas including Georges Bay, Tamar River, Northwest Bay, and Spring Bay, however the only area with sufficient sample size and seasonal and spatial overlap with the IMAS fishery-independent survey regions was Coles Bay, with *n* = 262 lengths measured in January to April (although the IMAS survey is typically completed by March, the latter month was included to maximise the sample size) from 2001 to 2003. To compare to the IMAS survey, GOB sites numbers 41 through 48 were subset as these sites are near the historical sampling location of Coles Bay. To provide sufficient sample size for a robust comparison, the three most recent years available from the IMAS survey (2022/23, 2023/24, and 2024/25) were pooled for the comparison.

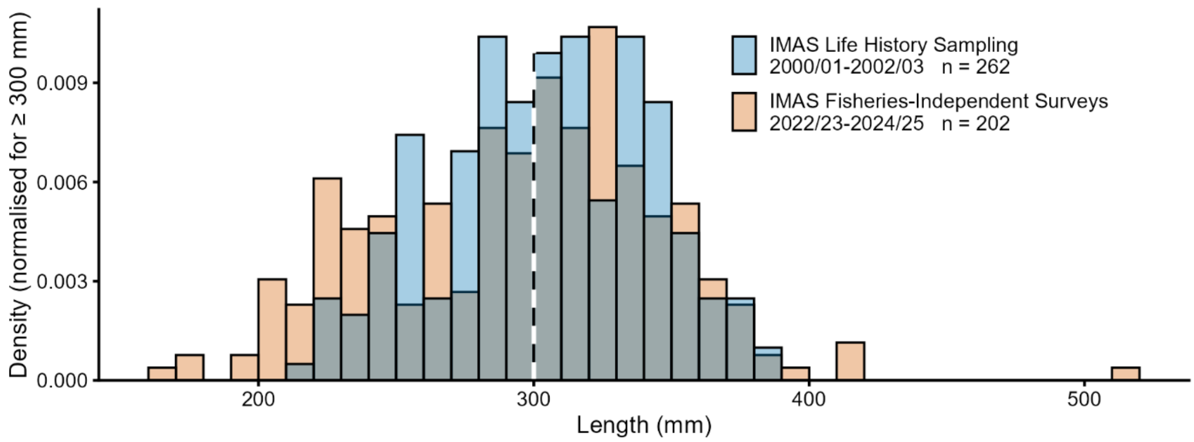


Figure 14. Comparison of Sand Flathead length-frequency distributions in Coles Bay between 2001-2003 collected by Bani et al. (2009), and the three most-recent surveys (pooled) from the IMAS fisheries-independent survey. Histograms are scaled to unit density for bins ≥ 30 cm. Samples for statistical comparison were truncated at 30 cm to account for the historical data collected for life history parameter estimation (i.e., likely involving intentional targeting of small juveniles). Total sample sizes by survey are indicated by '*n*'.

The historical data in this case was collected for life history work with hook and line and possibly gillnet and may have involved targeting smaller individuals for this purpose (i.e., which may have resulted in the bimodal distribution of lengths with mode around 220 mm; Figure 14). For the comparison of mean lengths, data were truncated at 300 mm as with the Creel Survey comparisons to mitigate against the effect of potential targeting of smaller flathead. However, with and without truncation there was not a significant difference in mean Sand Flathead lengths between the historical and modern samples (all data: historical 294.5 mm vs modern 302.6 mm, t = -1.945, p = 0.052, 95% CI of the difference = -16.2–0.084 mm; ≥ 300 mm lengths only: 334.4 mm vs 330.5 mm; t = 1.20, p = 0.232, 95% CI = −2.46–10.11 mm).

4.2.4 Discussion

Overall, comparison of historical biological datasets with contemporary IMAS fishery-independent surveys provides strong evidence that the size composition of Sand Flathead has declined through time across much of Tasmania, with the most consistent and pronounced changes occurring in southeast Tasmania. Across multiple independent data sources spanning the early 1990s to early 2000s, historical populations generally contained larger fish than those observed in recent surveys, indicating a sustained long-term truncation of size structure. This pattern is of direct management relevance because reductions in the abundance of larger and older fish are widely recognised as important indicators of diminished reproductive capacity, reduced age-structure resilience, and increased vulnerability to ongoing exploitation and environmental variability (Berkeley et al., 2004b, Hixon et al., 2014).

The most robust historical comparison was provided by data from the CSIRO Nursery Project data from the early 1990s (Stevens and West, 1993), which enabled spatially harmonised comparisons with contemporary IMAS survey sites in Norfolk Bay and the D'Entrecasteaux Channel. In Norfolk Bay, historical mean lengths exceeded the pooled contemporary period by approximately 29 mm, while in the D'Entrecasteaux Channel the corresponding difference was approximately 39 mm. Importantly, these differences remained evident after multiple sensitivity analyses designed to reduce potential bias associated with gillnet selectivity, including restriction to 2-inch mesh catches and truncation of smaller size classes. The persistence of these effects across alternative model treatments indicates that methodological differences between surveys are unlikely to account for the observed temporal shift, supporting a genuine decline in average size composition through time within these regions.

Comparisons with the 1997/98 and 2000/01 TAFI creel surveys provided further support for broad regional declines in size structure (Lyle and Campbell, 1999, Lyle et al., 2002). Fish retained in historical recreational surveys were larger on average than those measured in contemporary IMAS fishery-independent surveys across most comparable regions, including Bridport, St Helens, Norfolk Bay, the D'Entrecasteaux Channel, the northwest coast, and eastern Tasmania. Mean differences were typically in the order of 10–40 mm. Great Oyster Bay was the principal exception, where little evidence of change was detected in the 2000/01 comparison. A separate comparison with Coles Bay life-history sampling from 2001–2003 similarly suggested relative stability in this region, with no statistically significant difference in mean length between historical and recent samples (Bani, 2005). Collectively, these results indicate that long-term changes in size composition have not been spatially uniform, with southeast Tasmania exhibiting the clearest and strongest evidence of decline.

Interpretation of the creel survey comparisons should acknowledge several limitations. Historical angler-derived datasets may over-represent larger fish due to selective targeting and retention behaviour. Nonetheless, these biases would generally be expected to inflate historical mean size estimates rather than generate false declines consistently across multiple regions and independent datasets, especially as statistical comparisons to creel survey data was limited to fish above the minimum size limit. Accordingly, the repeated directional agreement among data sources remains highly informative. Further, subsequent comparisons between contemporary fishery-dependent frame donation samples and fishery-independent survey data from Tasmania's east coast reported in this study showed that much of the apparent right-shift in retained catch was attributable to the exclusion of sublegal fish rather than strong additional fisher selection among legal-sized fish. This suggests that retained catch samples can provide an incomplete and upwardly biased view for fishers of stock size structure primarily because undersized fish, although common in the population, are absent from landed catches. In practice, fishers may routinely encounter and release many smaller fish yet form perceptions of stock condition mainly from the legal-sized fish they retain. Such cognitive filtering is consistent with concepts of shifting baselines and availability bias, whereby memorable retained catch can disproportionately shape perceptions of population status (Pauly, 1995, Papworth et al., 2009, Jones et al., 2020).

A further notable finding from the historical creel surveys was the substantial retention of sub-legal Sand Flathead, indicating that non-compliance with minimum size regulations has likely contributed to fishing mortality over an extended period. In the 2000/01 creel survey, 28.9% of retained Sand Flathead were below the then minimum legal size of 30 cm (Lyle et al., 2002). Similar concerns were evident in the earlier 1997/1998 survey program, where 41% of retained flathead were undersized (Lyle and Campbell, 1999). These results demonstrate that non-compliance was geographically widespread rather than isolated to a single area, and that realised fishing mortality from the recreational sector may have remained materially higher than assumed under full compliance.

Importantly, perceptions of ongoing non-compliance persist within the contemporary recreational sector. In the 2023 IMAS survey of recreational fishers, although around three in four respondents agreed that most fishers comply with fishing rules, this implies that approximately one quarter of respondents did not share that view, indicating continued concern that a meaningful minority of fishers are not adhering to regulations (Tracey et al., 2023). The same survey also found strong support for increased compliance checks and enforcement, reinforcing that rule adherence remains an active management issue within the fishery. For a species already showing evidence of long-term size truncation and demographic stress, persistent removal of undersized fish would be expected to slow rebuilding, reduce recruitment into larger spawning classes, and weaken the effectiveness of management controls.

From a broader fisheries perspective, the patterns observed are consistent with prolonged size-selective fishing pressure leading to truncation of size structures of the stock, whereby populations become increasingly dominated by smaller and younger fish (Law, 2000, Hixon et al., 2014). Over extended timeframes, such processes may also contribute to altered growth and maturation schedules through fisheries-induced evolutionary or plastic responses, although this chapter does not directly test those mechanisms (Olsen et al., 2004, Heino and Dieckmann, 2009). Regardless of mechanism, the contemporary stock structure differs materially from that observed in previous decades.

The historical perspective developed in this chapter is therefore important because it helps counter shifting baseline effects and generational loss of historical perspective, whereby progressively reduced fish size and abundance can become normalised over time (Pauly, 1995, Sáenz-Arroyo et al., 2005, Jones et al., 2020). Present-day stock structure should not be assumed to represent a natural or acceptable reference condition. Rather, the evidence indicates that meaningful rebuilding of the Sand Flathead stock should include recovery not only in abundance, but also in size composition, age structure, and the contribution of larger, more fecund fish to the spawning population. These attributes are likely to be central to restoring productivity, resilience, and long-term fishery quality in Tasmania.

5 Objective 2: Determine the spatial and temporal variability of key life history characteristics and population structures of Sand Flathead

5.1.1 Introduction

Understanding spatial and temporal variation in life-history characteristics is fundamental to assessing stock condition, productivity, and rebuilding potential in exploited fisheries. Variation in growth, longevity, maturation schedules, size composition, and sex structure can strongly influence reproductive output, resilience to fishing pressure, and the capacity of stocks to recover following depletion (Beverton and Holt, 1957, Stearns, 1998, Hutchings, 2005). Where substantial regional heterogeneity exists, statewide averages may mask important localised declines or differences in productivity, potentially leading to ineffective management responses. This issue is increasingly recognised globally, with studies demonstrating that biologically meaningful variation often occurs at finer spatial scales than traditional management boundaries, creating potential mismatches between stock structure and management units (Olsen et al., 2004, Kuparinen et al., 2016b, Wright et al., 2021). Similar challenges have been documented in Australian coastal fisheries, where regional differences in recruitment, growth, connectivity and exploitation patterns can be pronounced, reinforcing the need for spatially explicit monitoring and management responses (Moore et al., 2018).

Previous chapters identified evidence of long-term decline in stock condition, particularly in southeast Tasmania, including reduced catches, truncated size structure, and historical loss of larger individuals. Understanding whether these patterns are also reflected in regional life-history characteristics is critical for evaluating rebuilding options and determining whether management should be spatially differentiated.

Fishery-independent surveys undertaken by IMAS since 2012 provide the first standardised statewide opportunity to compare population characteristics among Tasmanian regions (Ewing et al., 2014). These surveys commenced in three long-term regions (D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays, and Great Oyster Bay) and were subsequently expanded to include Flinders Island, Bridport, St Helens, Mercury Passage, Tamar Estuary, and the northwest coast.

This chapter uses these surveys to quantify spatial and temporal variability in key biological characteristics of Sand Flathead, including length structure, age composition, growth, length-weight relationships, and sex ratios. The analyses provide important context for understanding regional productivity, identifying areas of demographic truncation, and informing rebuilding targets and future harvest strategies.

5.1.2 Methods

5.1.2.1 Survey design and biological sampling

Sand Flathead were sampled during standardised fishery-independent hook-and-line surveys conducted between 2011/12 and 2024/25. Sampling was undertaken primarily during January to March to maximise seasonal consistency among years and regions. Surveys initially focused on the three long-term southeast and east coast regions (Ewing et al., 2014) in the D'Entrecasteaux Channel (DEC), Fredrick Henry and Norfolk Bay (FH-NB) and Great Oyster Bay (GOB). In 2021, regions were expanded to include additional Tasmanian regions, including Mercury Passage (MP), St Helens, Bridport, Tamar Estuary, and Stanley (Figure 15; Figure 16). Fishing was generally conducted within a maximum of three (not necessarily consecutive) days per region, with between 15–21 sites fished in each region. Samples were also opportunistically and haphazardly collected from around Flinders Island in February and October 2023 and February and December 2024. Sites within the sampled regions were chosen to represent a range of suitable habitats (including depths) for targeting Sand Flathead and to provide wide spatial coverage within the given region (Figure 15; Figure 16).

At each site, standardised hook-and-line methods were used a two-snood paternoster rig, each with a suicide style hook (size 3/0) baited with squid. All captured Sand Flathead were measured for total length (mm). Where retained for biological analysis, fish were sexed, weighed, and sagittal otoliths removed for age determination.

Each site was fished concurrently by three fishers for 30 minutes, with the vessel allowed to drift. All captured Sand Flathead were measured for total length (mm). The first 100 Sand Flathead landed in the DEC, FH-NB and GOB and the first 80 fish landed within each of the other regions were retained for biological analysis, with fish sexed, weighed, and sagittal otoliths removed for age determination.

Otoliths were cleaned, dried, stored individually, embedded in epoxy resin, and sectioned transversely through the nucleus. Sections were mounted on microscope slides using clear casting medium, covered with a coverslip, and digitally imaged using a Leica DFC 450C camera mounted on a Leica MZ12.5 stereo microscope at 20–25× magnification.

Age was estimated by experienced readers from the number of opaque zones visible in sectioned otoliths, with edge type recorded as narrow translucent, wide translucent, or opaque, following the protocol developed for Sand Flathead by Jordan (1998). A reference library of 100 randomly selected otoliths was maintained for reader training, calibration, and routine checks of ageing precision to minimise reader drift through time. Each fish was assigned a decimal age based on date of capture, opaque zone count, seasonal timing of annulus formation, and an assumed birth date of 1 October.

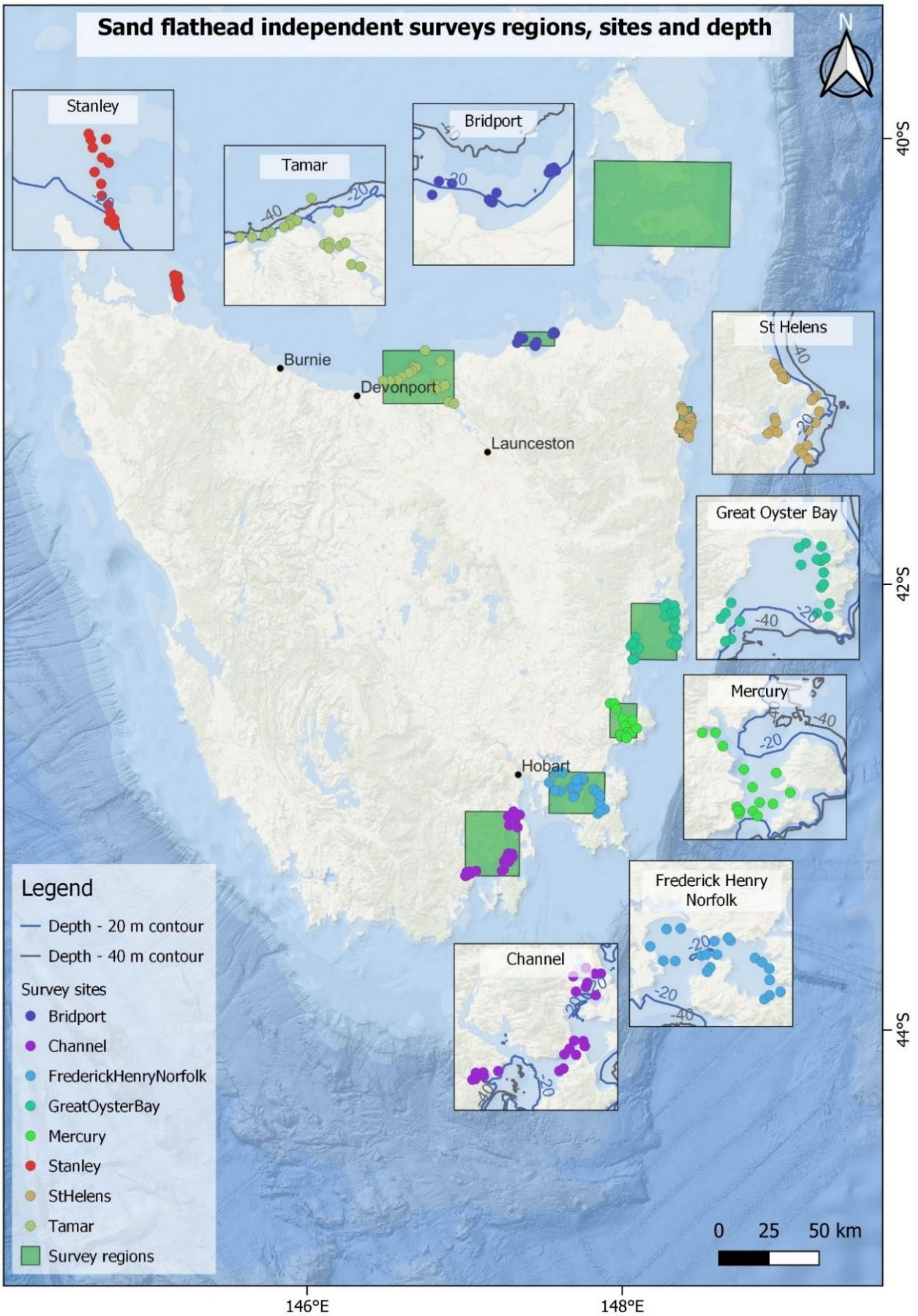


Figure 15. The nine Sand Flathead fishery-independent sampling regions, sites and depth around Tasmania: (1) D'Entrecasteaux Channel, (2) Frederick Henry-Norfolk Bay, (3) Mercury Passage, (4) Great Oyster Bay, (5) St Helens, (6) Bridport, (7) Tamar Estuary, and (8) Stanley. Flinders Island sites were sampled haphazardly.

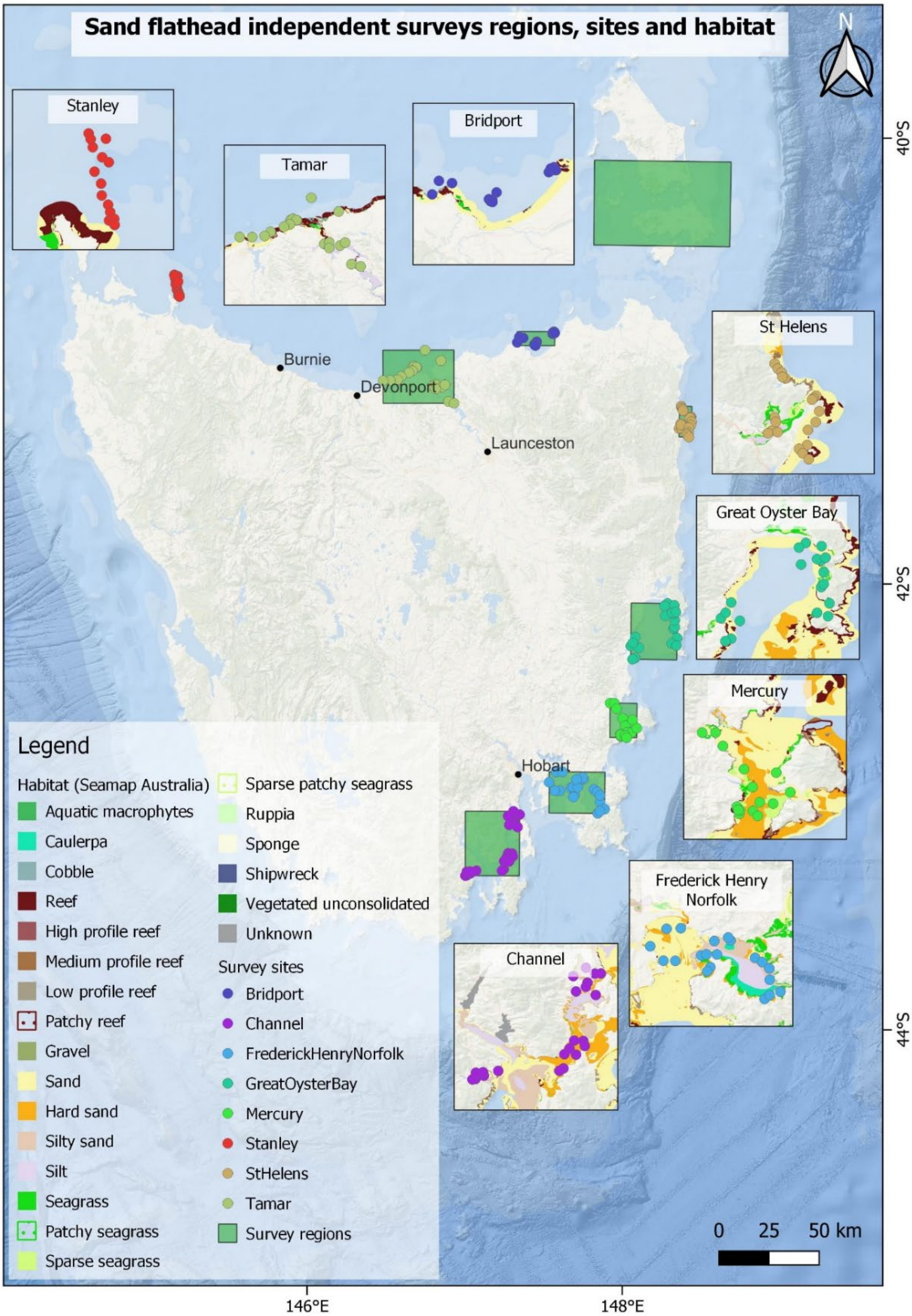


Figure 16. The nine Sand Flathead fishery-independent sampling regions, sites and habitat around Tasmania: (1) D'Entrecasteaux Channel, (2) Frederick Henry-Norfolk Bay, (3) Mercury Passage, (4) Great Oyster Bay, (5) St Helens, (6) Bridport, (7) Tamar Estuary, and (8) Stanley. Flinders Island sites were sampled haphazardly.

5.1.2.2 Analytical overview

Length and age composition

Regional and sex-specific population structure of Sand Flathead was examined using length- and age-frequency distributions derived from fishery-independent survey data. Length- and age-frequency distributions for females and males within each region were visualised using smoothed density curves generated from binned data and smoothed with a Gaussian kernel to facilitate comparison of distributional patterns among regions and between sexes. For length-frequency plots, vertical dashed lines indicate sex-specific median lengths within each region, while a vertical dotted line denotes the current minimum legal-size limit (350 mm). For age-frequency plots, vertical dashed lines indicate sex-specific median ages. Sample sizes and median values are presented within each panel.

Differences in length and age distributions between females and males within each region were formally tested using two-sample Kolmogorov–Smirnov (*KS*) tests, which assess overall differences in distribution shape, location and spread. Statistical significance was assessed at $\alpha = 0.05$. Summary statistics, including sample size (*n*), minimum, maximum, mean and median values, were calculated separately for each sex within each region for both length (mm) and age (years). All analyses in this and subsequent sections were conducted in R (R Core Team, 2024).

Length–weight relationships

Length–weight relationships (LWRs) were analysed to examine regional and sex-specific patterns in morphology and/or body condition of Sand Flathead collected during fishery-independent surveys around Tasmania. Prior to analysis, data were screened for anomalous observations using a global log–log regression of weight against length. Standardised residuals were calculated, and individuals with absolute residuals greater than three were treated as outliers and excluded. For each region and sex, LWRs were described using the power function $W = aL^b$ where W is total weight (g), L is total length (mm), $a$is the intercept, and b is the allometric growth exponent. The relationship was fitted as a linear model on log-transformed data $\log(W) = \log(a) + b\log(L)$, with separate models fitted for females and males within each region.

Differences in LWRs among regions and between sexes were tested using analysis of covariance (ANCOVA) $\log(W) \sim \log(L) \times Sex \times Region$. Significant interactions between log-transformed length and explanatory variables were interpreted as differences in the allometric exponent (b), while main effects of sex and region were interpreted as differences in intercepts (i.e. weight-at-length). Model significance was assessed using F-tests at $\alpha = 0.05$. Region- and sex-specific estimates of $b$were extracted from fitted models, with 95% confidence intervals calculated from the standard errors of regression coefficients. These estimates were used to quantify and visualise spatial variation in growth scaling among regions.

Growth analysis

Prior to fitting growth models, we assessed whether age structure and growth relationships varied among years within each region and sex to determine whether pooling data across years was appropriate. Analyses were conducted separately for each region–sex combination after excluding fish collected from estuarine inside sites (Tamar-Inside and St Helens-Inside). Interannual differences in age structure were tested using Kruskal–Wallis tests, with Age as the response variable and Year as the grouping factor. This non-parametric approach was used because age data were discrete and often non-normally distributed. Interannual differences in growth (length-at-age relationships) were examined using analysis of covariance (ANCOVA), with Length (mm) modelled as a function of Age, Year, and their interaction: $Length \sim Age \times Year$. The Age × Year interaction tested for differences in growth rate among years; where non-significant, it was removed and the main effect of Year was used to test for differences in mean length-at-age. Statistical significance was assessed at α = 0.05, with *p*-values adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate procedure.

Although interannual differences in age composition and, in some cases, length-at-age relationships were detected, year-specific datasets were often characterised by limited sample sizes and truncated age distributions, particularly for older fish. These constraints frequently produced unstable or biologically unrealistic parameter estimates when von Bertalanffy growth functions (VBGFs) were fitted separately by year. Data were therefore pooled across all available years within each region and sex to maximise sample size, improve representation across the full age range, particularly older individuals, and enhance parameter estimation, model stability and convergence. This approach was considered appropriate because annual samples were often sparse and unevenly distributed across ages, limiting reliable estimation of year-specific VBGFs. Resulting pooled growth curves were interpreted as integrated mean growth trajectories across the sampling period rather than evidence of temporally invariant growth.

Sex-specific growth curves were estimated for each region using non-linear least squares regression to fit the von Bertalanffy growth function: $L_t = L_\infty(1 - e^{-k(t-t_0)})$ where L_t is length at age t, L_∞ is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at zero length. For each region and sex, two formulations were fitted: (1) an unconstrained model in which all parameters were freely estimated, and (2) a constrained model with $t_0 = 0$ to reduce parameter uncertainty and facilitate regional comparison. Models were compared using Akaike Information Criterion (AIC) and likelihood ratio tests (LRTs), with the constrained model preferred where fit was comparable (ΔAIC ≤ 2) and parameter interpretation improved. Prior to modelling, anomalous observations were identified using a global log–log length–weight regression, and individuals with standardised residuals exceeding ±3 were excluded. Length-at-age data from all survey years (2021–2025, and from 2012 onward in the three long-term eastern and south-eastern regions) were then pooled within regions for growth analyses.

Spatial and sex-specific differences in growth were evaluated using a hierarchical modelling framework. Sex effects were first tested within each region by comparing models with shared parameters across sexes against models allowing sex-specific L_∞ and k (and t_0 where unconstrained). Regional variation was then examined by comparing pooled-region models with models allowing region-specific growth parameters. Additional comparisons were undertaken for adjacent estuarine and coastal systems (e.g. Tamar River and Georges Bay/St Helens), and alternative structures were considered where t_0 was fixed at zero but L_∞ and k varied among regions or sexes. Model selection was based on LRTs, AIC, and biological plausibility of parameter estimates. Diagnostic checks included inspection of fitted curves against observed data, residual patterns, and convergence behaviour. Uncertainty in pooled growth curves was quantified using bootstrapped confidence intervals generated by resampling regional datasets and refitting VBGFs.

To assess whether regional differences in growth patterns were influenced by unequal age composition, a shared age-range sensitivity analysis was undertaken for both constrained and unconstrained VBGFs. For each sex, the overlapping age range common to all nine regions was identified and models were refitted using only fish within that interval. The shared range was 2.15–8.55 years for females and 2.35–10.46 years for males.

Potential pooling of spatial regions for estimation of growth parameters was also evaluated using unconstrained VBGFs fitted to grouped and individual regions within five predefined spatial categories: south-east (D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays), east (Great Oyster Bay and Mercury Passage), north-east (St Helens and Bridport), north/north-west (Tamar and Stanley), and Flinders Island. Flinders Island was treated as a standalone region and excluded from pooling tests. Analyses were conducted separately for females and males, with data restricted to the shared age range within each grouping to ensure comparability. For each grouping, a pooled model assuming common growth parameters was compared with a region-specific model allowing separate L_∞, k, and t_0 estimates. Model performance was assessed using LRTs and AIC, with ΔAIC calculated as $AIC_{pooled} - AIC_{separate}$, where positive values support region-specific models. Pooling was considered justified where LRT results were non-significant ($p \geq 0.05$) and/or ΔAIC values were small (<2), while values of 2–10 indicated weak to moderate evidence against pooling and values >10 indicated strong support for retaining region-specific growth parameters.

Sex ratios

Sex ratios were analysed to characterise spatial and temporal variation in population structure and to examine relationships between sex composition and size distribution. Analyses were based on fishery-independent survey data collected across nine coastal regions around Tasmania. To ensure comparability among marine populations, estuarine sites (Tamar Estuary and Georges Bay) were excluded, and analyses were restricted to coastal sampling locations outside the Tamar River and coastal St Helens regions. Only individuals with recorded sex were retained, with sex coded as a binary response (female = 1, male = 0). Data were aggregated by region, year, and length class as appropriate for subsequent analyses.

Spatial and temporal variation in sex ratios was assessed using a generalised linear model (GLM) with binomial error structure and logit link, specified as $Sex \sim Region + Year$ where the response represented the probability of an individual being female. Region was treated as a categorical predictor and Year as a fixed effect. Model significance was evaluated using Wald tests, and fitted values were used to interpret differences in sex ratio among regions and through time.

Sex ratios were also calculated directly as the proportion of females within each region and year, with uncertainty quantified using the binomial standard error:

$$SE = \sqrt{\frac{p(1-p)}{n}}$$

where p is the proportion of females and n is sample size. Approximate 95% confidence intervals were calculated as $p \pm 1.96 \times SE$. These estimates were used to visualise regional and temporal patterns in sex composition and to support interpretation of model outputs.

To align with the proposed monitoring framework and evaluate broader-scale patterns, regions were additionally grouped into five spatial categories: south-east (D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays), east (Great Oyster Bay and Mercury Passage), north-east (St Helens and Bridport), north/north-west (Tamar and Stanley), and Flinders Island. Sex ratios were recalculated for these pooled regions, and temporal trends were visualised using annual estimates with binomial confidence intervals to assess whether aggregation preserved key spatial patterns.

Relationships between sex ratio and size structure were examined by grouping individuals into 25 mm length classes based on total length (mm). Within each region and pooled region, the proportional contribution of each sex within a length class was calculated as:

$$p_{sex} = \frac{n_{sex}}{n_{total}}$$

where n_{sex} is the number of individuals of a given sex within a length class and n_{total} is the total number of individuals in that class. These proportions were used to characterise sex-specific size distributions and assess whether spatial variation in sex ratio was associated with differences in length structure across the population.

5.1.3 Results

A total of 6,936 Sand Flathead were collected during annual fishery-independent surveys conducted around the southeast of Tasmania between 2012–2025 across three regions (Channel, Frederick Henry-Norfolk Bays, Great Oyster Bay) and the expanded survey area of an additional six regions around the state from 2021–2025. Fish ranged in size from 121 to 554 mm TL and in age from 0 to 20 years (Table 6).

Table 6. The total number (*n*), minimum (Min), maximum (Max) and mean total lengths (TL, mm) and ages (years) of Sand Flathead caught from six locations within five regions around Tasmania from 2021 – 2025, and from 2012 – 2025 for three long-term SEC/EC locations (Channel, Frederick Henry-Norfolk Bay, GOB).

Region	Location	*n*	Min TL	Max TL	Mean TL	Min Age	Max Age	Mean Age
SEC	Channel	1,435	121	390	267	0	11	5
	Fred-Norfolk Bay	1,462	171	426	277	1	12	5
EC	Great Oyster Bay	1,529	211	500	301	2	14	5
	Mercury Passage	408	208	394	306	1	10	5
	St Helens	369	183	407	292	1	15	5
NEC	Bridport	392	218	443	310	1	11	4
	Tamar	523	179	458	282	1	13	4
NWC	Stanley	400	200	435	301	2	17	5
FI	Flinders Island	418	215	554	379	2	20	7

5.1.3.1 Regional length structure

Northern and northeastern regions generally supported larger fish. At Bridport, 47% of fish exceeded 320 mm and 21% exceeded 350 mm, while at Stanley the corresponding values were 19% and 8%. Flinders Island exhibited the largest overall size structure, with 76% of fish ≥320 mm and 53% ≥350 mm, together with strong representation of older, larger individuals (Table 8; Figure 17).

Marked regional variation in Sand Flathead length structure was evident across Tasmania. South-eastern regions, particularly the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays, consistently exhibited the smallest fish and the lowest proportion of legal-sized individuals. Mean lengths in these regions were approximately 267 mm and 277 mm, respectively (Table 6). Within all regions, females were consistently larger than males, with median lengths exceeding those of males and length-frequency distributions shifted toward larger size classes. Kolmogorov–Smirnov tests confirmed significant sex differences in length distributions throughout Tasmania (all $p < 0.001$; Table 7; Figure 17). Across all regions, fish above both minimum size limits were overwhelmingly female, comprising 100% of individuals ≥350 mm in most regions and 83% at Stanley and Flinders Island.

Table 7. Results of Kolmogorov–Smirnov (KS) tests comparing length and age distributions between females and males of Sand Flathead across nine regions around Tasmania. *D* represents the KS test statistic. Significant values ($p < 0.05$*) indicate differences in distributions between sexes. *n* = sample size

Region	*n*F	*n*M	Length KS *D*	Length *p*	Age KS *D*	Age *p*
Channel	1,036	399	0.219	**<0.001***	0.157	**<0.001***
Frederick Henry-Norfolk Bays	884	578	0.178	**<0.001***	0.198	**<0.001***
Mercury Passage	305	103	0.221	**<0.001***	0.296	**<0.001***
Great Oyster Bay	1,227	302	0.371	**<0.001***	0.243	**<0.001***
St Helens	120	63	0.327	**<0.001***	0.100	0.761
Flinders Island	273	145	0.378	**<0.001***	0.117	0.135
Bridport	222	170	0.228	**<0.001***	0.279	**<0.001***
Tamar	155	184	0.239	**<0.001***	0.188	**0.004***
Stanley	253	147	0.242	**<0.001***	0.141	**0.044***

Length-frequency distributions relative to both the current (350 mm TL) and previous (320 mm TL) minimum legal sizes further highlighted pronounced regional contrasts (Table 8). In the Channel and Frederick Henry–Norfolk Bays, 94–95% of fish were <320 mm and 98–100% were <350 mm, leaving ≤2% of individuals above the current minimum size limit. Similarly, in the Tamar, most fish also occurred below both thresholds. Mercury Passage and St Helens showed intermediate but still truncated size structures, with 71–73% of fish <320 mm and 86–89% <350 mm. Great Oyster Bay was comparatively stronger than southeast Tasmania, although 63% of fish remained <320 mm and 86% <350 mm.

By contrast, northern and northeastern regions generally supported larger fish. At Bridport, 47% of fish exceeded 320 mm and 21% exceeded 350 mm, while at Stanley the corresponding values were 19% and 8%. Flinders Island exhibited the largest overall size structure, with 76% of fish ≥320 mm and 53% ≥350 mm, together with strong representation of older, larger individuals (Table 8; Figure 17).
These results indicate substantial statewide heterogeneity in stock structure and suggest southeast Tasmania has experienced the greatest long-term truncation of the age frequency distributions.

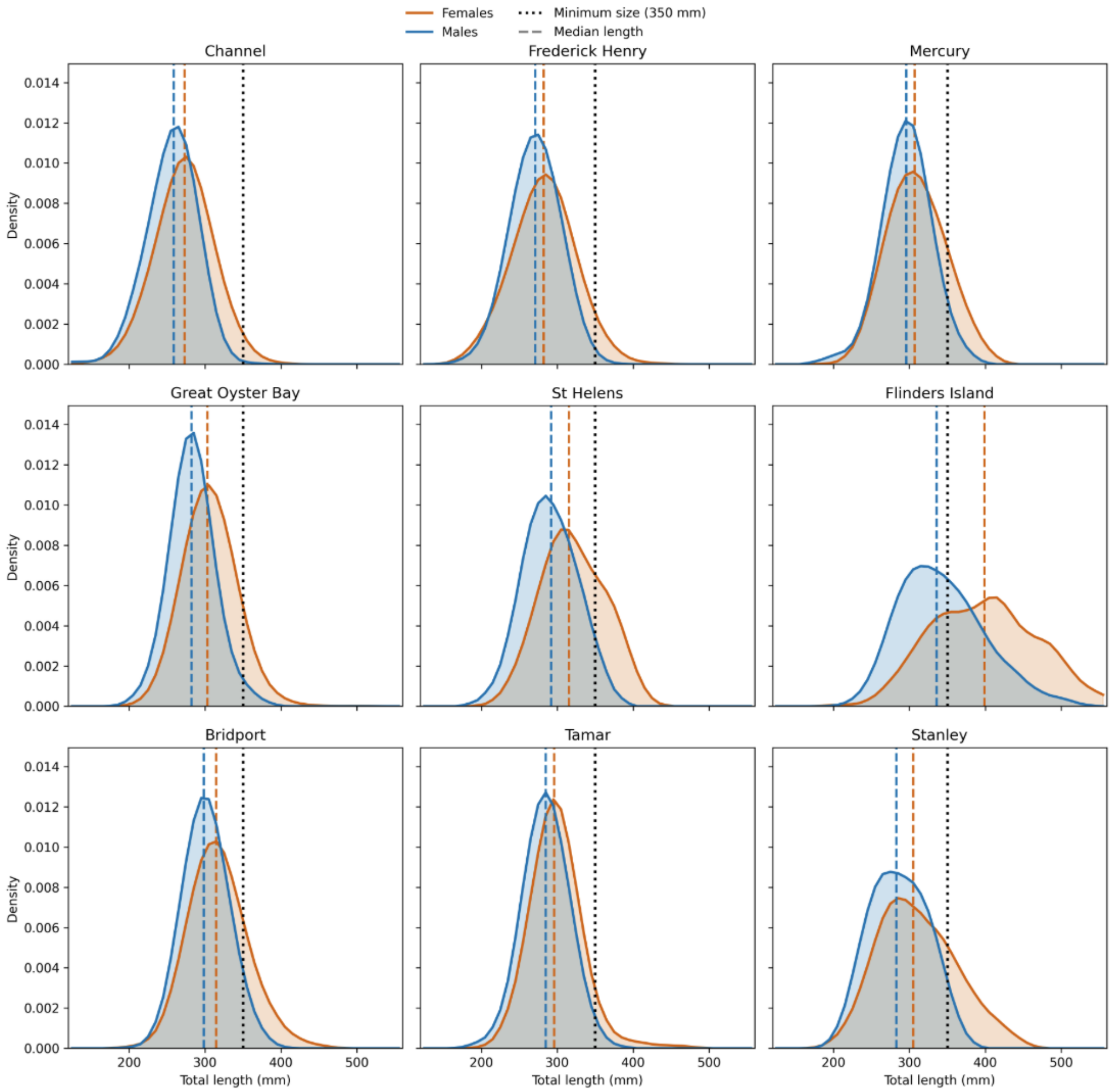


Figure 17. Sex-specific length-frequency density distributions for Sand Flathead from nine regions around Tasmania. Panels are arranged geographically from south-east to north-west. Shaded curves represent smoothed density distributions for females and males. Dashed vertical lines indicate sex-specific median lengths (coloured by sex), and the dotted vertical line represents the current minimum legal-size limit (350 mm). Axes are standardised across panels, and sample sizes and median lengths for each sex are shown within panels.

Table 8. The number (*n*) and percentage of Sand Flathead below and above the minimum size limit (MSL) of 320 mm (until May 2023) and 350 mm (from May-2023) caught at nine locations within five regions around Tasmania in 2025. %F denotes the percentage of females.

Region	Location	< 320 mm			> 320 mm			< 350 mm			> 350 mm		
		n	**%**	**%F**	***n***	**%**	**%F**	***n***	**%**	**%F**	***n***	**%**	**%F**
SEC	Channel	94	94	66	6	6	100	100	100	68	0	0	N/A
	Nor-Fred	95	95	73	5	5	80	99	99	73	1	1	100
EC	Mercury	57	71	60	23	29	91	72	86	65	8	10	100
	GOB	62	63	74	37	37	97	85	86	80	14	14	100
	St Helens	47	73	55	17	27	71	57	89	54	7	11	100
NC	Bridport	39	53	46	34	47	94	58	79	60	15	21	100
	Tamar	90	81	43	21	19	71	109	98	48	2	2	100
NWC	Stanley	65	81	52	15	19	73	74	93	54	6	8	83
FI	Flinders Is.	13	24	54	42	76	79	26	47	61	29	53	83

5.1.3.2 Age composition

Age-frequency distributions showed pronounced regional variation, with clear spatial structuring evident across Tasmania (Figure 18; Table 6). South-eastern regions (e.g., Channel, Frederick Henry–Norfolk Bays, Mercury Passage) were characterised by truncated age distributions dominated by younger individuals, with relatively narrow ranges and low representation of older age classes. In contrast, northern regions, particularly Flinders Island and Stanley, exhibited broader age distributions extending to substantially older individuals, indicating greater longevity and a stronger presence of older cohorts.

The oldest fish recorded in the surveys was 20 years from Flinders Island, followed by 17 years at Stanley, 15 years at St Helens, and 14 years at Bridport (Table 6). Fish aged 10 years or older were uncommon in southeast Tasmania but occurred more regularly in northern regions, particularly Flinders Island, Stanley, St Helens, and Bridport.

In contrast to length structure, where females were consistently larger than males, age structure showed a different pattern. Median and maximum ages were consistently higher in males across all regions, indicating a greater representation of older individuals in male samples (Figure 18). This decoupling between size and age suggests sex-specific growth and/or mortality dynamics, whereby females attain larger sizes at younger ages, while males persist to older ages but at smaller asymptotic sizes.

Collectively, these patterns indicate stronger survival to older age classes in northern Tasmania and reduced representation of older fish in southeast Tasmania, consistent with regional differences in mortality and exploitation history.

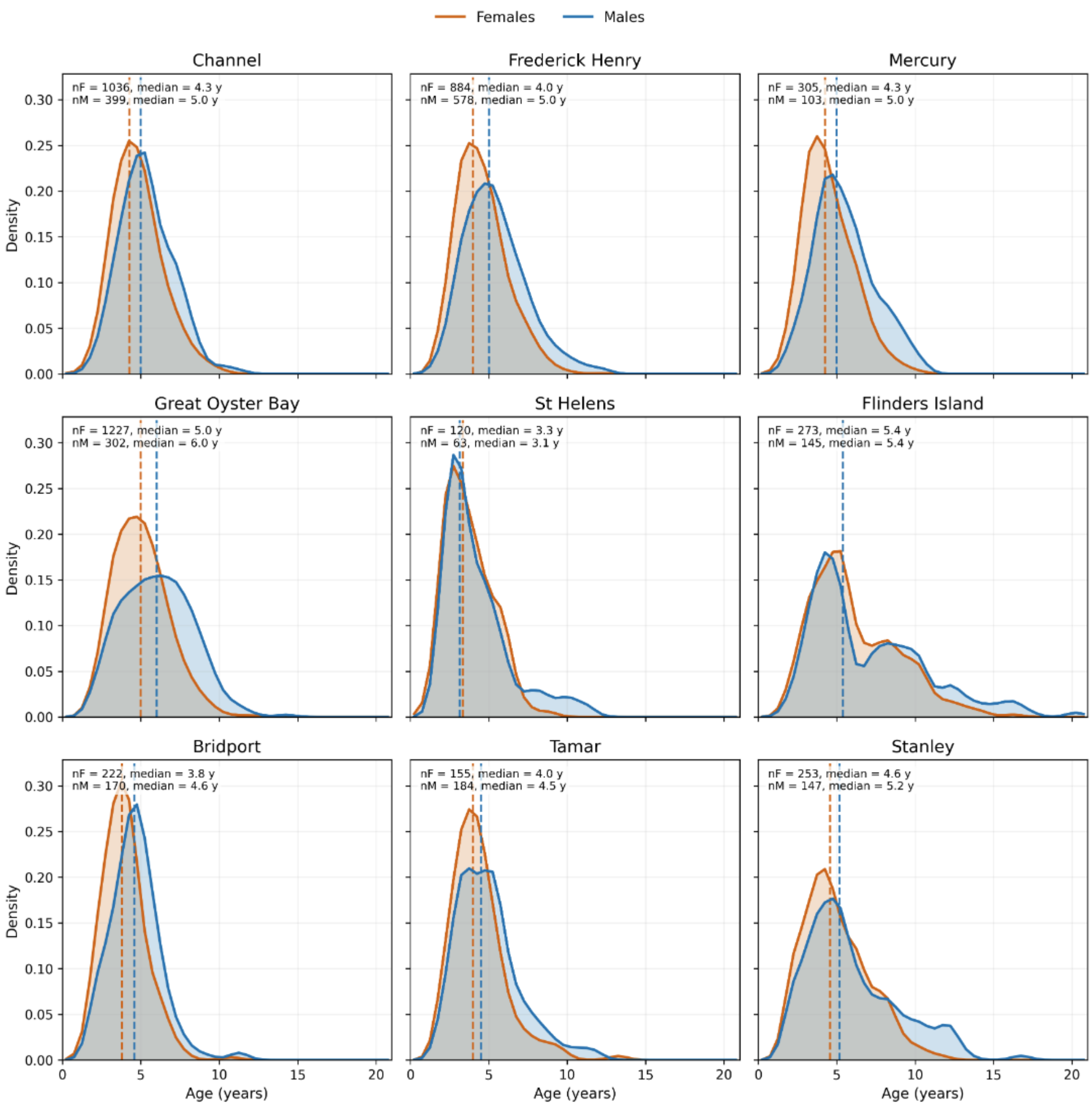


Figure 18. Sex-specific age-frequency density distributions for Sand Flathead from nine regions around Tasmania. Panels are arranged geographically from south-east to north-west. Shaded curves represent smoothed density distributions for females and males, with dashed vertical lines indicating sex-specific median ages. Axes are standardised across all panels, and sample sizes and median ages for each sex are shown within panels.

5.1.3.3 Length–weight relationships

Length-weight relationships differed significantly among regions and between sexes, although slopes were broadly similar statewide (Table 9). Following removal of 0.7% outliers, 6,886 fish were retained for analysis, comprising 4,687 females and 2,199 males. Females were generally heavier than males at equivalent length, particularly at larger sizes, with a slightly steeper allometric exponent (b = 3.170, R^2 = 0.974) than males (b = 3.117, R^2 = 0.958). Both sexes exhibited positive allometric growth (b > 3), indicating weight increased disproportionately with length (Figure 19).

Regional intercept differences were statistically significant, indicating modest spatial variation in body condition and morphology among areas (Figure 20). Fish from northern and northeastern regions generally tended to be heavier at a given length than those from some southern regions, although the magnitude of these differences was small relative to the much stronger statewide contrasts in size structure, age composition, and growth. Accordingly, while condition varied among regions, regional productivity differences were more strongly expressed through variation in length, age, and growth than through weight-at-length alone.

Table 9. Results of analysis of covariance (ANCOVA) testing the effects of sex and region on length–weight relationships of Sand Flathead. Significant interactions between log-transformed length and explanatory variables indicate differences in the allometric exponent (*b*). Statistical significance (*) assessed at α = 0.05.

Parameter/ Interaction	**df**	***F***	***P***
Sex	1	7.89	**0.005***
Region	8	125.89	**<0.001***
Sex × Region	8	2.09	**0.033***
log(L)	1	180971.26	**<0.001***
log(L) × Sex	1	1.73	0.188
log(L) × Region	8	5.97	**<0.001***
log(L) × Sex × Region	8	0.44	0.900
Residual	6485		

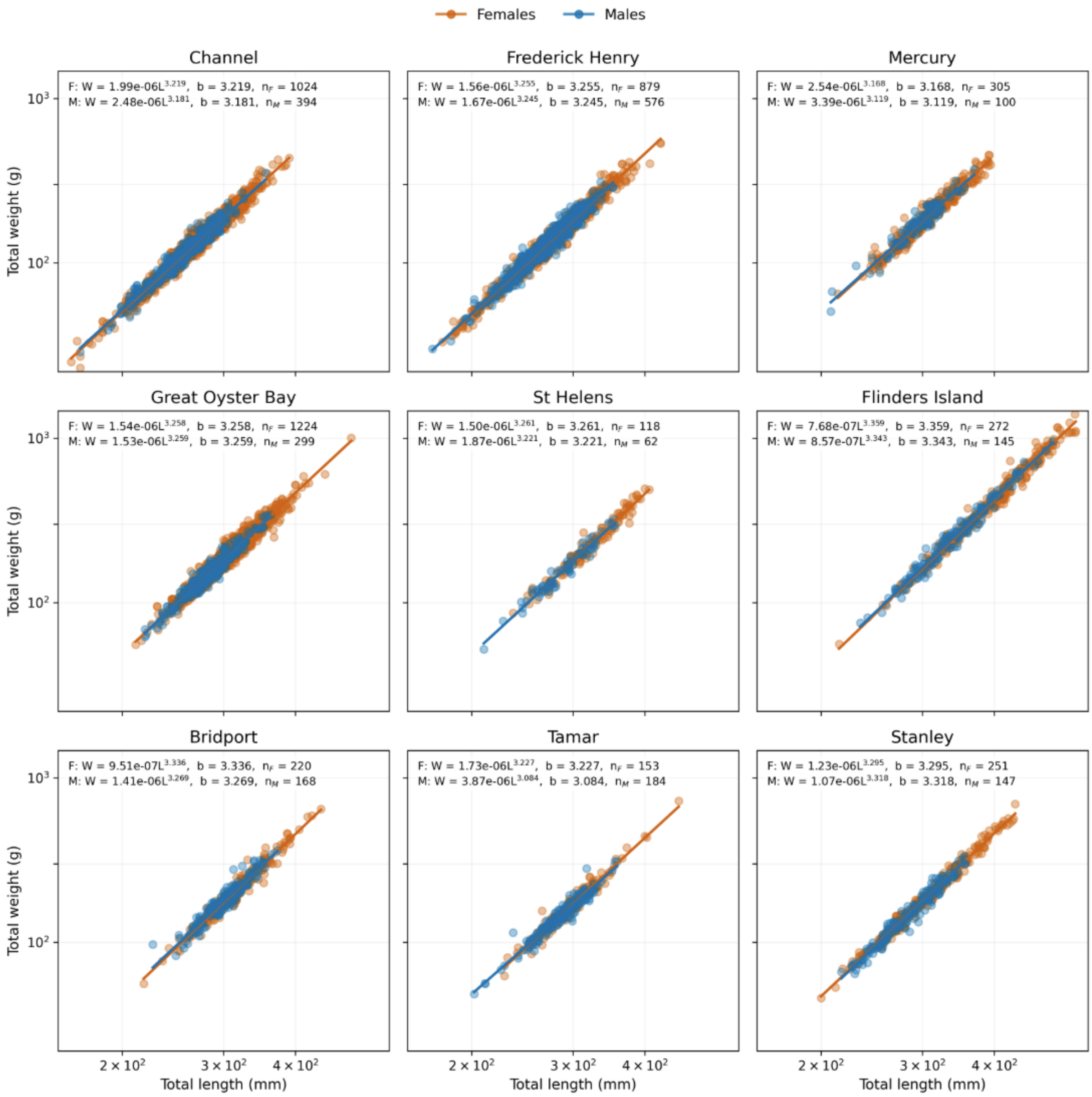


Figure 19. Sex-specific regional length–weight relationships for Sand Flathead collected during fishery-independent surveys from nine regions around Tasmania. Panels are arranged geographically from south-east to north-west. Points represent individual fish and coloured lines represent sex-specific fitted length–weight relationships for females and males. The fitted regression equation, allometric exponent (b), and sample sizes for females (nF) and males (nM) are shown within each panel. Both axes are plotted on logarithmic scales, and axis labels are shown on outer panels only.

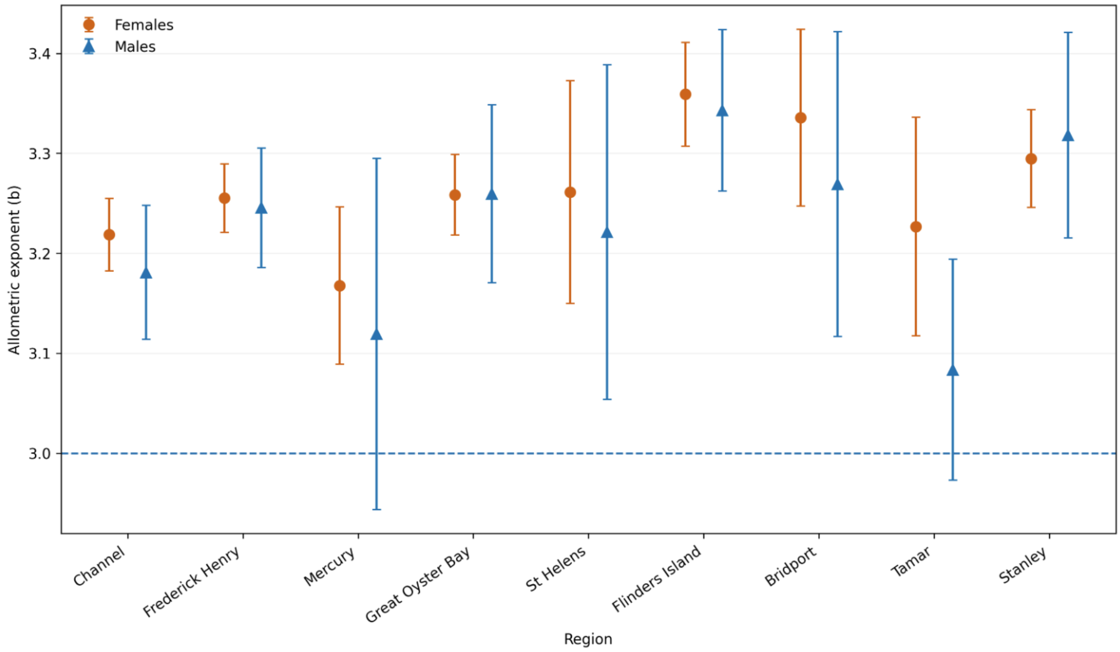


Figure 20. Regional comparison of the allometric exponent (*b*) from sex-specific length–weight relationships of Sand Flathead estimated using the model $W = aL^b$. Points represent slope estimates from log-transformed regressions for females (circles) and males (triangles) within each region. Error bars indicate 95% confidence intervals. Regions are ordered geographically from south-east to north-west. The dashed horizontal line indicates the isometric growth expectation ($b = 3$).

5.1.3.4 Interannual growth variability and justification for pooling years

Prior to fitting pooled regional growth models, annual variation in age composition and length-at-age relationships were examined within each region and sex to assess whether year-specific growth models were justified (Appendix Figure 85; Appendix Figure 86; Appendix Table 37). Kruskal–Wallis tests indicated significant interannual differences in age composition for 14 of 18 region–sex combinations, demonstrating that cohort structure frequently varied among years. The strongest evidence of annual shifts in age composition occurred in Great Oyster Bay females ($\chi^2 = 22.6$, $p < 0.001$), followed by the Channel females ($\chi^2 = 21.3$, $p < 0.001$), Great Oyster Bay males ($\chi^2 = 20.4$, $p < 0.001$), and Frederick Henry–Norfolk females ($\chi^2 = 19.8$, $p < 0.001$). Significant interannual differences were also evident for both sexes in Bridport, Tamar, and St Helens, and for females in Stanley. By contrast, no significant interannual age differences were detected for Mercury Passage males ($\chi^2 = 7.1$, $p = 0.13$), Flinders Island females ($\chi^2 = 5.2$, $p = 0.27$), Flinders Island males ($\chi^2 = 4.7$, $p = 0.32$), or Stanley males ($\chi^2 = 6.5$, $p = 0.16$), suggesting comparatively stable annual age structure in those subsets.

ANCOVA analyses of length-at-age relationships further demonstrated that annual growth patterns varied among regions (Appendix Table 37). Significant Age × Year interactions, indicating differing annual growth slopes, were detected in 10 of 18 region–sex combinations. The strongest effects occurred in Great Oyster Bay females ($F = 4.10$, $p < 0.001$, $\Delta AIC = +21.3$), Channel females ($F = 3.92$, $p < 0.01$, $\Delta AIC = +18.6$), Great Oyster Bay males ($F = 3.88$, $p < 0.01$, $\Delta AIC = +18.9$), and Frederick Henry–Norfolk females ($F = 3.76$, $p < 0.01$, $\Delta AIC = +17.4$). Significant slope differences were also detected for Channel males, Frederick Henry–Norfolk males, Mercury Passage males, St Helens females, and Stanley males. In contrast, Age × Year interactions were not significant for both sexes at Flinders Island, for both sexes at Bridport and Tamar, for Mercury Passage females (Appendix Figure 85), and for St Helens males (Appendix Figure 86), indicating more parallel annual growth trajectories in those regions.

Where Age × Year interactions were not significant, several regions still exhibited significant main effects of Year, indicating shifts in mean size-at-age among years despite broadly parallel slopes. This occurred for Mercury Passage females ($F = 4.12$, $p < 0.01$, ΔAIC = +11.5), Bridport females ($F = 3.98$, $p < 0.01$, ΔAIC = +12.6), Bridport males ($F = 3.54$, $p = 0.01$, ΔAIC = +10.9), Tamar females ($F = 3.77$, $p < 0.01$, ΔAIC = +11.8), Tamar males ($F = 3.61$, $p < 0.01$, ΔAIC = +10.7), and Stanley females ($F = 3.44$, $p = 0.01$, ΔAIC = +9.8). By contrast, no evidence of annual growth differences was detected for either sex at Flinders Island or for St Helens males (Appendix Table 37).

Collectively, these analyses show that interannual variability in age structure and growth was common across Tasmania, particularly in the long-term southeast and east coast regions where stronger cohort turnover and changing growth trajectories were evident. However, annual subsets were frequently characterised by reduced sample sizes, truncated age ranges, and sparse representation of older fish, especially in newer survey regions. This often produced unstable or biologically unrealistic year-specific von Bertalanffy estimates. Accordingly, data were pooled across all available survey years within each region and sex to maximise sample size, improve representation across the full observed age range, and enhance parameter identifiability. The resulting pooled growth curves should therefore be interpreted as integrated mean growth trajectories across the survey period rather than evidence of temporally invariant growth.

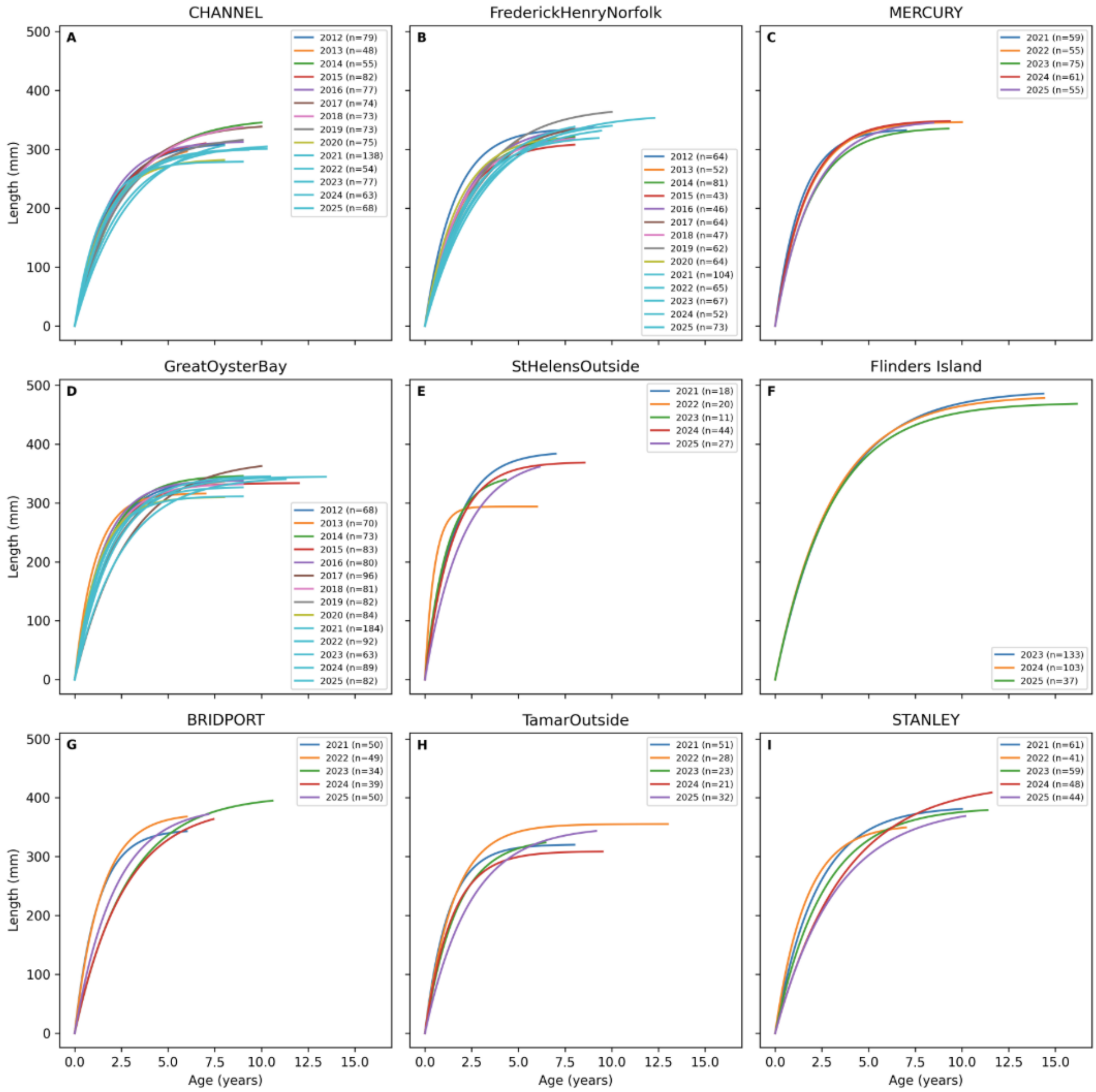


Figure 21. Year-specific von Bertalanffy growth curves for female sand flathead across Tasmanian regions arranged from south-east to north-west. Lines represent annual growth curves, with colours corresponding to individual years as indicated in panel legends. Sample sizes (n) are shown for each year. Inside estuarine sites were excluded.

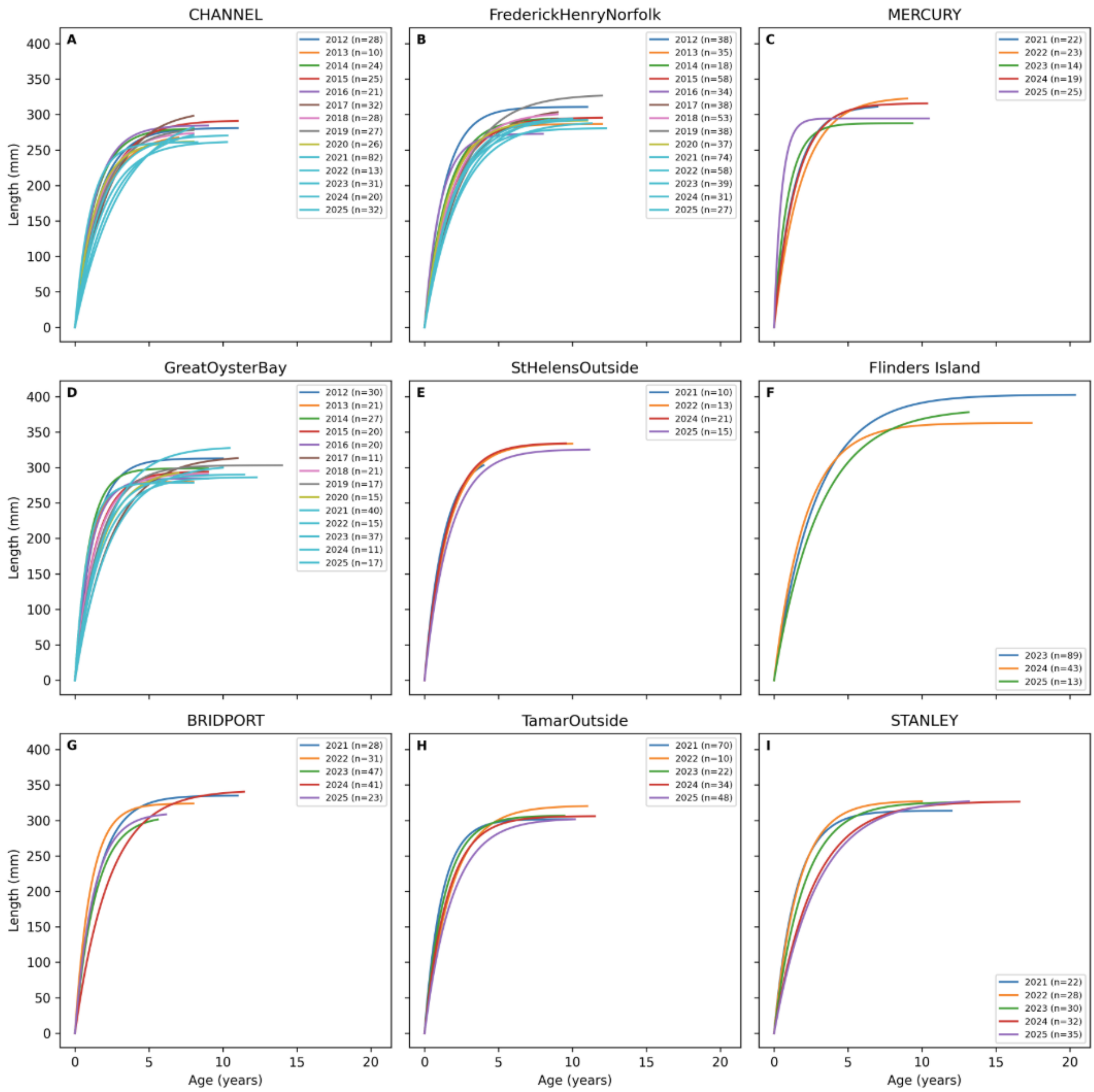


Figure 22. Year-specific von Bertalanffy growth curves for male sand flathead across Tasmanian regions arranged from south-east to north-west. Lines represent annual growth curves, with colours corresponding to individual years as indicated in panel legends. Sample sizes (n) are shown for each year. Inside estuarine sites were excluded.

5.1.3.5 Sex-specific growth

Sex-specific von Bertalanffy growth function (VBGF) models indicated pronounced and highly consistent growth dimorphism across Tasmania. Likelihood ratio tests comparing models with shared versus sex-specific growth parameters showed that female and male curves differed significantly in all assessed regions under both constrained and unconstrained model formulations (all $p < 0.001$), confirming that growth should be modelled separately by sex across the stock range (Figure 23; Figure 24; Table 10; Table 11).

Under the constrained model ($t_0 = 0$), support for sex-specific growth was strong in every region, with likelihood ratio test (LRT) statistics ranging from 47.0 in the Tamar to 295.2 in Frederick Henry–Norfolk Bays, and corresponding ΔAIC values from 43.0 to 291.2 (Table 10). Particularly strong evidence for sex-specific growth was observed in

Frederick Henry–Norfolk Bays (LRT = 295.23), Great Oyster Bay (283.59), Flinders Island (196.96), and the Channel (196.75), indicating substantial divergence between female and male growth trajectories in these regions. Lower, but still highly significant, support was evident in Mercury Passage (49.96) and the Tamar (47.02). Fitted constrained curves are shown in Figure 23.

Table 10. Results of likelihood ratio tests (LRT) and Akaike Information Criterion (ΔAIC) comparisons assessing sex-specific differences in von Bertalanffy growth curves of Sand Flathead within each region under the constrained model ($t_0 = 0$). Models allowing separate growth parameters for females and males were compared with models assuming shared parameters. Positive ΔAIC values indicate support for sex-specific growth. Significance levels are indicated as *** ($P < 0.001$), ** ($P < 0.01$), * ($P < 0.05$), and ns (not significant).

Region	***n***	**LRT**	**ΔAIC**
Channel	1,435	**196.75*** **	192.75
Frederick Henry-Norfolk Bays	1,462	**295.23*** **	291.23
Mercury Passage	408	**49.96*** **	45.96
Great Oyster Bay	1,529	**283.59*** **	279.59
St Helens	183	**60.91*** **	56.91
Flinders Island	418	**196.96*** **	192.96
Bridport	392	**66.97*** **	62.97
Tamar	339	**47.02*** **	43.02
Stanley	400	**134.27*** **	130.27

Table 11. Results of likelihood ratio tests (LRT) and Akaike Information Criterion (ΔAIC) comparisons assessing sex-specific differences in von Bertalanffy growth curves of sand flathead within each region under the unconstrained model. Models allowing separate growth parameters for females and males were compared with models assuming shared parameters. Positive ΔAIC values indicate support for sex-specific growth. Significance levels are indicated as *** ($P < 0.001$), ** ($P < 0.01$), * ($P < 0.05$), and ns (not significant).

Region	***n***	**LRT**	**ΔAIC**
Channel	1,435	**222.25*** **	216.25
Frederick Henry-Norfolk Bays	1,462	**384.96*** **	378.96
Mercury Passage	408	**77.56*** **	71.56
Great Oyster Bay	1,529	**425.02*** **	419.02
St Helens	183	**77.70*** **	71.70
Flinders Island	418	**251.11*** **	245.11
Bridport	392	**125.72*** **	119.72
Tamar	339	**86.64*** **	80.64

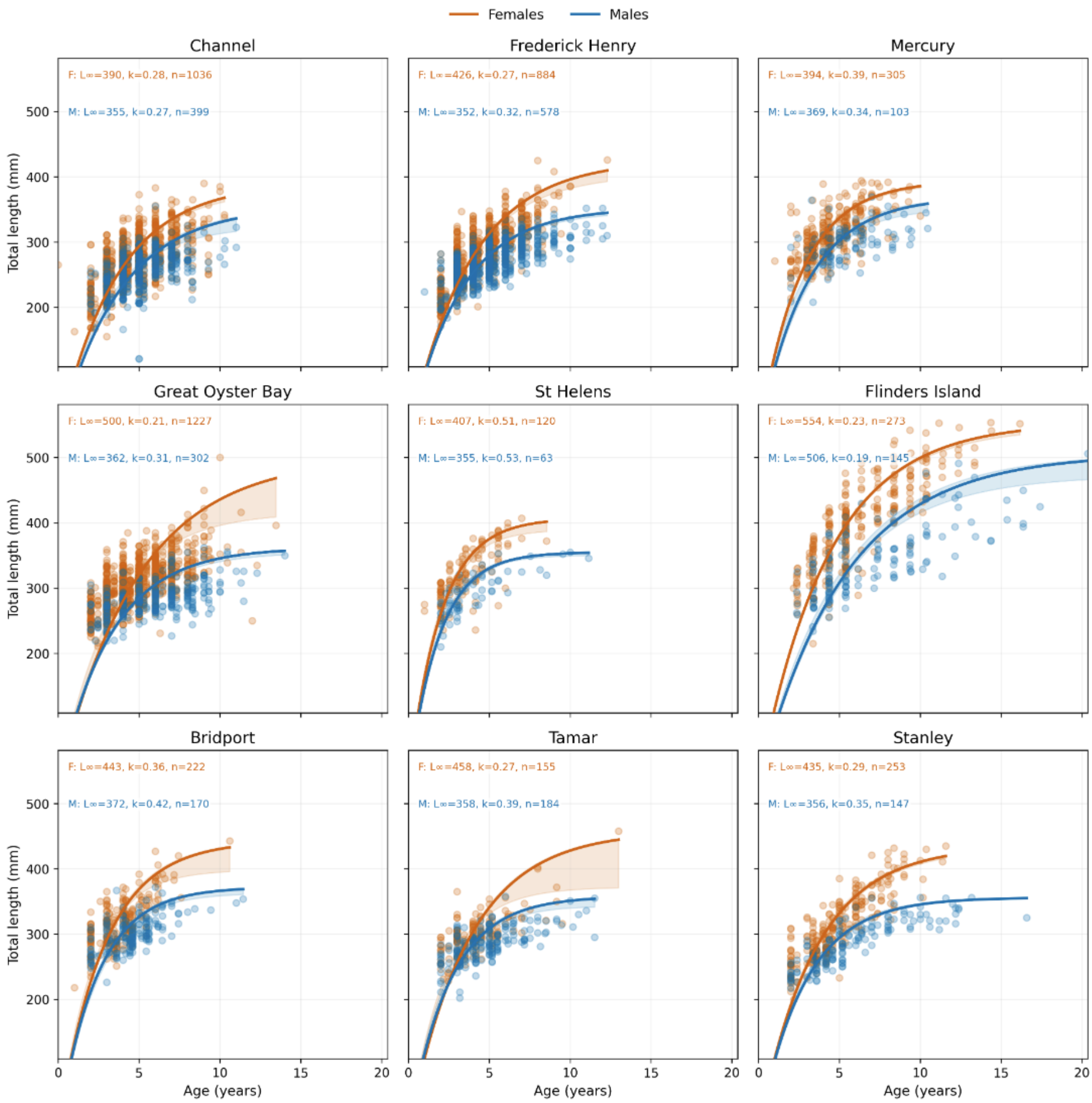


Figure 23. Sex-specific von Bertalanffy growth curves for Sand Flathead across nine regions around Tasmania. Panels are arranged geographically from south-east to north-west. Points represent observed length-at-age data and solid lines represent fitted growth curves with t_0 constrained to zero. Shaded ribbons indicate 95% confidence intervals. Fitted parameter estimates (L_∞ and k) and sample sizes are shown within each panel for females and males.

Results from the unconstrained model were consistent with those of the constrained formulation, with all tested regions again strongly supporting separate female and male growth parameters (Table 11). LRT statistics were generally larger, ranging from 77.6 in Mercury Passage to 425.0 in Great Oyster Bay, while ΔAIC values ranged from 71.6 to 419.0, reflecting improved model fit when t_0 was estimated rather than fixed. Strongest support occurred in Great Oyster Bay (LRT = 425.02), Frederick Henry–Norfolk Bays (384.96), Flinders Island (251.11), and the Channel (222.25). These unconstrained fitted curves are presented in Figure 24. The consistency of regional rankings between formulations indicates that sex-specific growth differences were robust to model structure and not dependent on assumptions regarding early growth.

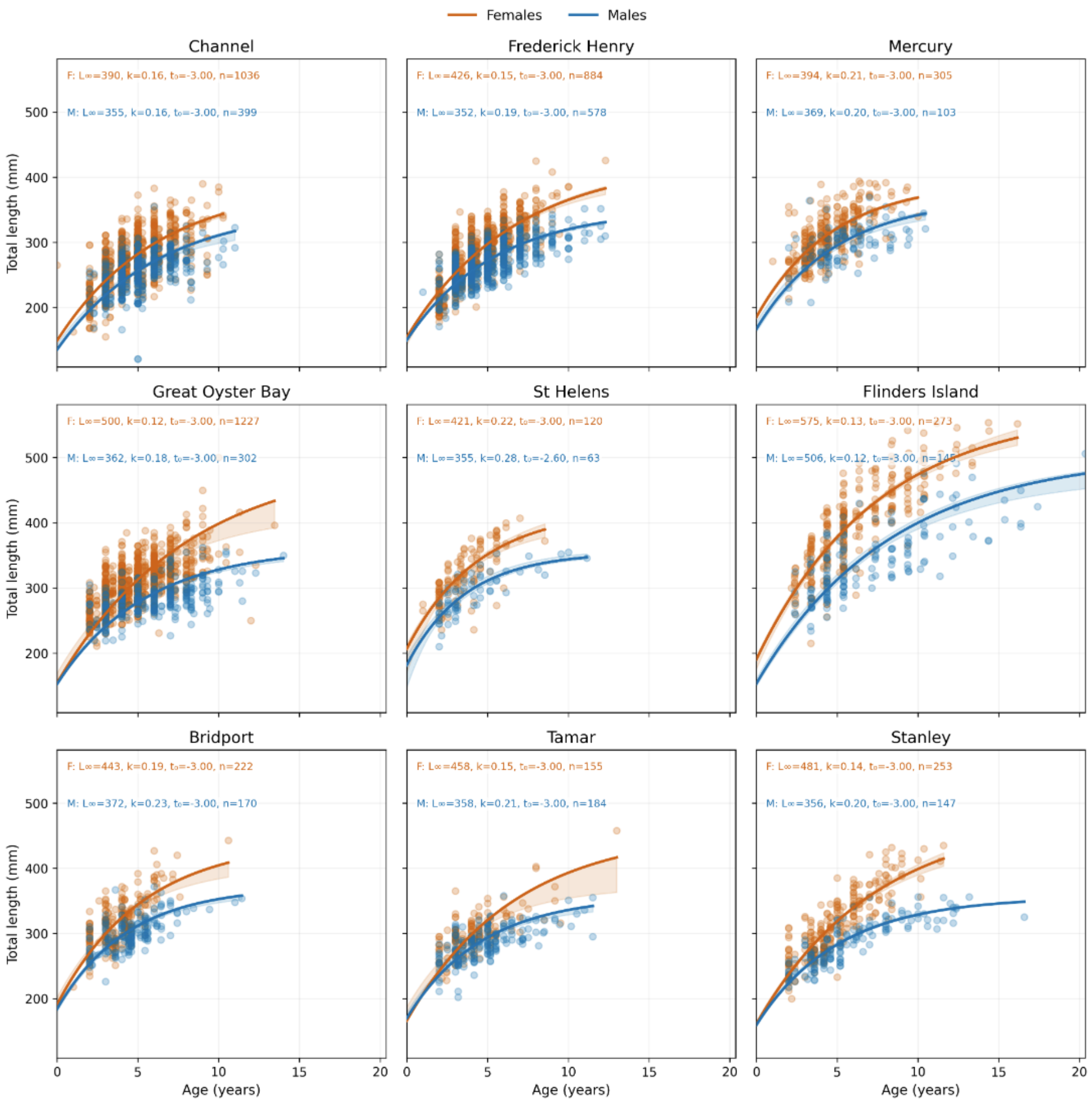


Figure 24. Sex-specific von Bertalanffy growth curves for Sand Flathead across nine regions around Tasmania. Panels are arranged geographically from south-east to north-west. Points represent observed length-at-age data and solid lines represent fitted growth curves with t_0 estimated (unconstrained). Shaded ribbons indicate 95% confidence intervals. Fitted parameter estimates (L_∞, k, and t_0) and sample sizes are shown within each panel for females and males.

Across both formulations, females consistently attained larger asymptotic lengths (L_∞) than males in every region (Figure 23; Figure 24). Differences between sexes were modest among younger fish (approximately ages 2–4 years) but increased progressively with age as female growth trajectories continued toward larger adult sizes while male growth slowed earlier. The greatest visual separation between sexes occurred in regions containing strong representation of larger and older fish, particularly Flinders Island, Great Oyster Bay, Frederick Henry–Norfolk Bays, and the Channel, whereas divergence was less pronounced in regions with fewer older fish such as Mercury Passage and the Tamar.

A shared age-range sensitivity analysis further confirmed that observed regional and sex-specific growth differences were not an artefact of unequal representation of older age classes among regions. When analyses were restricted to age ranges common to all regions (females: 2.15–8.55 years; males: 2.35–10.46 years), constrained model parameter estimates changed only modestly relative to the full dataset. Mean changes in asymptotic length (L_∞) were small for males (−4.3 mm) and moderate for females (−21.9 mm), while corresponding changes in the growth coefficient (k) were minor for both sexes (Appendix Figure 81). Unconstrained models showed similarly small average shifts, but parameter estimates remained more variable and less stable than constrained fits (Appendix Figure 82).

Pairwise comparisons based on the shared age-range dataset remained broadly consistent with those from the full dataset, with strong support for region-specific growth retained across most regional contrasts. Although some reductions in statistical significance were evident, particularly among geographically proximate regions, ΔAIC values remained positive for most comparisons, indicating continued support for spatial growth differences (Appendix Figure 83; Appendix Figure 84). Importantly, restricting analyses to a common age range did not alter the overarching pattern of stronger growth in northern and northeastern Tasmania relative to southeast regions. Comparisons between constrained and unconstrained shared age-range models yielded similar spatial rankings, but unconstrained models exhibited greater variability in significance levels and ΔAIC values, indicating reduced parameter stability. Consequently, constrained formulations provided the more robust basis for regional comparison.

Collectively, these results demonstrate that the principal growth patterns identified in the full dataset were biologically robust and not driven by sample truncation or unequal age composition among regions. They also show that female Sand Flathead contribute disproportionately to the upper size classes of the stock, indicating that management measures affecting larger fish are likely to have sex-specific consequences for stock structure, spawning potential, and overall reproductive capacity.

5.1.3.6 Regional growth variation

Strong regional growth differences were evident within both sexes, with fitted von Bertalanffy growth curves showing clear spatial structuring across Tasmania (Figure 25; Figure 26; Figure 27). Prior to statewide comparisons, preliminary analyses identified significant differences between estuarine and adjacent coastal growth trajectories in both the Tamar River and Georges Bay (St Helens) systems. Fish from estuarine sites generally exhibited lower asymptotic lengths (L_∞) and, in some cases, higher growth coefficients (k), consistent with earlier attainment of smaller maximum size. To avoid conflating estuarine and coastal growth dynamics, fish captured within the Tamar Estuary and Georges Bay were excluded from subsequent regional growth analyses, and only adjacent coastal samples were retained for the “Tamar” and “St Helens” regional comparisons (Appendix Figure 85; Appendix Figure 86).

Following this standardisation, fish from northeastern Tasmania, particularly Flinders Island, Bridport, and St Helens (coastal), generally attained larger predicted sizes at age than fish from southeast Tasmania, especially the Channel and Frederick Henry–Norfolk Bays. These differences became increasingly pronounced with age. For fish aged approximately 5–8 years, predicted lengths in northeastern regions were commonly 20–50 mm greater than those in southeast Tasmania, depending on sex and region pairing. The strongest contrasts were typically observed between Flinders Island and the southeast regions, where fitted curves indicated substantially faster attainment of larger adult sizes (Figure 25; Figure 26; Figure 27).

Great Oyster Bay and Mercury Passage were generally intermediate, while the Tamar coastal region and Stanley more closely aligned with mid-range growth trajectories. Regional contrasts were also reflected in asymptotic size estimates (L_∞), with northern and northeastern regions generally exhibiting larger female and male L_∞ values than southeast Tasmania (Appendix Table 33, Table 34). Regions supporting larger and older fish in survey catches, particularly Flinders Island, Bridport, and St Helens, also tended to exhibit stronger predicted growth trajectories.

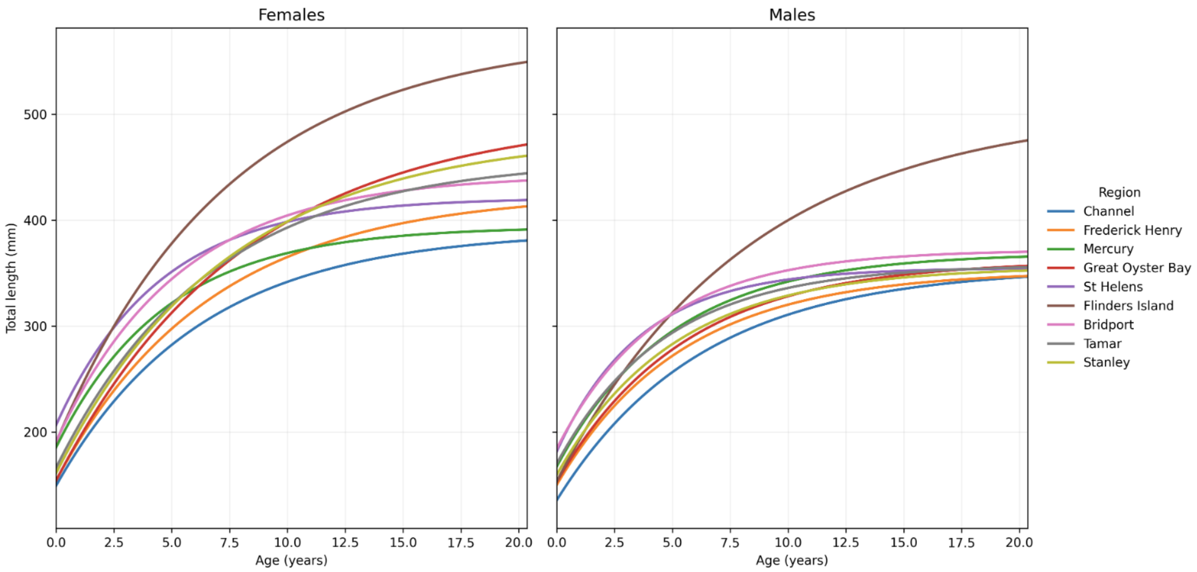


Figure 25. Regional comparisons of von Bertalanffy growth curves for female and male Sand Flathead across nine regions around Tasmania. Separate panels show females and males. Lines represent fitted region-specific growth curves with t_0 estimated (unconstrained).

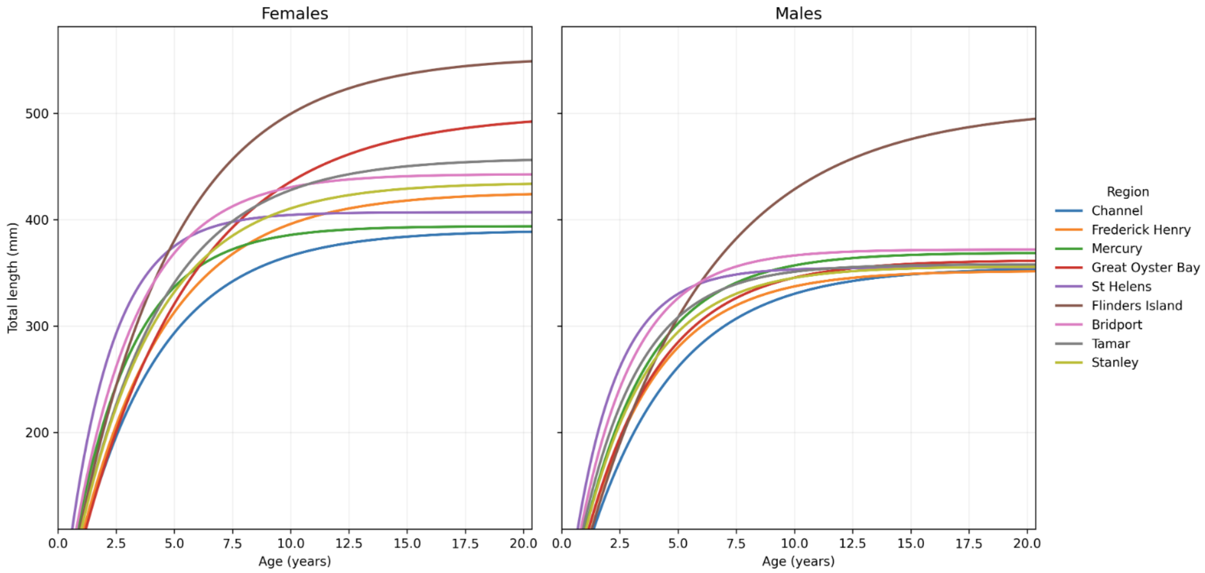


Figure 26. Regional comparisons of von Bertalanffy growth curves for female and male Sand Flathead across nine regions around Tasmania. Separate panels show females and males. Lines represent fitted region-specific growth curves with t_0 constrained to zero (t_0=0 yr^{-1}).

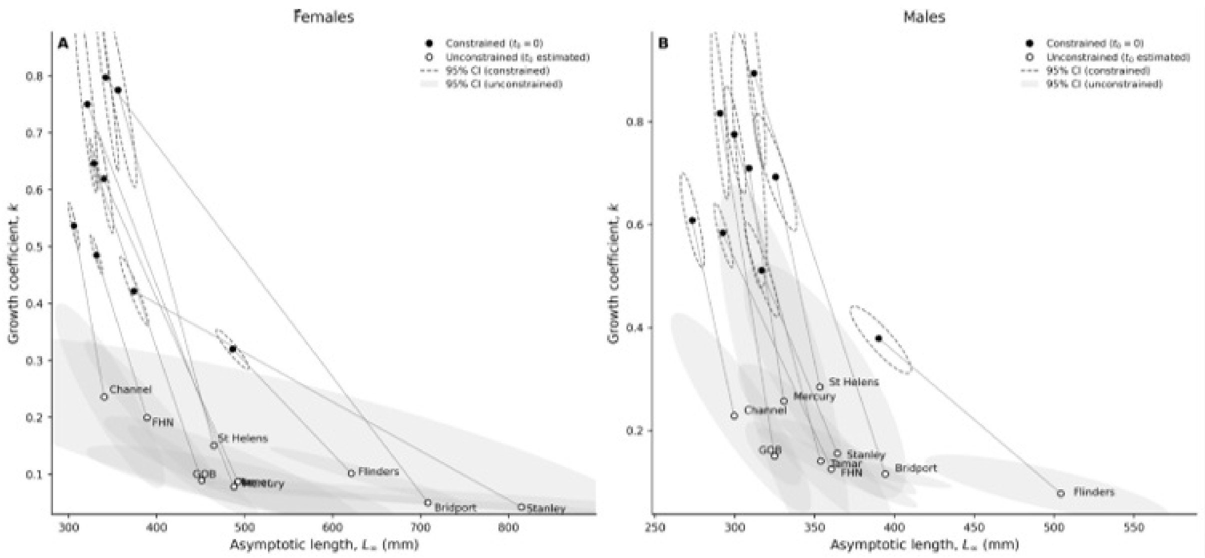


Figure 27. Regional von Bertalanffy growth parameter estimates for female and male sand flathead under constrained ($t_0 = 0$) and unconstrained (t_0 estimated) model formulations. Points represent region-specific estimates of asymptotic length (L_∞) and growth coefficient (k). Dashed ellipses show bootstrapped 95% confidence regions for constrained models, while shaded ellipses show bootstrapped 95% confidence regions for unconstrained models. Region labels identify unconstrained estimates, and thin connector lines link constrained and unconstrained estimates within each region.

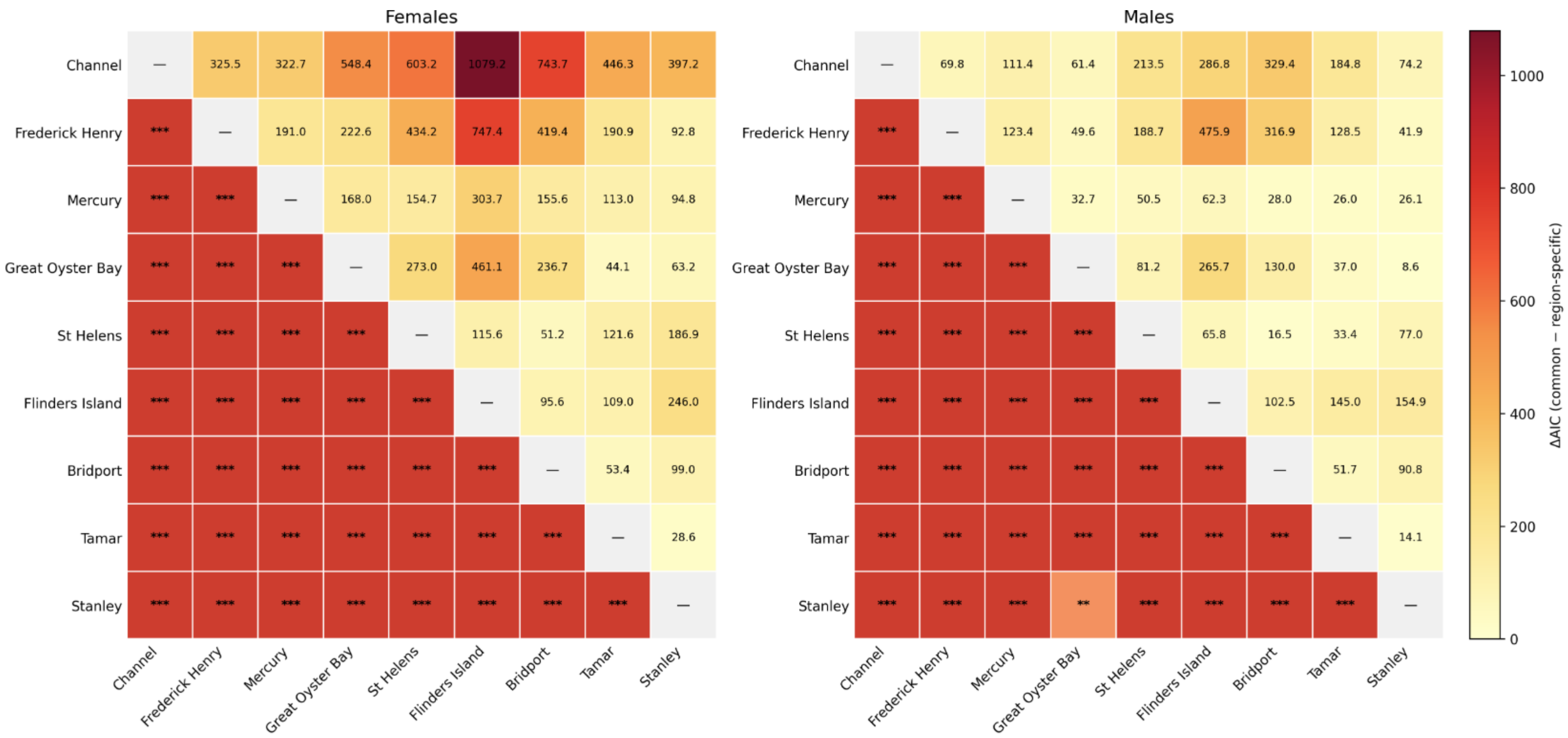


Figure 28. Pairwise comparisons of von Bertalanffy growth curves among regions for Sand Flathead, shown separately for females and males. The lower triangle displays the significance of likelihood ratio tests (LRTs) comparing a common growth model versus a region-specific model, with significance levels indicated as *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$), and ns (not significant). The upper triangle shows differences in Akaike Information Criterion (ΔAIC; common − region-specific), where positive values indicate stronger support for region-specific growth. Growth models were fitted with **t_0 = 0 (constrained).**

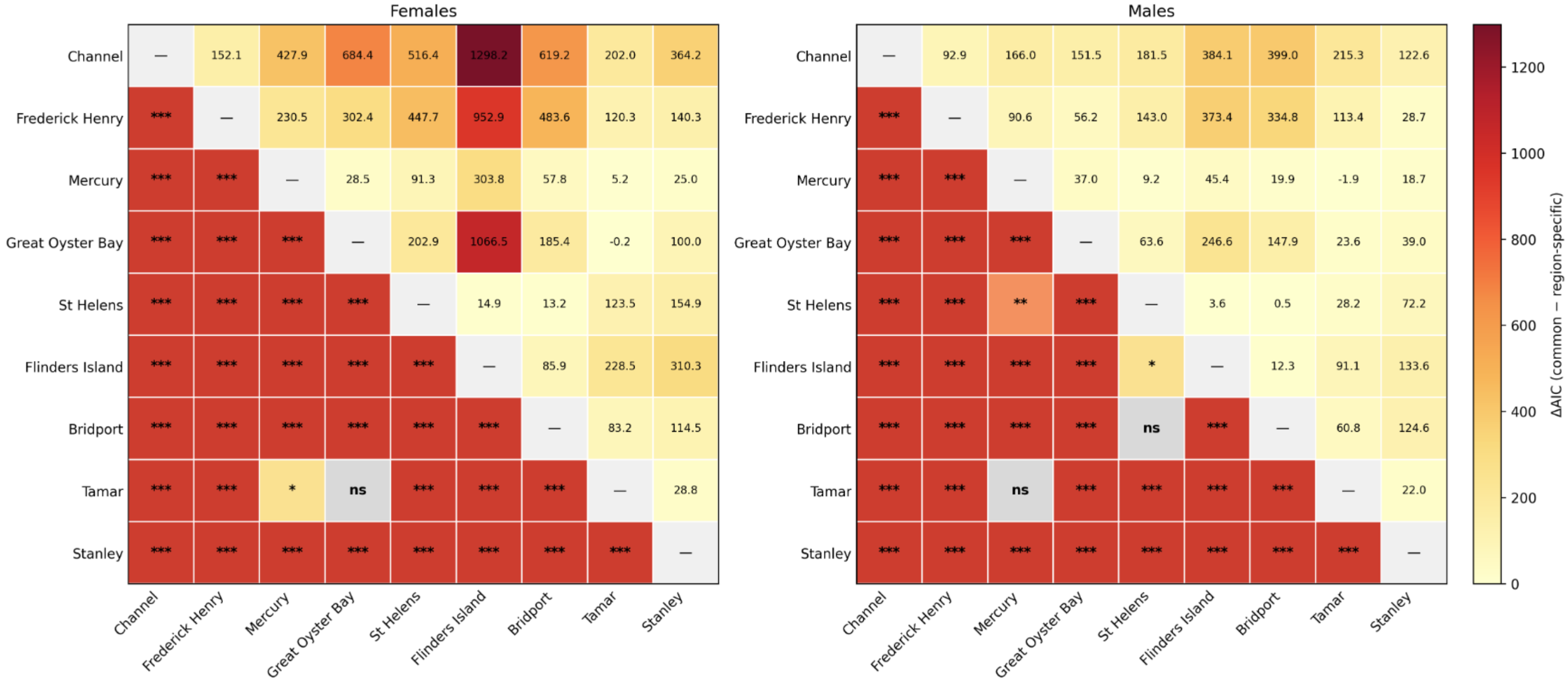


Figure 29. Pairwise comparisons of von Bertalanffy growth curves among regions for Sand Flathead, shown separately for females and males using **unconstrained growth models (t_0 estimated)**. The lower triangle displays the significance of likelihood ratio tests (LRTs) comparing a common growth model versus a region-specific model, with significance levels indicated as *** (p < 0.001), ** (p < 0.01), * (p < 0.05), and ns (not significant). The upper triangle shows differences in Akaike Information Criterion (ΔAIC; common − region-specific), where positive values indicate stronger support for region-specific growth.

Hierarchical model comparisons strongly supported region-specific growth parameterisation for both sexes, with likelihood ratio tests and ΔAIC values consistently favouring separate regional models over pooled statewide formulations (Appendix Table 33, Table 34). To further evaluate whether adjacent regions could be combined, grouped regional models were tested using data restricted to the age range shared within each proposed spatial grouping. For females, all four grouped comparisons strongly favoured retaining separate regional parameters, including the south-east (LRT = 196.68, ΔAIC = 190.68), east (LRT = 92.00, ΔAIC = 86.00), north-east (LRT = 17.46, ΔAIC = 11.46), and north / north-west groupings (LRT = 31.69, ΔAIC = 25.69) (Table 12; Figure 30).

For males, the same pattern was observed for the south-east (LRT = 89.49, ΔAIC = 83.49), east (LRT = 41.43, ΔAIC = 35.43), and north / north-west groupings (LRT = 21.81, ΔAIC = 15.81), all strongly supporting separate regional growth parameters. The sole exception was the north-east male grouping (St Helens and Bridport), where there was no evidence of regional differentiation (LRT = 1.69, p = 0.640, ΔAIC = −4.31), indicating that pooling was justified in this specific case (Table 12; Figure 30).

Although some geographically proximate regions therefore showed weaker separation, the overall evidence provides little support for broad spatial aggregation of growth parameters. A single statewide growth curve would inadequately represent Sand Flathead population dynamics, and even subregional pooling was generally unsupported except for north-east males.

These findings support incorporation of region-specific growth parameters into future stock assessments, biomass projections, and rebuilding analyses, particularly where depleted southeast stocks are compared with faster-growing northern populations.

Table 12. Results of likelihood ratio tests (LRT) and Akaike Information Criterion (ΔAIC) comparisons evaluating the appropriateness of pooling spatial regions for unconstrained von Bertalanffy growth models of sand flathead. Models assuming shared growth parameters within each spatial grouping were compared with models allowing region-specific parameters. Analyses were conducted separately for females and males using data restricted to the age range shared among regions within each grouping. Positive ΔAIC values indicate support for region-specific models. The final column indicates the recommended decision regarding pooling based on combined LRT and ΔAIC criteria.

Sex	**Group**	***n***	**Shared age range**	**LRT**	**df**	***p***	**ΔAIC**	**Decision**
Females	South-east	1,900	2.00–10.27	196.68	3	**<0.001**	190.68	Separate
Females	East	1,521	2.00–10.00	92.00	3	**<0.001**	86.00	Separate
Females	North-east	337	1.00–8.55	17.46	3	**<0.001**	11.46	Separate
Females	North / north-west	403	2.00–11.59	31.69	3	**<0.001**	25.69	Separate
Males	South-east	964	2.00–11.00	89.49	3	**<0.001**	83.49	Separate
Males	East	393	2.00–10.46	41.43	3	**<0.001**	35.43	Separate
Males	North-east	229	2.00–11.14	1.69	3	0.640	-4.31	Pool
Males	North / north-west	321	2.00–11.51	21.81	3	**<0.001**	15.81	Separate

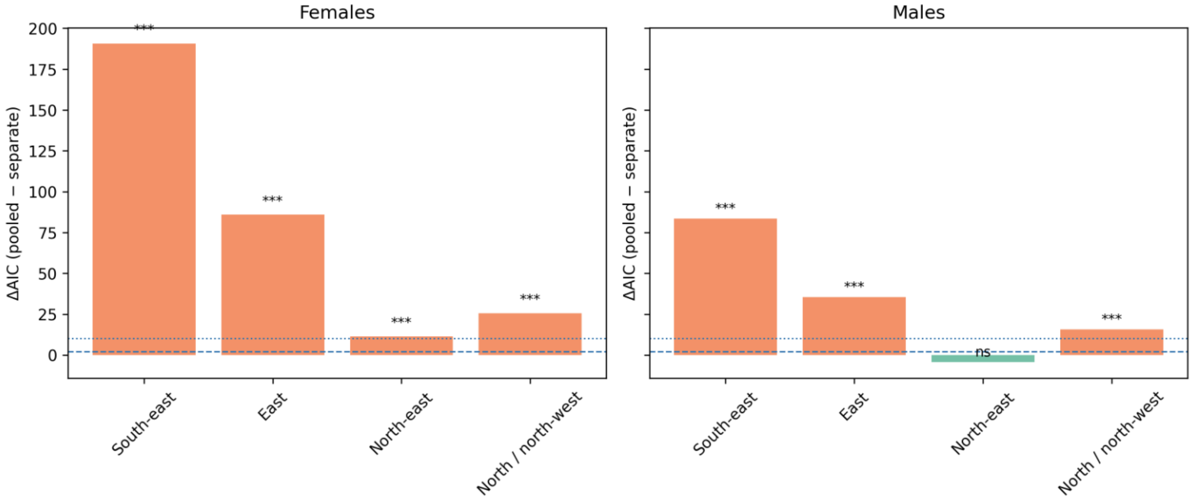


Figure 30. Evaluation of regional pooling for unconstrained von Bertalanffy growth models of Sand Flathead. Bars show differences in Akaike Information Criterion (ΔAIC; pooled − region-specific) for each proposed spatial grouping, calculated separately for females and males using data restricted to the shared age range within each group. Positive ΔAIC values indicate support for region-specific growth parameters. Horizontal dashed lines at ΔAIC = 2 and 10 denote thresholds for weak and strong evidence against pooling, respectively. Significance of likelihood ratio tests is indicated above bars ($p < 0.05$).

5.1.3.7 Sex ratios

Regional estimates of sex ratio from the fishery-independent surveys revealed clear spatial differences in the proportion of females, with most regions skewed to between 60 and 80% females in sampling (Figure 31). Several regions, particularly Flinders Island and some eastern locations, showed significantly female-biased compositions relative to the expected 1:1 ratio, based on binomial confidence intervals around regional estimates. Flinders Island exhibited the strongest female bias, consistent with the high abundance of larger fish in that region and the tendency for females to dominate upper size classes.

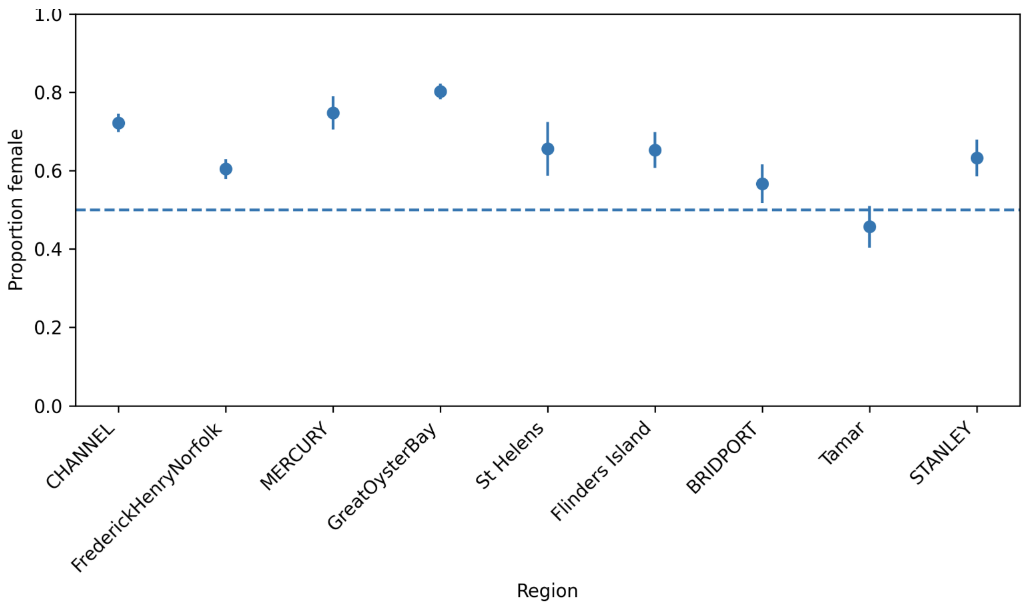


Figure 31. Proportion of female Sand Flathead by region based on fishery-independent surveys. Points represent estimated proportions and error bars indicate 95% binomial confidence intervals. The dashed horizontal line indicates a 1:1 sex ratio (0.5). Regions are ordered geographically from south-east to north-west.

Sex ratios varied among pooled regional groupings but showed limited temporal variation through time (Figure 32). Generalised linear modelling (binomial GLM) indicated a significant effect of region on the probability of an individual being female ($p < 0.001$), whereas the effect of year was not significant ($p > 0.05$), indicating no consistent directional temporal change in sex ratio across the survey period. This suggests that differences in sex composition are primarily spatially structured rather than driven by interannual recruitment variability or changing sex-specific mortality.

When regions were pooled into five broader spatial categories (south-east, east, north-east, north / north-west, and Flinders Island) (Figure 32). Interannual variation within pooled regions was weak, with annual estimates typically overlapping in their 95% confidence intervals and no coherent temporal trends evident.

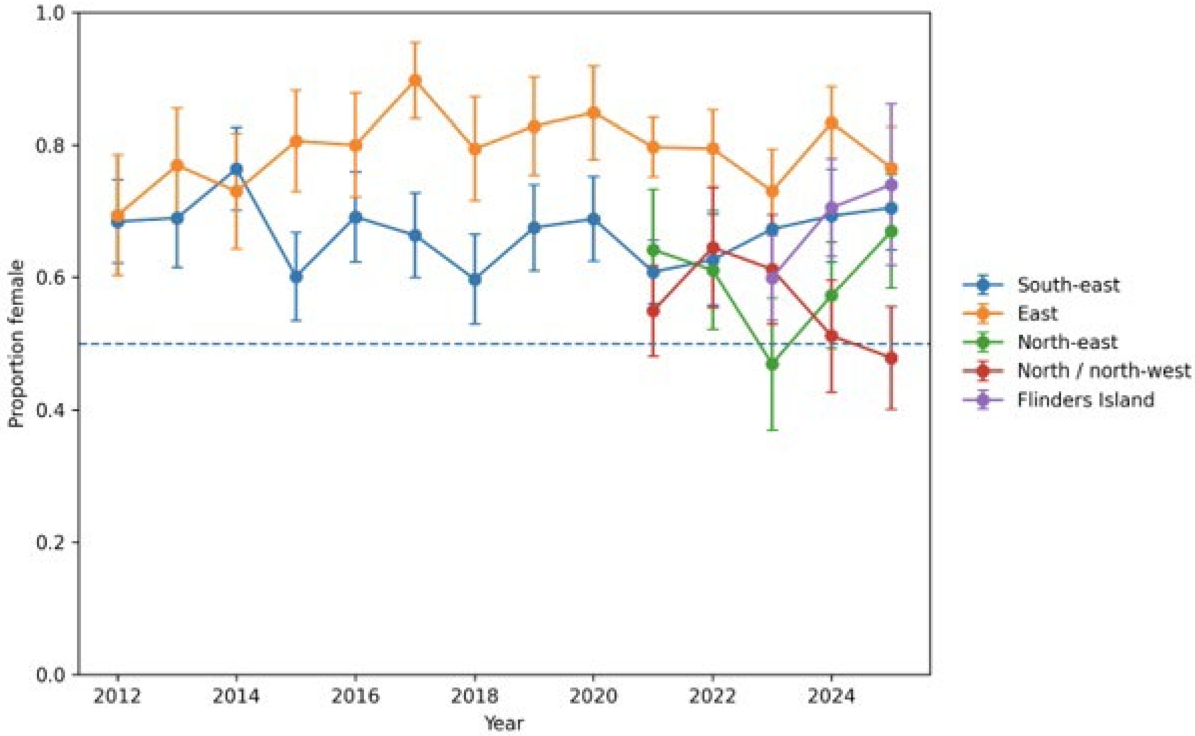


Figure 32. Temporal variation in sex ratio (proportion female) of Sand Flathead across four pooled regions: south-east, east, north-east, north/northwest and Flinders Island. Points represent annual estimates and error bars indicate 95% binomial confidence intervals.

Patterns in sex ratio were strongly associated with regional size structure (Figure 33). Across all pooled regions, females increasingly dominated larger length classes, whereas males were more prevalent among smaller fish. This ontogenetic shift was most pronounced in Flinders Island, where larger individuals were common and female dominance extended across a substantial proportion of the adult size range. In contrast, south-east Tasmania, where size structures were strongly truncated, displayed more balanced overall sex ratios because relatively few fish reached the larger size classes where females predominate. Eastern, north-eastern, and north / north-west groupings showed intermediate patterns, with increasing female dominance at larger sizes but less extreme whole-population bias than Flinders Island.

These results indicate that statewide variation in sex ratio is driven principally by differences in size composition and sexual dimorphism in growth rather than by persistent temporal shifts. Regions supporting larger and older fish therefore tend to exhibit higher female representation, which may increase local spawning biomass and reproductive capacity. Conversely, regions characterised by truncated size structure may appear closer to parity simply because larger, female-dominated size classes are poorly represented.

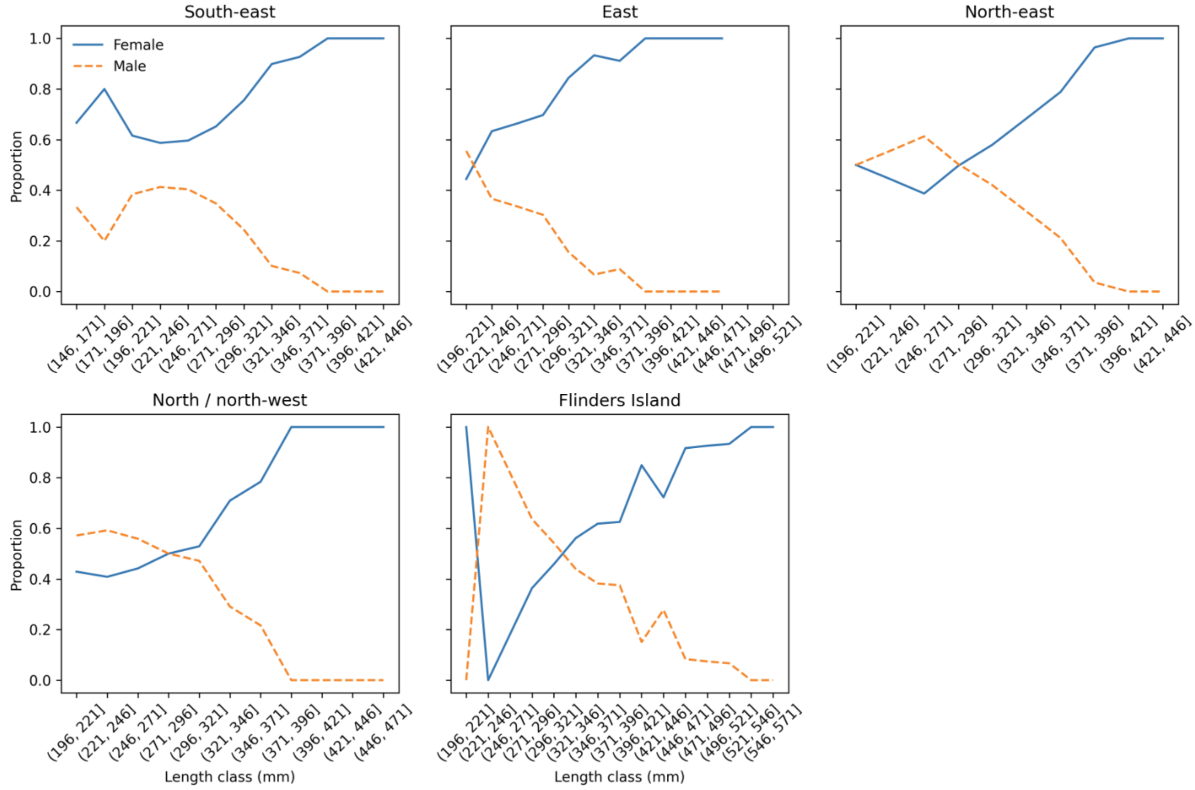


Figure 33. Proportional contribution of females and males to samples across length classes for Sand Flathead within each pooled region. Lines represent the proportion of each sex within each size class, illustrating sex-specific differences in size structure among regions.

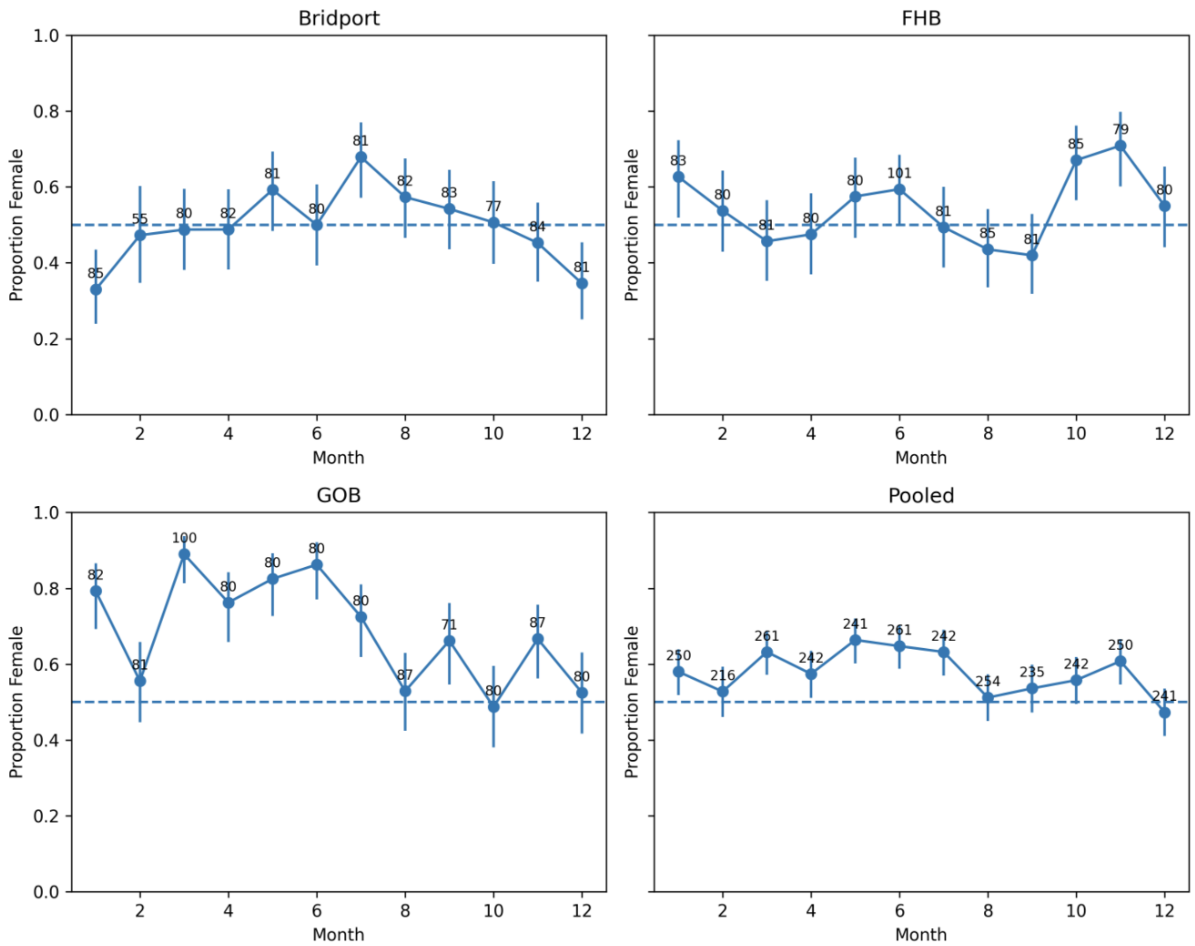


Figure 34. Monthly sex ratio (expressed as proportion female) for Bridport, FHB and GOB, with pooled values shown for all three regions combined. Points indicate monthly proportions, error bars show 95% confidence intervals, and numbers above points indicate monthly sample sizes. The dashed horizontal line represents a 1:1 sex ratio.

Additional monthly analyses from reproductive sampling in Bridport, Fredrick Henry-Norfolk Bays, and Great Oyster Bay demonstrated that sex ratio also varied seasonally and that seasonal patterns differed among regions (Figure 34). Collectively, these results indicate that statewide variation in sex ratio is driven principally by differences in size composition and sexual dimorphism in growth, while shorter-term seasonal variability likely reflects region-specific movement, behavioural, or reproductive processes. Regions supporting larger and older fish therefore tend to exhibit higher female representation, which may increase local spawning biomass and reproductive capacity. Conversely, regions characterised by truncated size structure may appear closer to parity because larger, female-dominated size classes are poorly represented. In heavily exploited regions, this pattern is also consistent with the effects of long-term size-selective fishing, whereby preferential removal of larger individuals may disproportionately reduce the abundance of females and shift sampled sex ratios toward males or parity.

5.1.3.8 Year-class structure and recruitment signals

Pooled frequency distributions of inferred birth years for the five long-term monitored management regions indicated relatively continuous year-class representation, with no evidence of persistently missing cohorts or recruitment collapse across the

observed period (Figure 35). Most year classes were represented by measurable numbers of fish in subsequent samples, suggesting that recruitment has occurred regularly enough to maintain cohort continuity within surveyed populations.
Overall variability in cohort strength appeared moderate rather than extreme. Birth-year frequencies generally fluctuated within a relatively narrow range, indicating limited evidence for highly episodic recruitment success or widespread recruitment failure. This pattern suggests that recent population dynamics have been influenced more by post-recruitment processes such as fishing mortality, growth, and survival than by strongly erratic annual recruitment.

The principal exception occurred in the south-east coast (SEC) region, where cohorts corresponding to approximately 2012 and 2014 were comparatively weakly represented in later samples (Figure 35). These weaker year classes were also evident in interannual age-frequency analyses when data were examined by capture year, indicating that the signal was consistent across analytical approaches rather than arising solely from pooled birth-year reconstruction.

Despite this evidence of ongoing recruitment, the demographic significance of recent cohort strength remains uncertain because no robust benchmark exists for historical recruitment magnitude under less depleted stock conditions. Consequently, while the data provide little evidence of complete recruitment failure, they do not indicate whether recent recruitment has been sufficient to sustain biomass, rebuild truncated age structures, or restore historical productivity in depleted regions.

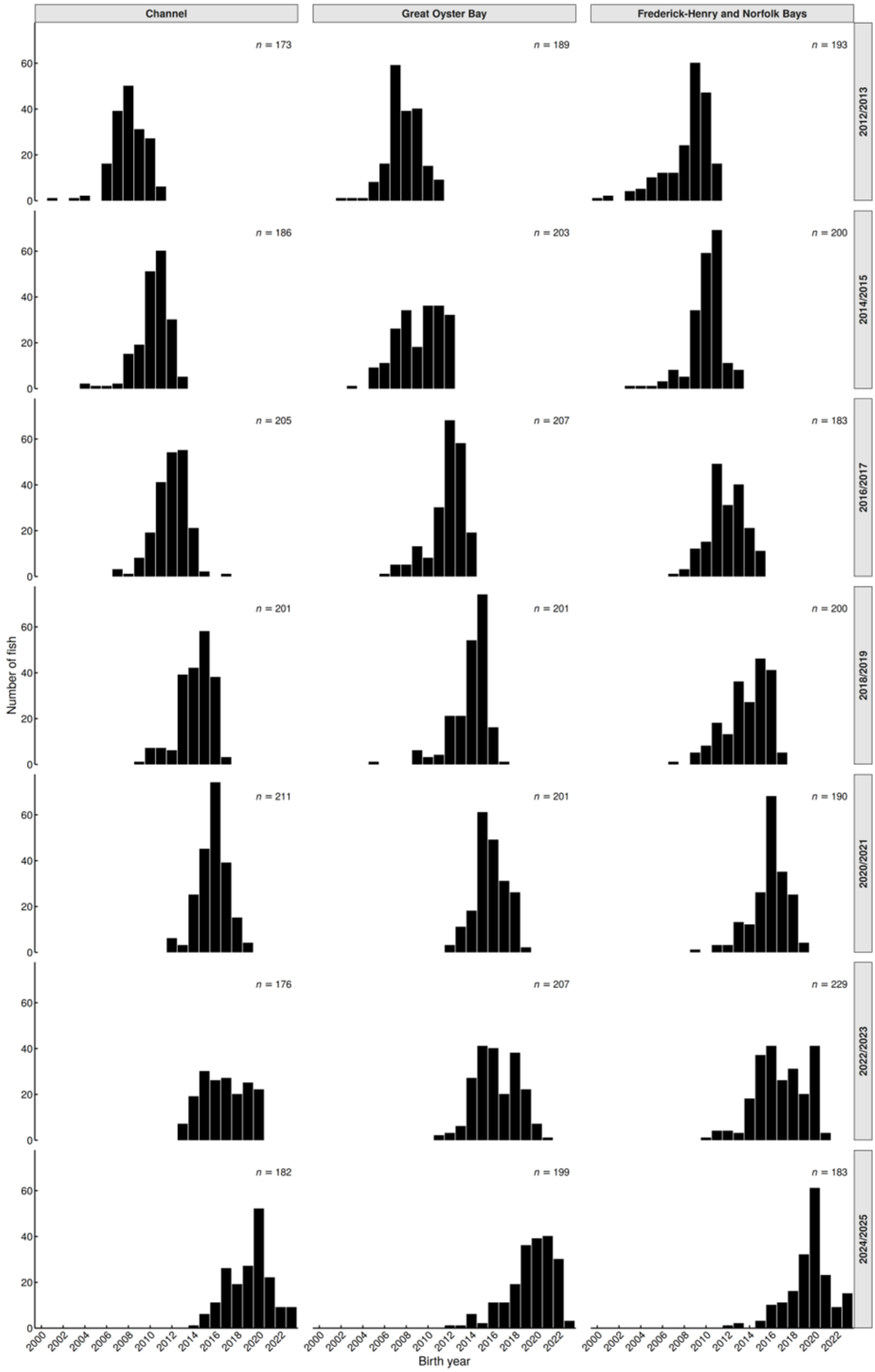


Figure 35. The number of Sand Flathead in each year class collected from the Channel, Frederick-Henry and Norfolk Bays and Great Oyster Bay between 2012 and 2025. *n* = sample size in each two-year grouping.

5.1.4 Discussion

The results demonstrate that Sand Flathead populations around Tasmania exhibit strong and spatially coherent variation across multiple life-history traits, including size structure, age composition, growth, sex composition and cohort representation. Concordant spatial differences across several biological indicators suggest that regional patterns are not random sampling artefacts, but reflect genuine differences in demographic condition, productivity and exploitation history. Similar findings in other marine fishes have shown that biologically meaningful heterogeneity can occur at spatial scales smaller than formal management units, creating risk that aggregated stock assessments obscure local depletion or divergent productivity trajectories (Stephenson, 1999, Reiss et al., 2009). The present findings therefore indicate that Sand Flathead should not be interpreted solely through a homogeneous statewide biological framework.

The clearest statewide contrast was between southeast Tasmania and northern or northeastern regions. The Channel and Frederick Henry–Norfolk Bays were characterised by smaller fish, reduced representation of older age classes and comparatively weaker adult growth trajectories, whereas Flinders Island, Bridport, St Helens and parts of northern Tasmania retained larger and older fish with stronger size-at-age relationships. Spatial gradients of this type commonly arise through interacting effects of fishing intensity, habitat quality, temperature, prey availability, density dependence and local adaptation (Conover and Present, 1990, Yamahira and Conover, 2002). Given the long history of concentrated recreational fishing effort in southeast Tasmania, the observed demographic truncation is also consistent with sustained size-selective exploitation reducing abundance of larger and older individuals.

The growth analyses demonstrate that statewide pooling of biological parameters is not appropriate for Sand Flathead. Classical fisheries models show that exploitation outcomes, yield-per-recruit and optimum size at first capture are highly sensitive to growth rate (k) and asymptotic size (L_∞) (Beverton and Holt, 1957). Because many contemporary stock assessments also derive natural mortality or productivity assumptions from life-history parameters, misspecification of growth can propagate through biomass, depletion and rebuilding estimates (Pauly, 1980, Then et al., 2015). This is equally relevant to modern length-based assessment approaches, which rely on robust estimates of L_∞, mortality-growth relationships, maturity schedules and representative size composition (Hordyk et al., 2015b). The strong support for region-specific growth curves in this study therefore indicates that use of pooled statewide parameters could overestimate productivity in truncated southern regions or underestimate potential in stronger northern components.

Growth estimates themselves, however, require careful interpretation where populations are heavily size-truncated. In regions where large and old fish are rare, fitted von Bertalanffy models may underestimate true maximum size potential or inflate apparent growth coefficients because the upper tail of the size distribution has been removed. Similar caution has been raised widely in fisheries science, where growth parameter estimates are known to be sensitive to incomplete age ranges and selective sampling of survivors (Francis, 1990). The contrast with Flinders Island, where older and larger fish remained well represented, suggests that northern regions may better approximate less-truncated life-history conditions than depleted south-eastern systems. However, the potential for environmentally driven regional differences cannot be discounted.

The substantial spread in size-at-age observed across regions also indicates pronounced growth plasticity in Sand Flathead. Growth plasticity is common in fishes and may reflect environmental conditions, density dependence, prey supply or compensatory responses to fishing (Lorenzen and Enberg, 2002, Audzijonyte et al., 2013). Such plasticity has two important implications. First, age may be a less reliable proxy for vulnerability or biomass where size-at-age varies strongly among regions. Second, persistent size-selective harvest may favour slower-growing phenotypes if faster-growing individuals enter the fishery earlier and experience disproportionate mortality. Although evolutionary inference is beyond the scope of this study, fisheries-induced shifts in growth and maturation traits are now well documented in exploited stocks (Olsen et al., 2004, Heino and Dieckmann, 2009, Kuparinen et al., 2016a).

Sex-specific growth patterns add a further management dimension. Females consistently attained larger sizes than males and dominated upper size classes, particularly in regions where larger fish remained common. This implies that fishing mortality directed at larger fish is also likely to disproportionately remove females. For many marine fishes, larger and older females contribute disproportionately to reproductive output through higher fecundity, larger eggs and more viable offspring (Berkeley et al., 2004a, Hixon et al., 2014). Consequently, loss of large females in truncated southern regions may reduce spawning potential more severely than suggested by total biomass alone.

Patterns in sex ratio were consistent with this interpretation. Female-biased populations were most evident in regions with stronger size structure, whereas heavily fished or truncated regions tended to be closer to parity. This suggests that observed regional sex ratios are largely emergent properties of size structure and sexual dimorphism rather than intrinsic differences in primary sex ratios. Seasonal shifts in sex ratio within some regions further imply that movement, habitat use or spawning behaviour may alter local availability to sampling gears during parts of the year, a common feature in demersal fishes during reproductive periods (Lowerre-Barbieri et al., 2011).

Recruitment patterns provide a more nuanced perspective on stock status. The absence of persistently missing year classes suggests that recent population dynamics are not being driven solely by complete recruitment failure. Instead, post-recruitment processes such as fishing mortality, reduced survival to older ages and demographic truncation may be more influential in shaping current stock condition. This distinction is important because many depleted fish stocks continue to recruit while remaining trapped in low-biomass states due to insufficient adult survival or spawning biomass (Hutchings, 2000, Shelton and Mangel, 2011). For Sand Flathead, continued recruitment should therefore not be interpreted as evidence that depleted south-eastern populations are rebuilding adequately as productivity impairment may be masked.

Taken together, the findings suggest that rebuilding Sand Flathead stocks should focus not only on biomass recovery, but on restoration of demographic quality, particularly larger fish, broader age structure and strong spawning biomass. Age truncation can amplify population variability and reduce resilience to environmental fluctuations because fewer age classes contribute to recruitment buffering (Anderson et al., 2008). Management measures that simply maintain juvenile supply without rebuilding adult structure may therefore stabilise depleted states rather than restore historical productivity.

The results also highlight the value of integrated monitoring. Length structure, age composition, growth, sex ratios and cohort signals each captured different dimensions of stock condition but together provided a coherent diagnosis of regional status. Multi-indicator approaches are increasingly recognised as more robust than reliance on any single metric, particularly in data-moderate fisheries where uncertainty around individual parameters may be substantial (Hilborn and Walters, 1992, Punt et al., 2016). Continued fishery-independent monitoring across Tasmania will therefore be essential for tracking rebuilding progress, evaluating management responses and refining future harvest strategies.

5.1.5 Conclusion

Sand Flathead populations around Tasmania exhibit pronounced and management-relevant spatial variation in contemporary biological condition. Across multiple indicators, northern and northeastern regions retain stronger demographic structure, including larger fish, broader age composition, stronger growth trajectories and higher female representation, whereas southeast Tasmania is characterised by truncated size and age structures, reduced adult size potential and comparatively lower representation of larger females. These patterns indicate that regional differences in productivity and stock status are substantial and should be considered fundamental features of the fishery rather than minor local variation.

The findings demonstrate that a single statewide biological framework is unlikely to adequately represent Sand Flathead population dynamics. Strong support for region-specific growth models indicates that pooled life-history parameters may bias stock assessment outputs, biomass projections and rebuilding expectations, particularly where depleted southern regions are contrasted with stronger northern components. Incorporation of regional biological parameters into future assessment and harvest strategy frameworks is therefore likely to improve model realism and management performance.

The results also suggest that rebuilding should not be judged solely by recruitment presence or short-term abundance signals. While recent year classes were generally evident, recovery of depleted regions will depend more critically on restoration of integrity of the population structure, particularly larger fish, broader age structure, balanced sex composition and resilient spawning biomass. Protection and rebuilding of upper size classes, especially large females, are likely to be central to long-term recovery.

More broadly, the study highlights the importance of integrated monitoring programs that combine length structure, age composition, growth, sex ratios and recruitment indicators. No single metric fully described stock condition, but together these measures provided a coherent picture of regional status and rebuilding need.

Overall, spatial demographic variation appears to be a defining characteristic of Sand Flathead populations in Tasmania. Recognising and managing that variation will be essential if depleted southeast stocks are to rebuild while maintaining the stronger biological condition still evident in northern and northeastern regions.

6 Objective 3: Design, implement and assess the effectiveness of fishery dependent and fishery-independent biological sample collection techniques for Sand Flathead

6.1 Evaluation of Fishery-Independent Survey Design and Spatial Structure in Tasmanian Sand Flathead

6.1.1 Introduction

Previous chapters demonstrated strong spatial structuring in Sand Flathead size composition, age structure, growth, sex ratio and harvest dynamics across Tasmania. Effective rebuilding and future stock assessment now depend not only on understanding these biological differences, but also on whether the fishery-independent survey network adequately captures them through time. Long-term monitoring programs are most valuable when they are statistically robust, biologically informative, and efficient to operate.

Given the limited commercial fishery for Sand Flathead in recent history, the current prohibition on commercial harvest, and the relatively infrequent availability of comprehensive recreational fishery-dependent catch and effort data, length-frequency information from annual IMAS fishery-independent surveys now provides the principal independent basis for monitoring spatial variation and temporal trends in Sand Flathead size structure across Tasmania. Where catch and CPUE data are sparse, uncertain or potentially biased, independent biological sampling and standardised survey indices become especially important for assessing stock condition, demographic trends and management performance (Hilborn and Walters, 1992, Mesnil et al., 2009).

The principal strength of fishery-independent surveys lies in their consistency through time and space. When sampling design is maintained, repeated standardised surveys can provide robust detection of changes in abundance, size structure and regional demographic patterns that may be difficult to infer from fishery-dependent datasets alone (Vecchio et al., 2023). Such data are particularly valuable in recreational fisheries where catch reporting is often incomplete or temporally disparate and effort dynamics can vary through time.

Since 2012, standardised fishery-independent surveys have been undertaken consistently in core regions including the D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays and Great Oyster Bay, with additional northern and northeastern regions incorporated more recently to improve statewide coverage. As the stock has declined and management objectives have shifted toward rebuilding, it is timely to assess whether the existing survey design remains fit for purpose and whether refinements could improve future monitoring and assessment performance.

Interpretation of Sand Flathead length data at broader spatial scales that align with management units must also be supported by confidence that observed patterns reflect coherent population-level structure and genuine temporal trends, rather than localised site effects, sampling variability or artefacts of survey design. This is particularly important where management decisions may depend on distinguishing persistent regional differences from short-term sampling noise.

Accordingly, this chapter evaluates the spatial and temporal performance of the survey program using the accumulated length-frequency dataset. Specifically, analyses examined: (1) the statistical consequences of clustered site-based sampling, (2) the strength and persistence of regional differences in size structure, (3) temporal trends within and among regions, and (4) whether adjacent regions could be combined into broader reporting sectors without loss of biologically meaningful information. The aim was to identify a survey framework that preserves scientific value while improving efficiency for future stock assessment and management.

6.1.2 Methods

Fishery-independent survey length data collected between 2012 and 2025 were collated from all available Tasmanian survey regions (Figure 1; Figure 15). Analyses focused on total length (mm) data summarised as annual and regional length-frequency distributions. As length is measured for every fish sampled during the surveys (i.e., unlike age, sex or maturity which are sampled from a retained subset), length data represent the most complete biological dataset available across the monitoring program. Results are compared across financial year (FY; July to June) as most sampling has been conducted in the first three months of the calendar year but surveys have occasionally begun before the new year.

Because fish were sampled from multiple fixed sites nested within broader survey regions, observations were not statistically independent. To quantify the extent of clustering in fish lengths within sites, intraclass correlation coefficients (ICC) were estimated for annual regional datasets. Associated design effects (DEFF) were then calculated to evaluate the reduction in effective sample size arising from clustered sampling. In practical terms, these analyses were used to assess whether survey precision would be improved more efficiently by increasing the number of fish sampled (and therefore measured) at existing sites or by increasing the number of independently sampled sites.

Regional differences in annual size composition were quantified using the first Wasserstein distance (W_1), which measures the minimum redistribution required (in mm of flathead length) to transform one length-frequency distribution into another and therefore provides an intuitive measure of overall separation between two samples (e.g., between two annual or regional survey length frequencies). Pairwise regional comparisons were undertaken within survey years. To account for the hierarchical survey design, uncertainty around W_1 estimates was quantified using site-aware bootstrap resampling. Statistical significance of pairwise differences was assessed using site permutation procedures that preserved site structure.

Shape differences in annual regional length frequencies were further explored using principal components analysis (PCA) applied to binned length-frequency data, allowing visualisation of similarities among regions and identification of the principal gradients in size composition through time.

Temporal trends in length structure were examined using linear mixed-effects models, with year and region fitted as continuous fixed effects and random effects for sites within regions. To assess whether temporal change differed across portions of the length frequency distribution not reflected in the mean, generalised additive models (GAMs) were also fitted to lower, median and upper quantiles of fish length.

To evaluate opportunities for simplifying future reporting units, alternative regional pooling scenarios were compared with W_1 distances, mixed-model fit statistics, temporal trend coherence, and biological interpretability. Candidate region pooling structures included a three coastal sector and a four coastal sector scenario. The preferred framework was selected based on retaining meaningful biological differences while improving monitoring efficiency and assessment practicality.

Full technical methods, equations, model diagnostics and supplementary pairwise W_1 comparison outputs are provided in Appendix 18.1

6.1.3 Results

6.1.3.1 Survey coverage and data utility

The fishery-independent survey program now spans 14 consecutive financial years (2011/12 to 2024/25) and represents the most extensive standardised independent biological dataset currently available for Sand Flathead in Tasmania. The three long-term monitoring regions, D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays, and Great Oyster Bay, have been sampled annually throughout the series, providing an uninterrupted time series across the southeast and east coast (Figure 36). Across these core regions, annual sample sizes were consistently strong, averaging approximately 235 in the Channel, 227 in Frederick Henry–Norfolk Bays, and 229 in Great Oyster Bay.

From 2020/21 onward, the survey footprint expanded beyond the original core regions to include Mercury Passage, St Helens Inside, St Helens Outside, Bridport, Tamar Inside, Tamar Outside, Stanley, and intermittent sampling of Flinders Island (Figure 36a). This expansion improved survey coverage into northeastern, northern, northwestern coastlines and estuarine environments, allowing comparison between historically depleted south-eastern regions and regions supporting stronger contemporary size structure.

Survey intensity varied among the expanded regions. Average annual sample sizes were relatively high at Mercury Passage (215 fish), and moderate at Bridport (99 fish) and Stanley (92 fish), Tamar Outside (136 fish) and Flinders Island (144 fish), and lower in the split estuarine/coastal designs at Tamar Inside (49 fish), St Helens Inside (51 fish) and St Helens Outside (55 fish).

Differences in annual sample size reflected variation in both the number of sites surveyed and realised catch rates. Core long-term regions typically sampled 17-21 sites per year, while Mercury Passage and Bridport generally sampled 13–14 sites. Split estuarine/coastal regions at Tamar and St Helens typically sampled 5-10 sites per component, depending on year and logistics (Figure 36b). Flinders Island surveys were more opportunistic, with 29 sites sampled in 2023/24, with two other years contributed catch totals without a fully structured fixed-site design.

Catch rates per site also varied markedly through time within regions (Figure 36c), indicating that survey information content depended not only on planned effort but also on realised local abundance or catchability. Annual mean catch rates per site ranged from 4.5–19.6 fish $site^{-1}$ in the long-term core regions. Some expanded regions also had variable average annual catch rates, for example St Helens Inside between 3.9 and 20.5 fish $site^{-1}$, and Stanley 8.5 to 27.9 fish $site^{-1}$. Such variability is important because it directly influences the precision of annual regional estimates and the power to detect temporal change.

Taken together, the survey program provides two complementary strengths. First, the long-running southeast and east coast series provide the statistical continuity required to evaluate long-term change and rebuilding trajectories. Second, the expanded statewide sampling since 2020/21 provides the geographic breadth to monitor the broader Sand Flathead population.

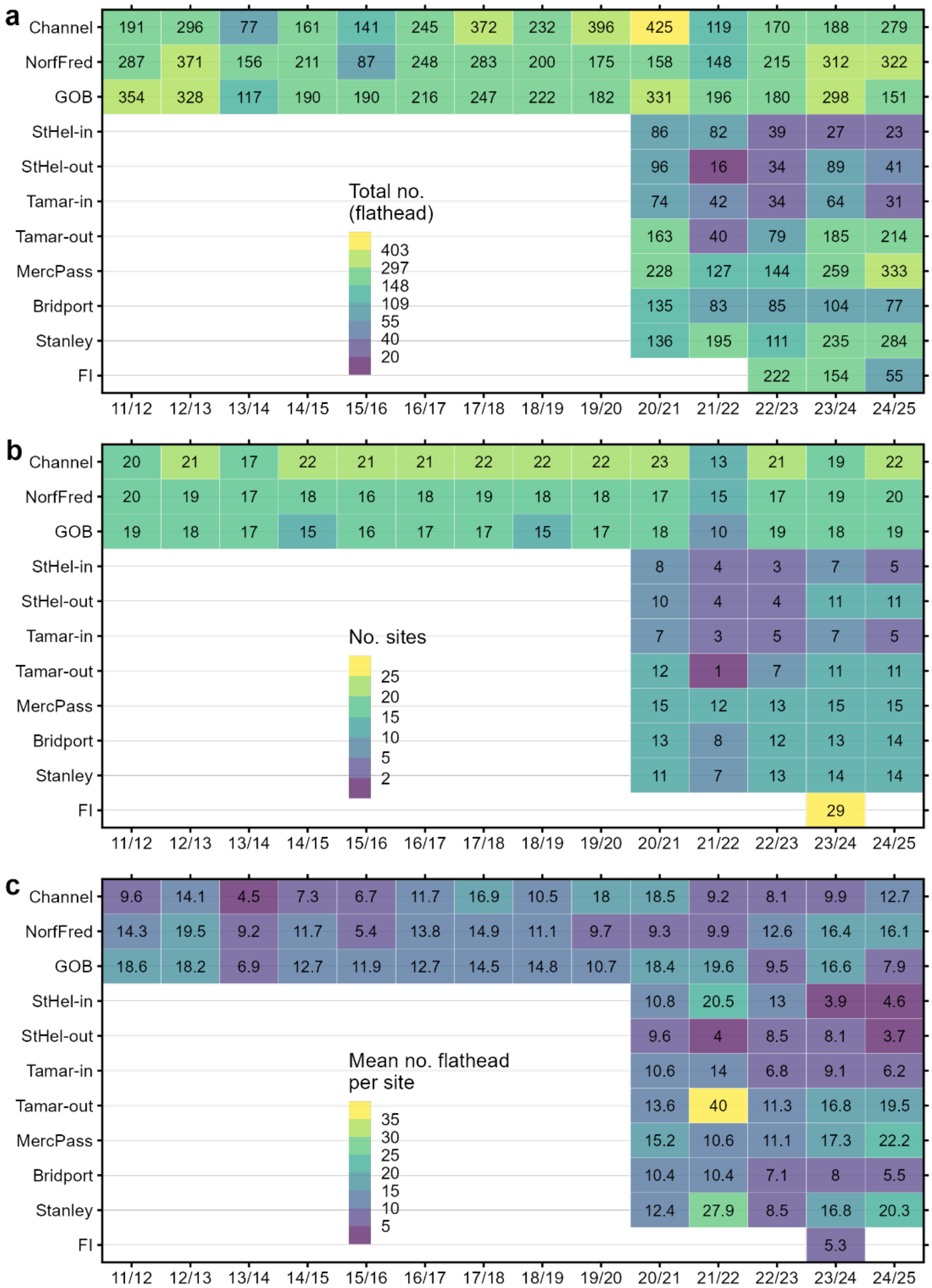


Figure 36. Overview of Sand Flathead fishery-independent survey sampling activity by region across financial year, including total samples (i.e., measured Sand Flathead); a), number of sites surveyed (b) and average number of samples per site (c). Flinders Island (FI) samples in 2022/23 and 2024/25 were not collected across structured survey sites so only appear in (a).

6.1.3.2 Survey design effect

Fish lengths were frequently clustered within sampling sites, consistent with localised aggregation of size classes across sites within survey regions. Across annual regional surveys, intraclass correlation coefficients (ICC) of mean length estimates were almost always greater than 0.05 and commonly exceeded 0.20, indicating substantial non-independence at the site level that must be statistically accounted for in analyses (Figure 37). In several cases, ICC values approached or exceeded 0.30. Quantile specific-ICCs were typically greater lower and upper ends of the length distribution (see Appendix Figure 87).

This clustering translated directly into reduced survey efficiency. Design effects (DEFF) for the pairwise regional Wasserstein distance (W_1) comparisons that are subsequently used to test for difference in length frequencies among regions were routinely greater than 2, and in some cases exceeded 3, indicating that the effective sample size of annual regional surveys was often reduced by half or more relative to the nominal number of fish measured. In practical terms, a survey measuring 200 fish under a DEFF of 2 would provide information equivalent to approximately 100 independently sampled fish. Full pairwise DEFF comparisons are presented in Appendix Figure 88.

These results demonstrate that survey precision is driven not only by the number of fish measured within sites but also the number of independent sites sampled. Increasing site replication would therefore often provide greater statistical benefit than increasing sampling effort at existing sites. Collectively, the findings confirm that the hierarchical survey design captures meaningful spatial structure in Sand Flathead length data, but that site-level clustering must be explicitly accounted for in analysis. Accordingly, all subsequent analyses were undertaken using statistical methods that considered site level clustering.

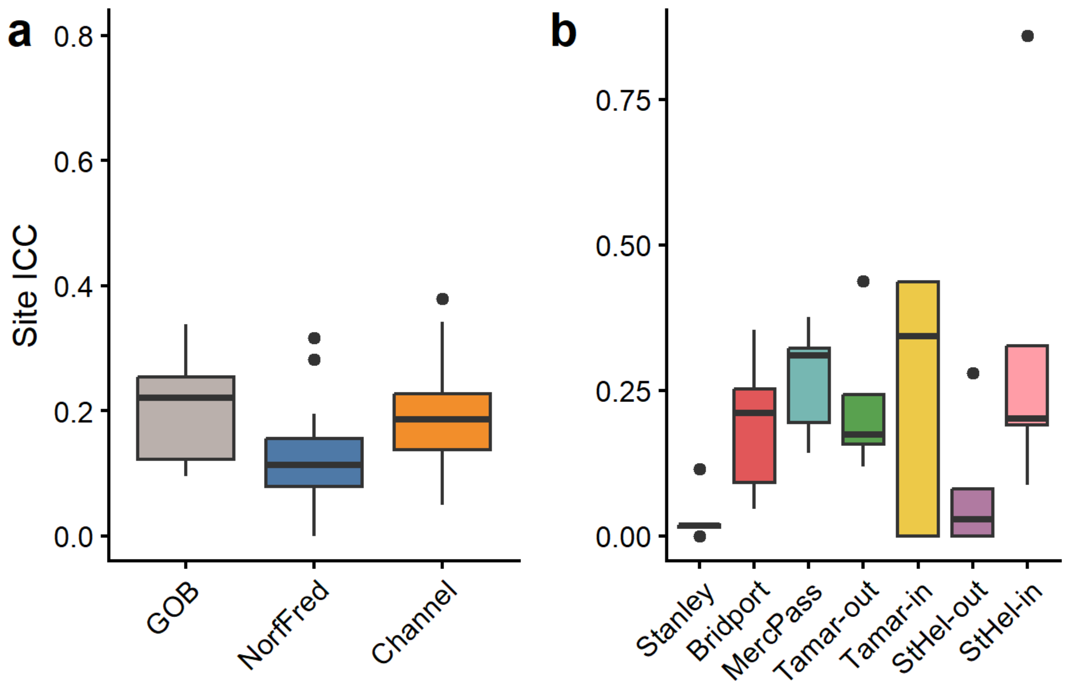


Figure 37. Summary of intraclass correlation (ICC) of Sand Flathead lengths of sites among regions per financial year for long-term (a) and expanded (b) survey regions. An ICC of 0.2 is considered substantial enough to require clustering (i.e., site structure of the survey) to be accounted for when comparing regions.

6.1.3.3 Regional differences in length composition

Marked regional differences in Sand Flathead size structure were evident throughout the monitoring program and remained broadly consistent through time. Across the long-term monitored regions (D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays, and Great Oyster Bay), south-eastern Tasmania consistently supported smaller fish and more truncated length-frequency distributions than Great Oyster Bay, a pattern evident since 2011/12 (Figure 38).

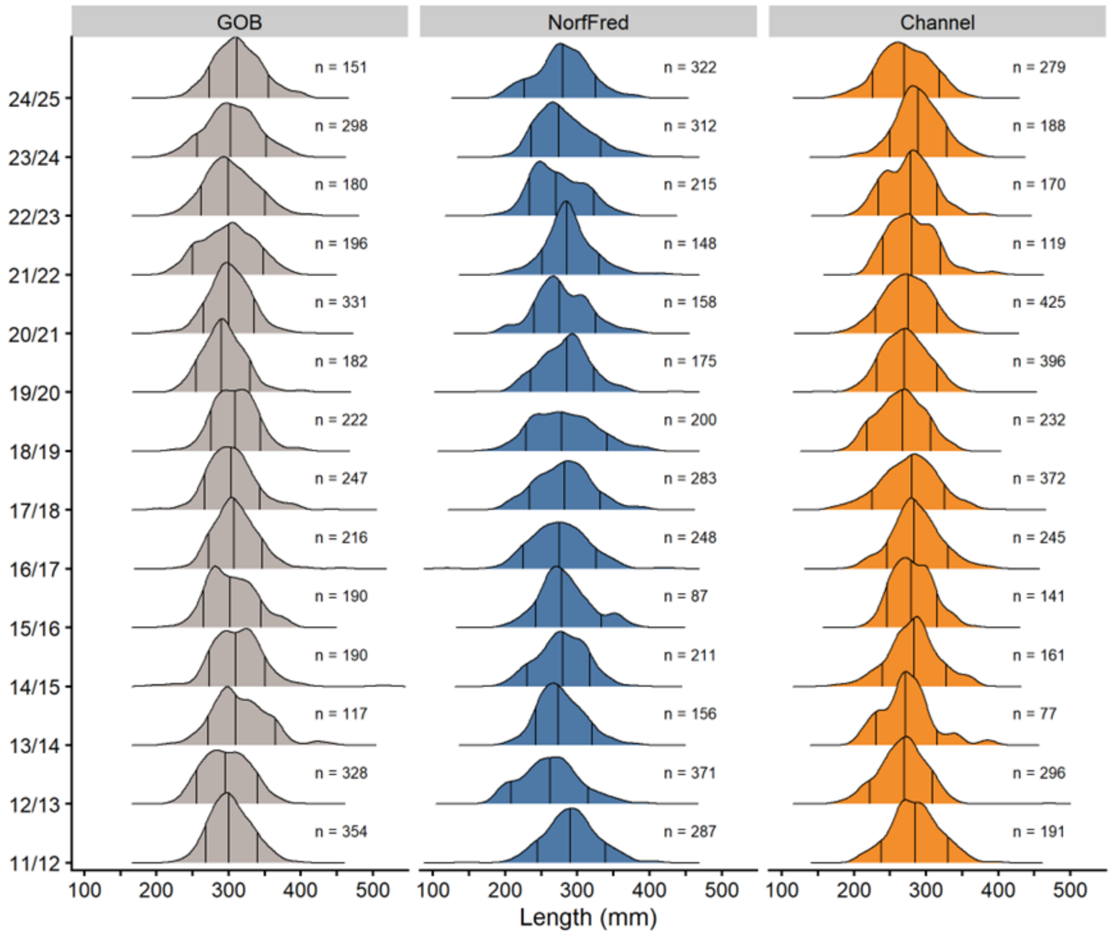


Figure 38. Regional length-frequency densities of Sand Flathead total lengths (mm) across long-term survey sites (GOB: Great Oyster Bay; NorfFred: Norfolk and Frederick Henry Bays; Channel = D'Entrecasteaux Channel) surveyed annually since financial year (Jul-Jun) 2011/12. Densities are scaled to equal area under the curve, and vertical lines denote the 10th percentile, median, and 90th percentile length quantiles for each Samples sizes for each length frequency are indicated by '*n*'.

Following expansion of the statewide survey network from 2020/21, broader spatial contrasts became clearer (Figure 39). Northern and northeastern Tasmania generally supported stronger size structure than the southeast. Flinders Island consistently displayed the largest fish statewide, with broad distributions extending well into upper size classes. Bridport and St Helens Outside also supported larger median and upper quantile lengths than south-eastern regions, while Great Oyster Bay and Mercury Passage were typically intermediate.

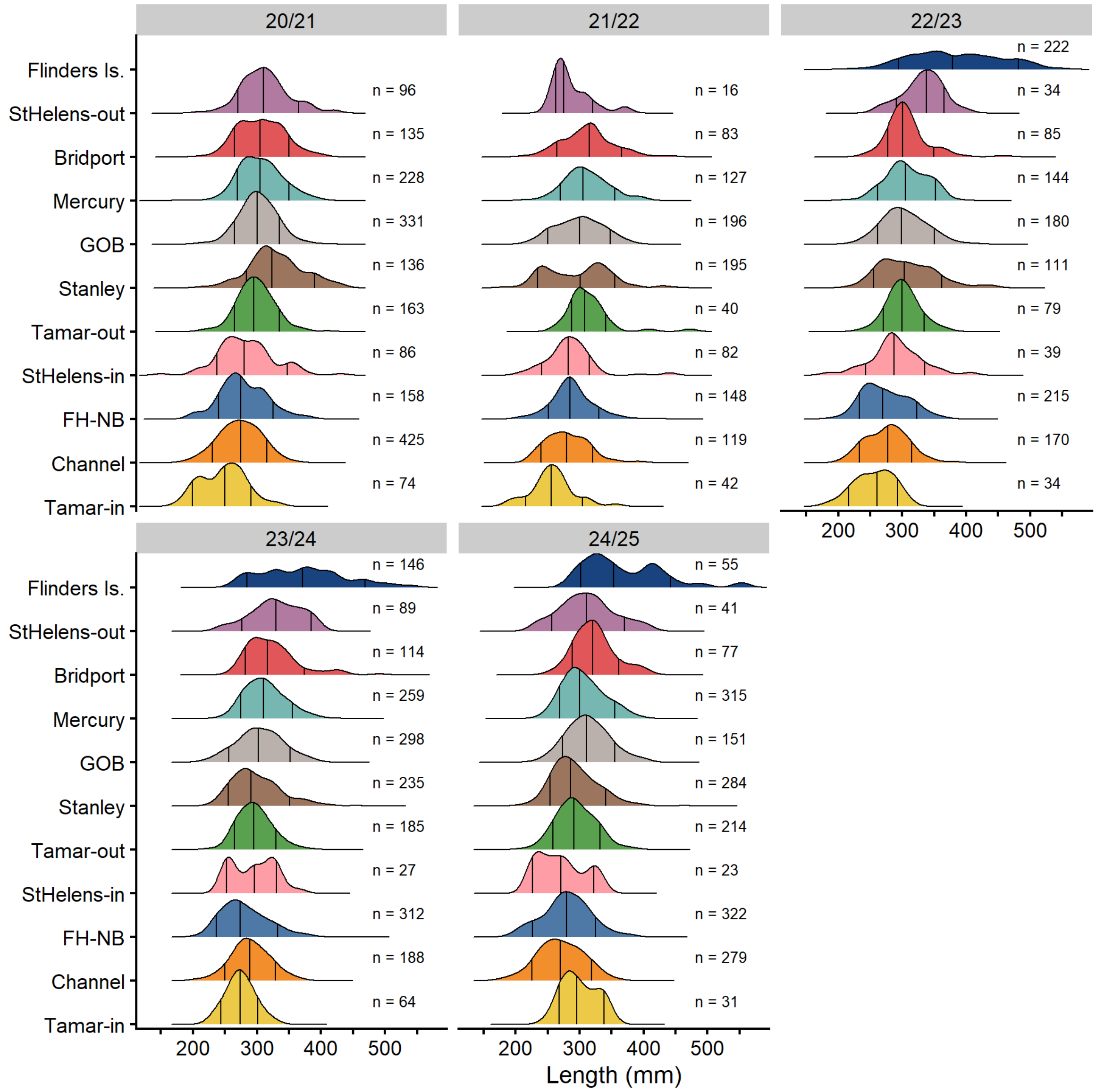


Figure 39. Regional length-frequency densities of Sand Flathead total lengths (mm) across all regions surveyed annually since financial year (Jul–Jun) 2020/21. Densities are scaled to equal area under the curve, and vertical lines denote the 10th percentile, median, and 90th percentile length quantiles for each Samples sizes for each are indicated by 'n'. Tamar-in and St Helens-in refer to sites inside the Tamar estuary and Georges Bay, respectively. The order of regions on the y-axis in each plot is the same for comparison and identification of relative regional length shifts year to year. Flinders Island samples collected in three of the surveys are presented as an outgroup.

Formal pairwise comparisons of annual regional length frequencies supported these visual patterns. The greatest and most persistent separation occurred between south-eastern regions and northeastern regions, whereas several geographically adjacent regions showed high similarity. In particular, Great Oyster Bay and Mercury Passage were consistently similar (W_1 < 10 mm), indicating largely redundant information in terms of size structure (Appendix Figure 92). By contrast, south-eastern regions remained distinct from Great Oyster Bay in almost all years, while Bridport increasingly diverged from Tamar Outside in later years through greater representation of larger fish (Appendix Figure 93; Appendix Figure 94). Length frequencies at Bridport and St Helens Outside were generally similar across years, supporting their treatment as a broader northeastern sector in subsequent analyses (Appendix Figure 95).

Comparisons between estuarine and adjacent coastal regions revealed additional fine-scale structuring. At St Helens, inside (Georges Bay) samples were consistently smaller than outside coastal samples, with significant differences in 2023/24 and 2024/25 and Wasserstein distances of approximately 40 mm (Figure 40). In the Tamar, inside and outside regions differed significantly in multiple years, with W_1 values up to ~60 mm, although these differences declined through time as lengths increased in the estuary while outer coastal samples remained relatively stable (Figure 41). These results indicate that estuarine populations were generally smaller than adjacent coastal populations.

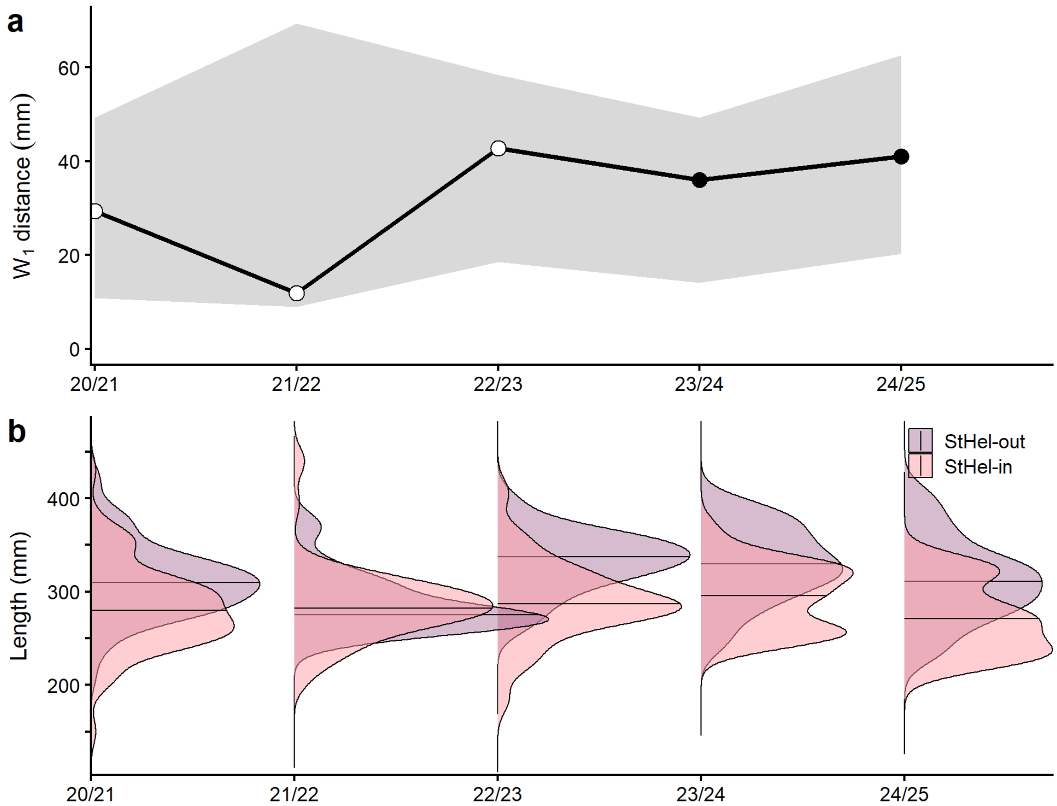


Figure 40. Wasserstein distance between length frequencies from surveys at St Helens-inside and St Helens-outside per financial year (a). 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected. b) Density plots of the two regions in each financial year overlaid to illustrate differences, horizontal lines indicate the median length of each region.

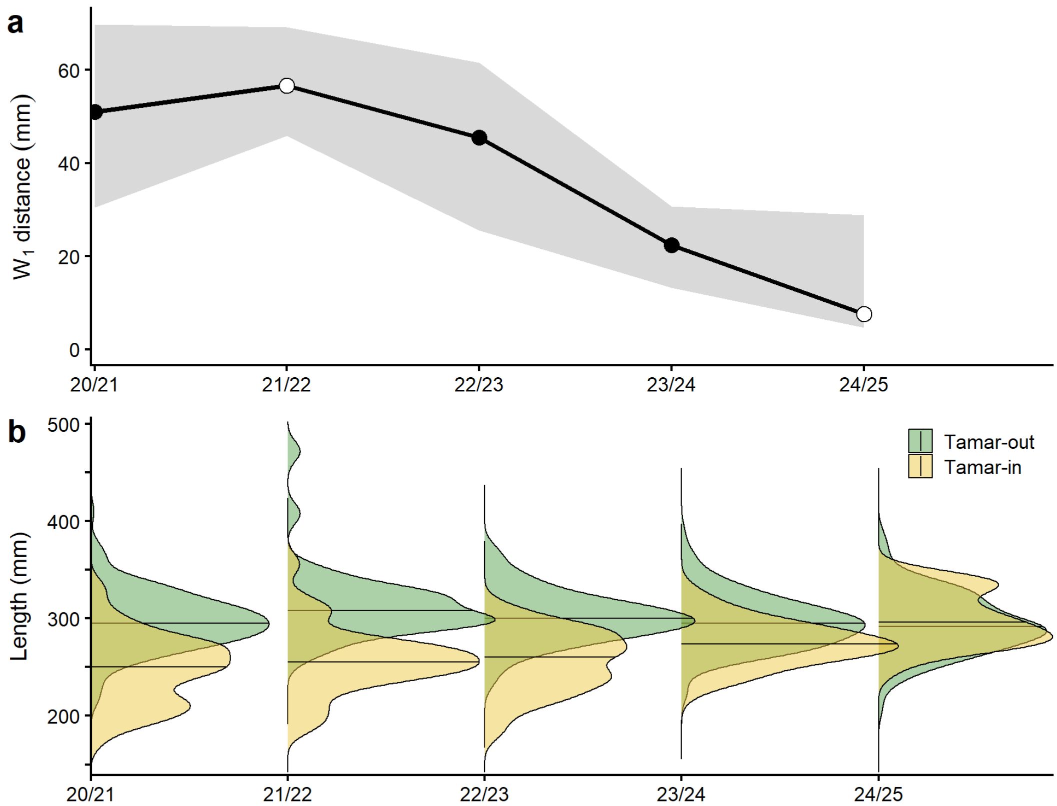


Figure 41. Wasserstein distance between length frequencies from surveys at Tamar-inside and Tamar-outside, per financial year (a). 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected. Below (b) are density plots of the two regions in each financial year overlaid, horizontal lines indicate the median length of each region.

Ordination analyses likewise identified a primary statewide gradient from small south-eastern sizes to larger-fish northeastern and northern regions, with estuarine samples from the Tamar and Georges Bay occupying distinct positions from adjacent coastal regions (Appendix Figure 89; Appendix Figure 90). A secondary gradient of narrow to broader-shaped length distributions was identified, with Flinders Island the broadest, followed by Stanley, Tamar-Inside, and St Helens-Outside.

Collectively, these results indicate that Sand Flathead size composition in Tasmania is strongly regionally structured. Some neighbouring regions provide overlapping information, whereas others capture persistent biological differences in mean size, upper-size structure, and demographic composition. Statewide stock condition therefore cannot be adequately represented by a single pooled length-frequency signal.

6.1.3.4 Region-specific temporal trends in size structure

Given the strong spatial structure evident among regions, temporal trends were evaluated within regions rather than across pooled statewide data. Among the long-term monitored regions (Great Oyster Bay, Frederick Henry–Norfolk Bays, and the Channel), length-frequency distributions were broadly consistent through the fourteen-year span of the dataset, with limited evidence of substantial year-to-year change (Figure 38). Pairwise comparisons of length structures across survey years detected no significant annual differences in Great Oyster Bay, only three significant contrasts in Frederick Henry–Norfolk Bays, and seven significant contrasts in the Channel from the 91 pairwise year combinations available across the 14-year series, indicating generally stable size structure in these core regions (Appendix Figure 96).

Linear mixed-model comparisons indicated that the most appropriate random-effects structure included correlated random intercepts and slopes for sites, allowing both site-specific mean lengths and temporal trajectories to vary within regions. For the long-term regions, only region was a significant fixed effect ($p = 0.003$), whereas neither year ($p = 0.982$) nor the region × year interaction ($p = 0.670$) was significant (Table 13; Figure 42). This indicates persistent differences in mean size among these regions, but no evidence of directional temporal change or differing trends through time.

Table 13. Type III Analysis of Variance (ANOVA) of the long-term survey regions length linear mixed model.

Term	Sum of Squares	Mean Square	Numerator DF	Denominator DF	F value	*p* value
year	0.6	0.587	1	57.713	0.001	0.9820
region	14,787.0	7,393.5	2	59.524	6.463	**0.0029**
year:region	924.3	462.1	2	57.786	0.404	0.6695

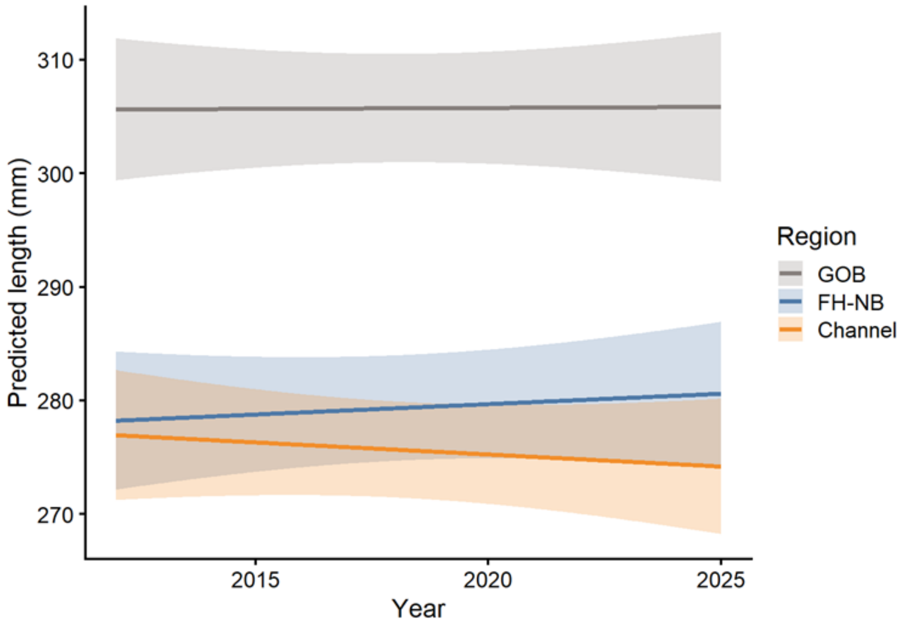


Figure 42. Predicted mean length (±95% CI) by region across years among the long-term survey regions.

By contrast, the expanded regional model showed significant effects of year ($p = 0.014$), region ($p < 0.001$) and their interaction ($p < 0.001$), demonstrating that both absolute size structure and temporal trends differed among regions (Table 14. Figure 43). An omnibus test of regional slopes was also significant ($F = 7.861$, $p < 0.001$), supporting estimation of region-specific trends.

Table 14. Type III Analysis of Variance (ANOVA) of the expanded survey regions length linear mixed model.

Term	Sum of Squares	Mean Square	Numerator DF	Denominator DF	F value	*p* value
year	7,554.1	7,554.1	1	63.6	6.430	**0.014***
region	68,532.4	11,422.1	6	54.0	9.722	**0.000***
year:region	63,697.3	10,616.2	6	54.5	9.036	**0.000***

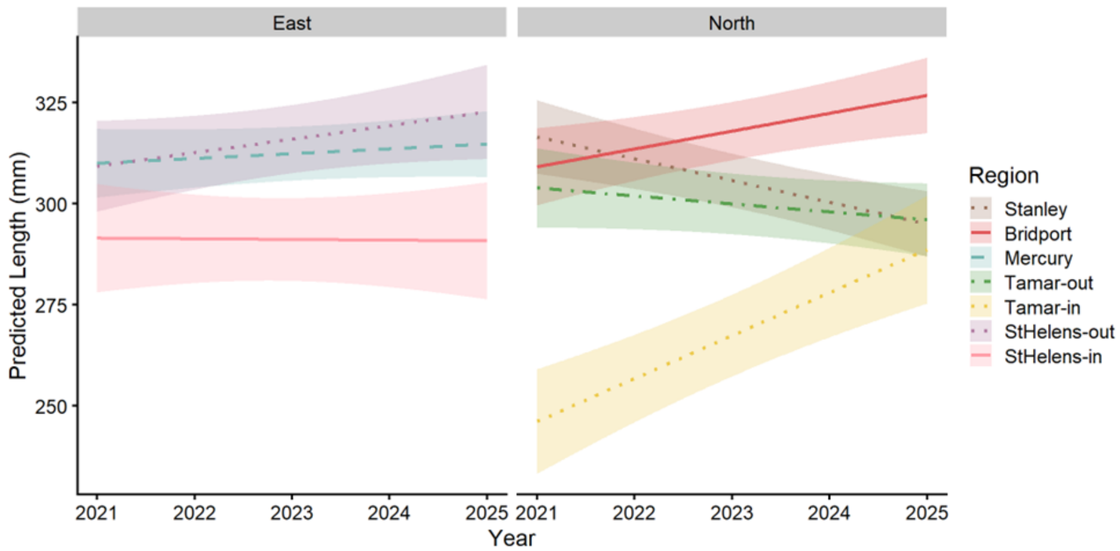


Figure 43. Predicted mean length (±95% CI) by region across years among the expanded survey regions.

The strongest negative trend occurred at Stanley, where mean length declined by −5.38 mm yr^{-1} (95% CI: −8.11 to −2.65 mm yr^{-1}). In contrast, significant positive trends were detected at Bridport (+4.41 mm yr^{-1}, 1.36 to 7.46), and Tamar Inside (+10.63 mm yr^{-1}, 6.43 to 14.84). Other regions showed no statistically significant directional change, including Mercury Passage (+1.19 mm yr^{-1}), Tamar Outside (−1.97 mm yr^{-1}), St Helens Outside (+3.36 mm yr^{-1}) and St Helens Inside (−0.16 mm yr^{-1}) (Table 15; Figure 43).

Table 15. Estimated marginal mean trends of Sand Flathead length for each survey region. *p* values indicate whether trends were significantly different than 0 (i.e., no trend). CLs indicate 95% confidence intervals in the trends in mm yr^{-1}. Note the long-term regions (GOB, NorfFred, Channel) were estimated from a separate model due to the difference in survey years available.

Survey Region	year slope (mm/yr)	SE	df	Lower CL	Upper CL	*p* value
Stanley	-5.38	1.37	63.5	-8.11	-2.65	**<0.001**
Bridport	4.41	1.53	85.7	1.36	7.46	**0.005**
Mercury	1.19	1.24	43.6	-1.31	3.68	0.342
Tamar-out	-1.97	1.42	48.3	-4.82	0.88	0.170
Tamar-in	10.63	2.12	91.8	6.43	14.84	**<0.001**
StHelens-out	3.36	1.95	128.5	-0.49	7.22	0.087
StHelens-in	-0.16	2.38	112.0	-4.89	4.56	0.946
GOB	0.02	0.33	55.8	-0.64	0.68	0.959
FH-NB	0.18	0.32	53.3	-0.45	0.82	0.565
Channel	-0.21	0.31	67.5	-0.83	0.41	0.496

Pairwise slope contrasts further showed that most significant differences involved Stanley or Tamar Inside, the regions with the most negative and most positive trajectories respectively (Appendix Table 36). Quantile trend analyses indicated that temporal changes were not uniform across the size distribution (Appendix Figure 98). For example, the decline at Stanley was driven largely by contraction of the upper size range (90th percentile declining from approximately 390 mm to 350 mm), whereas Tamar Inside showed an upward shift across the full distribution, particularly through loss of smaller fish from the lower tail. Bridport exhibited a broadly consistent upward shift in size composition through time.

Collectively, these results indicate that most long-term coastal regions remained relatively stable through time, whereas several northern and estuarine regions exhibited stronger recent changes in size structure, with some regions improving and others declining.

6.1.3.5 Optimisation of regional monitoring and reporting units

Given the strong and persistent regional structure in Sand Flathead size composition, candidate pooling schemes were evaluated to determine whether broader coastal sectors could be reported without substantial loss of biological resolution. Two alternative structures were assessed: a three-sector scheme (North, East, Southeast) and a four-sector scheme that separated a distinct Northeast region from the northern and eastern coasts (Table 16; Figure 44).

Table 16. Two candidate coastal grouping schemes investigated for pooled regional length frequency analyses of fishery-independent Sand Flathead survey regions.

<table>
<tr><th>Survey region</th><th>Three sectors</th><th>Four sectors</th></tr>
<tr><td>Great Oyster Bay</td><td rowspan="3">East</td><td rowspan="2">East</td></tr>
<tr><td>Mercury Passage</td></tr>
<tr><td>St Helens-outside</td><td rowspan="2">Northeast</td></tr>
<tr><td>Bridport</td><td rowspan="3">North</td></tr>
<tr><td>Stanley</td><td rowspan="2">North/NW</td></tr>
<tr><td>Tamar-outside</td></tr>
<tr><td>D’Entrecasteaux Channel</td><td rowspan="2">Southeast</td><td rowspan="2">Southeast</td></tr>
<tr><td>Frederick Henry & Norfolk Bays</td></tr>
</table>

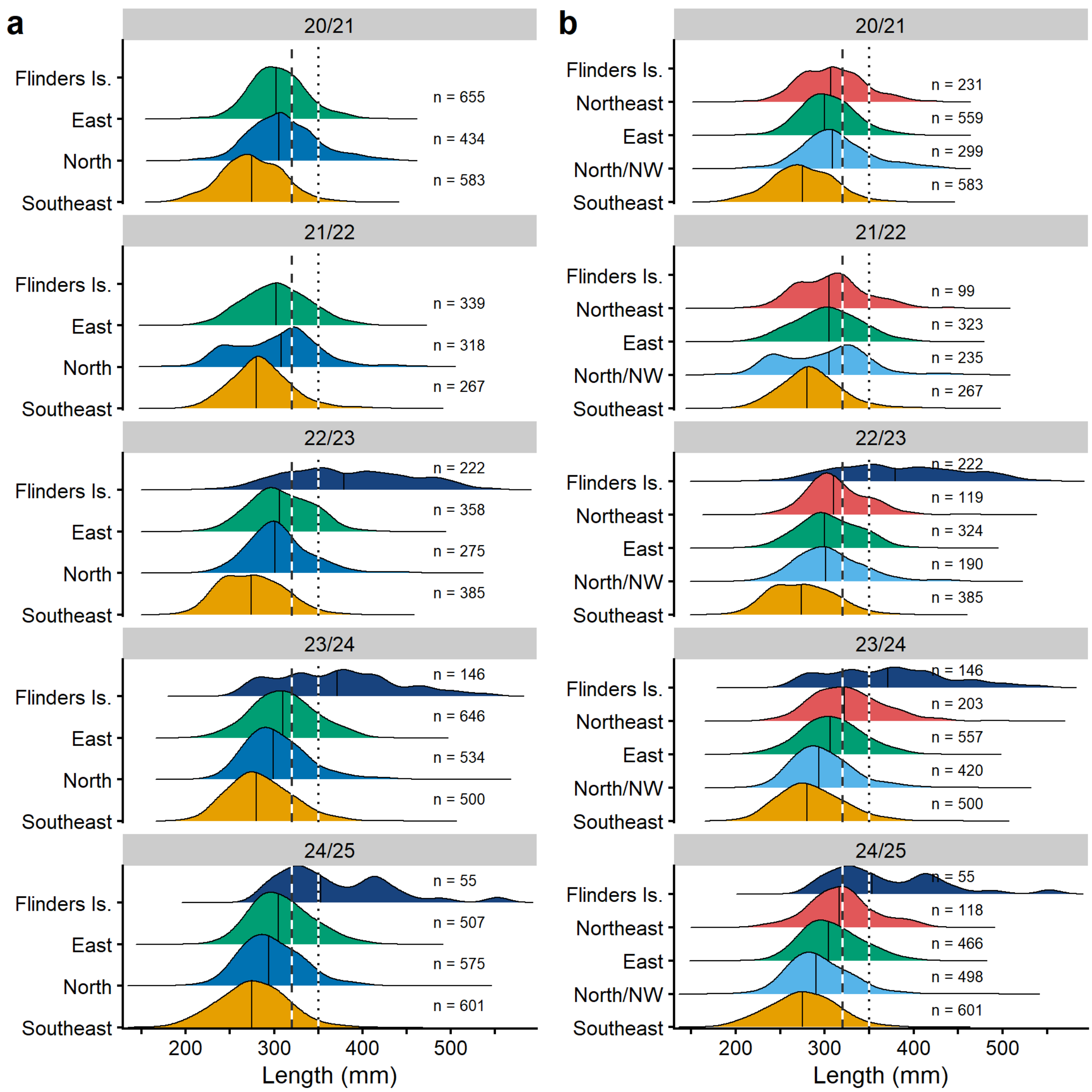


Figure 44. Length-frequency densities of flathead total lengths (mm) by coastal sector, under (a) the three-sector scheme and (b) the four-sector scheme. See Table 16 for sector assignments of survey regions. Densities are scaled to equal area under the curve, and vertical solid line denotes the median for each while the dashed and dotted lines are the former and current regulated minimum size limit for flathead of 320 mm and 350 mm respectively. Total samples sizes for each survey year are indicated by '*n*'. The order of regions on the y axis in each plot is the same for comparison and identification of relative regional length shifts year to year. Flinders Island samples collected in three of the survey years are presented as an outgroup.

Comparisons of pooled length-frequency distributions showed that the four-sector framework provided clearer spatial discrimination among regions. Under this structure, the North/Northwest, Northeast and East sectors length frequencies were significantly different from the Southeast in all recent survey years, with Wasserstein distances of 13.5–43.2 mm (Figure 45). Differences between the East and Northeast sectors were weaker but became significant in 2023/24 (W_1 = 16.4 mm), with a similar but non-significant pattern evident in 2024/25 (W_1 = 10.4 mm, p = 0.15), likely reflecting lower sample size in the Northeast that year (n = 117). Both the East and Northeast sectors were also significantly different from the North/Northwest in the final two survey years, with distances of 11.0–26.5 mm.

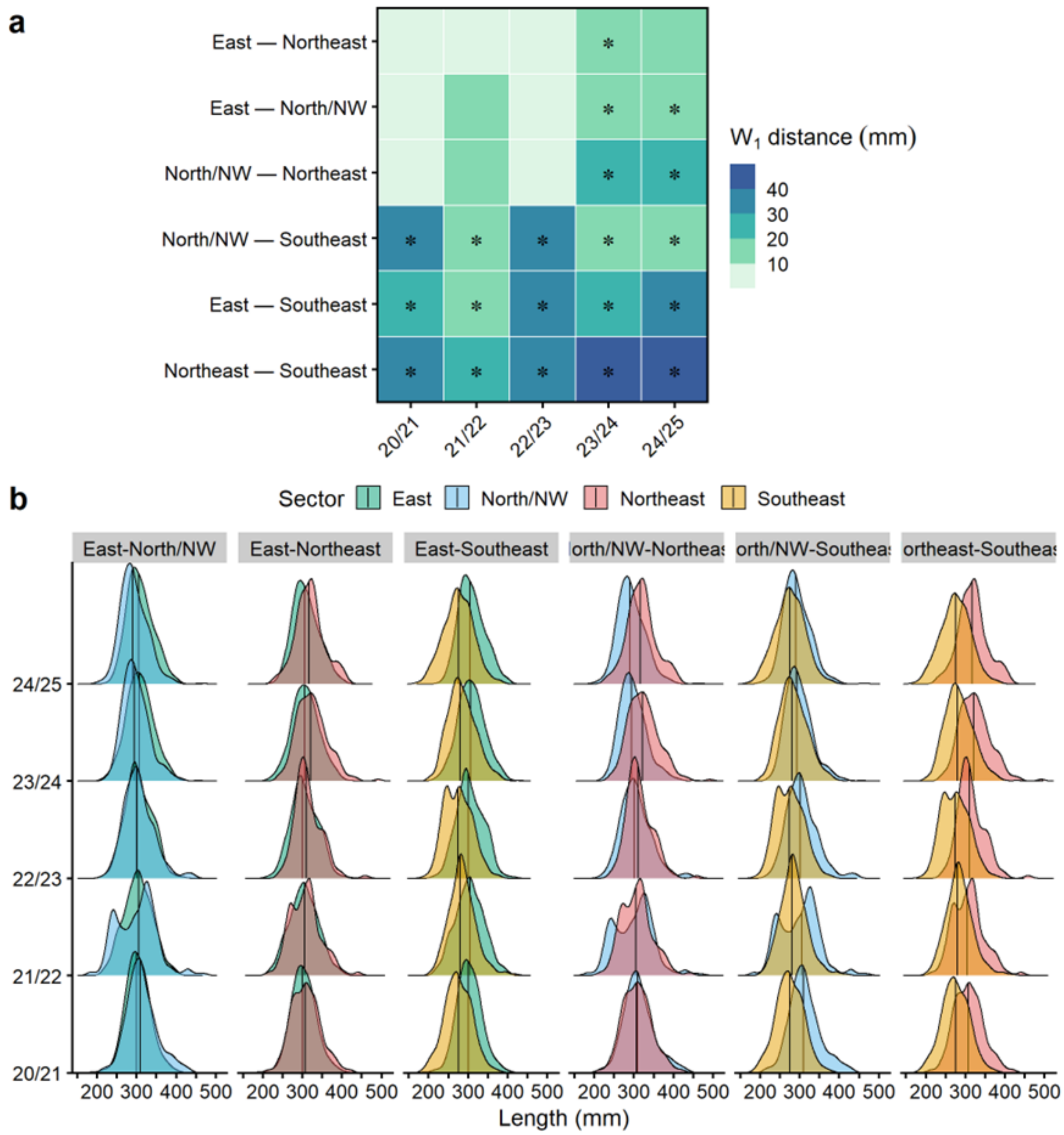


Figure 45. Wasserstein distance between length frequencies from coastal sectors classified with the four coastal sector scheme (North-Northwest, Northeast, East, Southeast; a). Significant differences are indicated by asterisks; (b) Density plots of the four coastal sectors in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each coastal sector.

By contrast, the three-sector scheme masked some of this emerging structure. The pooled East and North sectors were not significantly different in 2020/21–2022/23, with significant separation only appearing in the final two survey years (W1 = 10.5 and 12.4 mm) (Figure 46). This indicates that combining northeastern sites with broader East and North sectors reduced sensitivity to biologically meaningful regional contrasts.

Mixed-model comparisons of fish length further supported the four-sector framework. Models using the four-sector classification provided a better fit than equivalent three-sector models ($\Delta AIC = 45$), and likelihood ratio testing confirmed that the additional regional parameterisation was justified ($p < 0.001$).

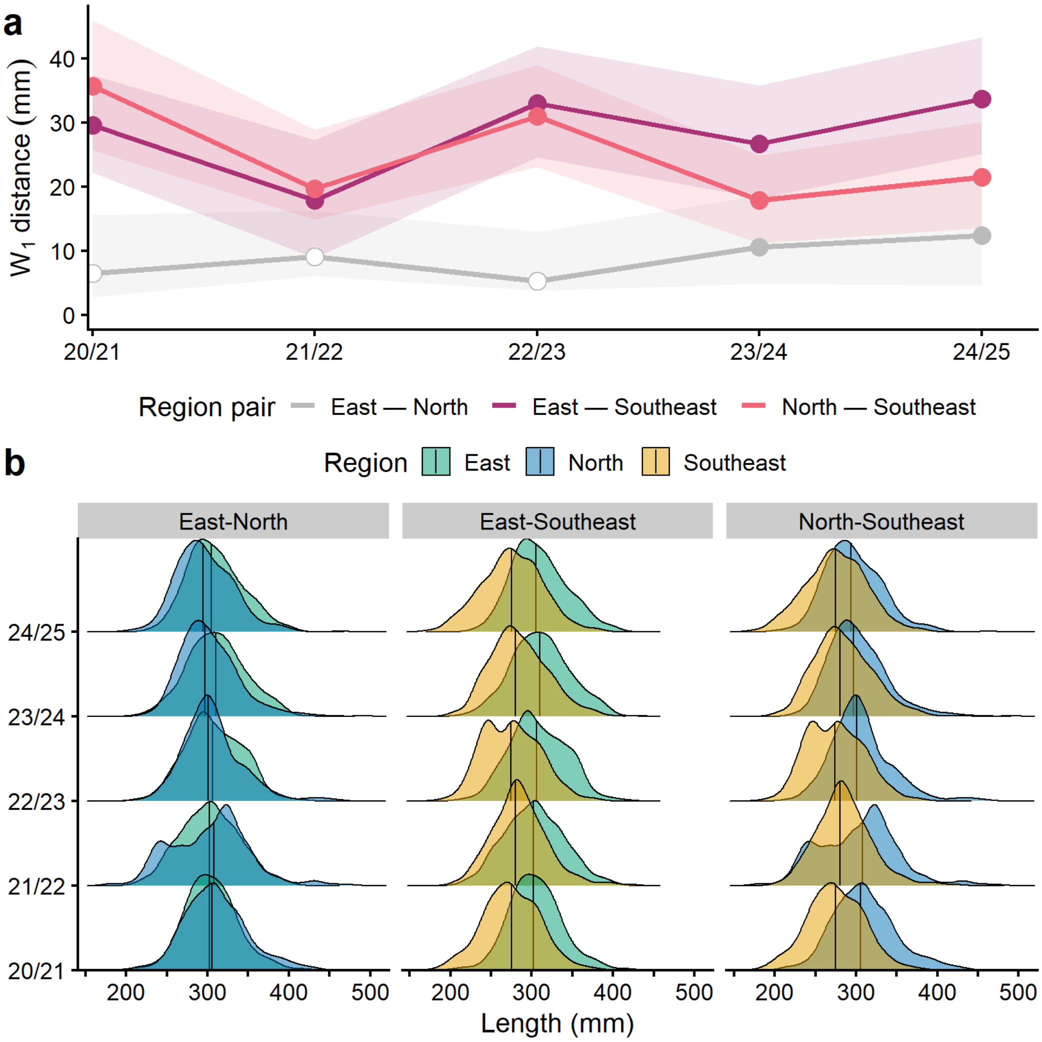


Figure 46. Wasserstein distance between length frequencies from coastal sectors with the three coastal sector scheme (North, East, Southeast; a). 95% confidence intervals are represented by bands, solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between coast length frequencies detected: (b) Density plots of the three coastal sectors in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each coastal sector.

Estimated mean length in the most recent survey year (2024/25) also demonstrated improved biological resolution under the four-sector structure (Figure 47). Mean length was highest in the Northeast (326 mm, 95% CI: 319–332 mm), followed by the East (312 mm, 307–317 mm), North/Northwest (296 mm, 291–302 mm), and lowest in the Southeast (278 mm, 274–283 mm). All pairwise contrasts were significant. Under the three-sector scheme, this finer northeast signal was obscured as the contribution of larger fish from Bridport and St Helens-outside were diluted when combined with North and East sector regions.

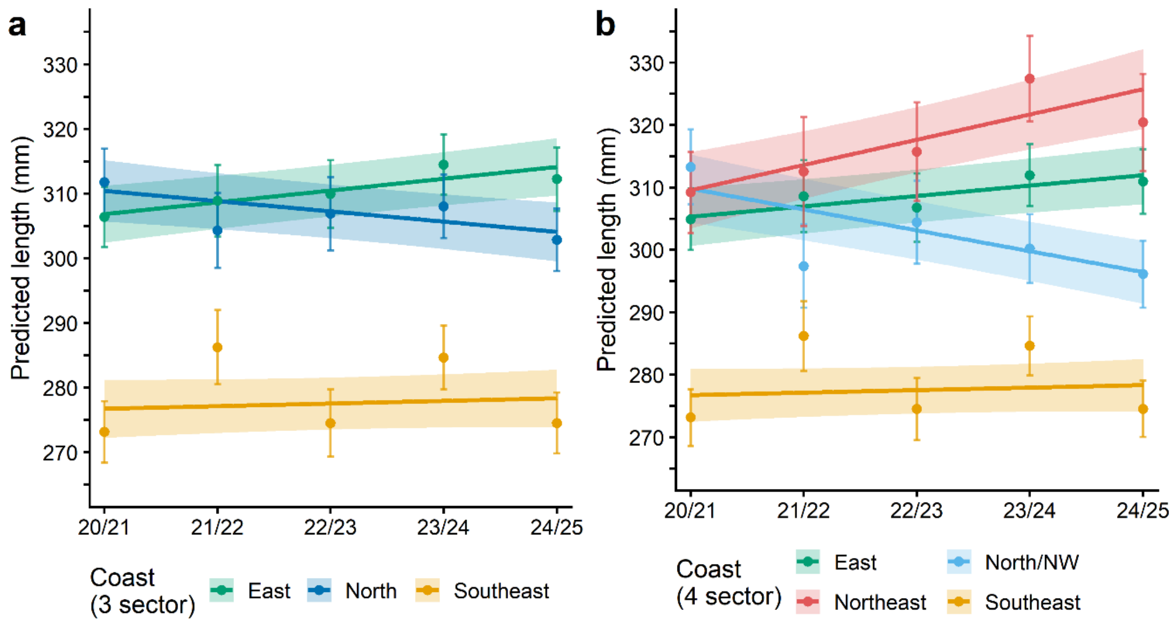


Figure 47. Estimated trends from linear mixed models using the 4-sector (a) and 3-sector (b) coast groups for pooling fishery-independent survey regions. The Northeast sector (a) includes Bridport and St Helens-outside, which are included in the 3-sector classification (b) as North and East, respectively. Bands represent 95% confidence intervals (CIs) The points represent annual estimates from the same model with survey FY treated as a categorical predictor rather than continuous (mean and 95% Cis).

Temporal trends in mean length also differed more clearly under the four-sector framework. Mean size increased most strongly in the Northeast (+3.90 mm yr^{-1}, 95% CI: 2.17 to 5.64), increased more modestly in the East (+1.66 mm yr^{-1}), declined sharply in the North/Northwest (−3.34 mm yr^{-1}), and showed little directional change in the Southeast (+0.40 mm yr^{-1}) (Table 17).

Table 17. Estimated marginal mean flathead length trends by coastal sector from linear mixed models. The southeast sector's trend was unchanged between coastal pooling schemes so only appears once.

Pooling scheme	Coastal sector	Trend (mm yr^{-1})	SE	95% CI Lower	95% CI Upper
3-sector	East	1.82	0.48	0.88	2.77
3-sector	North	−1.59	0.54	−2.63	−0.54
3-sector	Southeast	0.41	0.50	−0.58	1.39
4-sector	East	1.66	0.51	0.66	2.66
4-sector	Northeast	3.90	0.89	2.17	5.64
4-sector	North/NW	−3.34	0.61	−4.53	−2.15
4-sector	Southeast	0.40	0.50	−0.58	1.39

Temporal consistency within pooled sectors also improved under the four-sector framework. Year-to-year tests of differences among sectors of pooled length frequencies showed that the North/Northwest under the four-sector grouping exhibited a clearer signal of changing length frequencies from the beginning to the end of the data series which was obscured when combined with Bridport into the North under the three-sector grouping (Appendix Figure 99). This indicates that the finer four-sector arrangement revealed more biologically coherent signals in length through time.

Additional support for the four-sector grouping structure is provided by analysis of fish relative to the historical and current legal minimum size limits. Under the four-sector structure, only 12.5% of fish in the Southeast exceeded 320 mm and 2.9% exceeded 350 mm, compared with 43.6% and 18.1% respectively in the Northeast. Quantile GAM outputs also showed that sectoral trends reflected coherent shifts across the full-size distribution rather than isolated changes in one component of the stock (Appendix Figure 100; Appendix Table 37).

Collectively, these analyses indicate that the four-sector structure provides the most effective balance of statistical support, temporal coherence, practical reporting scale, and biological interpretability. It better resolved persistent differences in mean size, size-limit attainment, and temporal trajectories among neighbouring coastal regions while avoiding unnecessary fragmentation of areas with similar demographic structure. The preferred reporting units were therefore:

Southeast	=	Channel + Frederick Henry–Norfolk Bays
East	=	Great Oyster Bay + Mercury Passage
Northeast	=	Bridport + St Helens Outside (+ Flinders Island as reference)
North/Northwest	=	Tamar Outside + Stanley

6.1.4 Discussion

This chapter demonstrates that the fishery-independent survey program has become the most valuable source of contemporary information for assessing the status and rebuilding trajectory of Tasmanian Sand Flathead. In the absence of recent commercial catch-per-unit-effort series, and with only intermittent or partial fishery-dependent recreational datasets, standardised fishery-independent monitoring now provides the only independent evidence on spatial variation, temporal change, and demographic structure of the stock. This is particularly important in mixed-use or recreationally dominated fisheries, where catch and effort statistics are often incomplete, behaviourally influenced, or confounded by regulatory change (Hilborn and Walters, 1992, Walters and Martell, 2004, Cooke and Cowx, 2006). Internationally, fishery-independent surveys have long been recognised as a cornerstone of reliable stock diagnosis because they provide standardised observations that are less sensitive to changes in fisher behaviour, market incentives, or reporting systems than fishery-dependent indicators alone (Gunderson, 1993, Mesnil et al., 2009).

6.1.4.1 Survey design implications: site replication matters more than raw sample size

A central finding was that Sand Flathead lengths were strongly clustered within sampling sites. This presumably reflects localised aggregation of fish by size and/or habitat patchiness. Consequently, nominal sample sizes overstate the effective amount of independent information contributed by annual surveys. This is a common feature of hierarchical ecological data, where individuals sampled within the same location are more similar than individuals drawn randomly across the population (Thompson, 2012). In fisheries surveys, failure to account for clustering can lead to overconfident inference, inflated precision, and suboptimal sampling design (Pennington and Vølstad, 1994).

The practical implication is clear: increasing the number of fish measured at already sampled sites will often yield less benefit than increasing the number of independently sampled sites. This aligns with broader sampling theory showing that gains in precision are typically maximised through increased spatial replication when within-site correlation is substantial (Cochran, 1977). For the Sand Flathead program, this suggests future optimisation should prioritise maintaining or expanding site coverage, particularly in regions where abundance is patchy or catchability variable, rather than concentrating effort at a smaller number of productive locations. Increasing site replication, particularly when designed to sample the full range of available Sand Flathead habitat, will help ensure that the complete population size structure is represented in monitoring data and reduce the risk of pseudo replication arising from increased effort at existing sites. This is especially relevant under constrained budgets, where monitoring efficiency becomes as important as monitoring intensity.

6.1.4.2 Persistent spatial structure indicates Tasmania cannot be treated as a single homogeneous stock unit

The chapter also confirms that Sand Flathead size composition is strongly regionally structured across Tasmania. The long-term south-eastern regions, particularly the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays, consistently supported smaller fish and more truncated size distributions than Great Oyster Bay and northern or northeastern regions. Expanded statewide surveys further demonstrated that northeastern Tasmania and Flinders Island supported substantially stronger size structure, with greater representation of large fish.

This pattern is consistent with a broad international literature showing that coastal fish populations frequently exhibit marked spatial demographic heterogeneity, even when genetic separation is weak or absent (Begg et al., 1999, Kerr et al., 2010). Such heterogeneity can arise through differences in fishing mortality, growth conditions, recruitment dynamics, habitat quality, connectivity, or movement behaviour. In practical terms, the Sand Flathead stock appears better interpreted as a spatially structured population with regionally distinct demographic expression rather than a fully mixed statewide unit.

This finding is highly relevant to the wider objectives of the report. Earlier chapters documented historical expansion and intensification of exploitation, particularly in south-eastern Tasmania, while subsequent biological analyses identified truncation in size and age structure, reduced female contribution, and regional differences in growth and reproductive potential. Human dimensions work further indicated strong fisher awareness of declining stock condition and support for targeted rebuilding actions when clearly justified (Tracey et al., 2023). The present chapter adds the monitoring dimension by demonstrating that these biological and fishery signals are detectable through the existing survey network, and that the network can be refined to better support future stock assessment and management. Collectively, the evidence supports the conclusion that management responses based solely on statewide averages risk obscuring depleted areas and overstating stock condition in more heavily fished south-eastern Tasmania.

6.1.4.3 South-eastern Tasmania remains the rebuilding priority

The persistence of truncated size structure in the Channel and Frederick Henry–Norfolk Bays strongly supports the broader report conclusion that south-eastern Tasmania remains the principal rebuilding priority. These regions consistently exhibited low representation of larger fish despite more than a decade of monitoring. Given that larger Sand Flathead are disproportionately female and contribute strongly to reproductive output, persistent truncation has implications beyond mean size alone, potentially reducing local egg production, age diversity, and resilience to recruitment variability.

This interpretation is consistent with the concept of age and size truncation widely documented in exploited marine fish populations (Berkeley et al., 2004b, Hixon et al., 2014). Loss of older and larger individuals can reduce spawning stability, increase sensitivity to environmental variability, and slow rebuilding even when total abundance begins to recover. For Sand Flathead, earlier chapters showed that south-eastern Tasmania not only contains smaller fish, but also lower spawning potential and higher historical fishing pressure. The present chapter demonstrates that the size signal is persistent through time across the full breadth of data available and detectable independently of fishery-dependent data.

Accordingly, rebuilding measures directed at south-eastern Tasmania remain biologically justified. Progress should be assessed not only through catch or abundance indicators, but also through rebuilding of upper size classes, increased proportions of fish above legal size, and convergence toward healthier regional size distributions.

6.1.4.4 Temporal trends show recovery is not uniform

Temporal analyses showed that several long-term regions were relatively stable through time, whereas some northern and estuarine regions exhibited stronger recent directional change. Positive trends in Bridport and St Helens-outside contrasted with declining mean size at Stanley. Importantly, quantile analyses indicated that some trends were driven primarily by gains or losses in larger or smaller fish rather than uniform shifts across the full distribution.

This is an important management finding. Mean length alone can mask biologically meaningful changes in stock composition. Internationally, size-spectrum and quantile approaches are increasingly recognised as informative indicators of exploitation and rebuilding because they are sensitive to changes in larger age classes often missed by abundance metrics alone (Shin et al., 2005, Andersen and Beyer, 2006). For Sand Flathead, tracking upper length quantiles or the proportion of fish above threshold lengths may provide a practical complementary indicator of rebuilding success. This finding also enhances the value of fishery-dependent sampling, where larger sample sizes of fish above the minimum legal size can improve resolution of upper-tail size structure within each region. Such data are informative not only for monitoring the return of larger individuals to the population, but also for supporting length-converted catch curve analyses used to estimate total instantaneous mortality (Z) (Pauly, 1983, Sparre and Venema, 1998, Haddon, 2011).

The heterogeneity in regional trends also suggests that statewide recovery, if it occurs, is unlikely to be synchronous. Regions differ in productivity, fishing intensity, habitat, and recruitment connectivity. Management should therefore expect uneven rebuilding trajectories and avoid interpreting improvement in one region as evidence of universal stock recovery.

6.1.4.5 A four-sector framework provides the strongest basis for monitoring and future assessment

One of the clearest applied outcomes of the chapter was that a four-sector framework (Southeast, East, Northeast, North/Northwest) consistently outperformed a broader three-sector pooling scheme. The four-sector model better resolved differences in mean length, temporal trend, and size-limit attainment, while remaining practical for monitoring and reporting.

This has direct implications for later stock assessment chapters. Length-based and data-limited assessment methods are sensitive to assumptions about representative growth, mortality, selectivity, and size composition (Hordyk et al., 2015a, Hordyk et al., 2015b). If biologically distinct regions are pooled, estimated parameters may become blurred averages that poorly represent any one component of the stock. Conversely, excessive fragmentation can create sparse data problems. The four-sector framework identified here appears to strike an appropriate balance between biological realism and statistical practicality.

This structure is particularly useful for future rebuilding evaluation because it separates the depleted Southeast from stronger northern regions while also distinguishing the Northeast, where recent positive trends and stronger size structure were evident. That regional resolution will allow management to track whether recovery is occurring where most needed, rather than relying on statewide indicators diluted by healthier areas. More broadly, it reinforces a central message emerging across the report: effective rebuilding requires not only appropriate management settings but also monitoring systems capable of detecting whether those settings are working. The Sand Flathead survey program now provides that foundation.

6.1.4.6 Future directions

Several priorities follow from these findings. First, continued annual monitoring in the long-term south-eastern and eastern regions is essential to preserve the time series needed to evaluate rebuilding. Second, adequate sampling effort should be maintained in the Northeast sector, where fewer samples currently reduce precision despite clear biological distinctiveness. Third, indicators based on upper size classes, proportions above threshold lengths, and sector-specific trends should be incorporated into future harvest strategy development. Finally, the four-sector structure should be considered in subsequent stock assessment modelling, particularly for length-based methods where spatial pooling assumptions materially influence inference.

6.1.5 Conclusion

This chapter demonstrates that the Tasmanian Sand Flathead fishery-independent survey program is both scientifically valuable and strategically improvable. The survey has revealed persistent statewide spatial structure, confirmed south-eastern Tasmania as the principal rebuilding priority, shown that regional recovery trajectories differ, and identified a practical four-sector framework for future monitoring and assessment. In the context of the wider report, these findings provide the monitoring architecture required to translate biological diagnosis into measurable rebuilding outcomes.

6.1 Fishery Dependent Sampling

6.1.1 Introduction

Fishery-independent surveys provide the strongest basis for estimating stock status, abundance trends, and changes in population structure of Sand Flathead. However, they do not directly characterise the composition of fish retained by recreational fishers, which represents the component removed from the stock. Fishery-dependent biological sampling can therefore provide an important complementary source of information on realised harvest composition, fisher selectivity, and management performance.

Citizen science and cooperative sampling programs are increasingly recognised as valuable tools for ecological and fisheries monitoring because they can generate extensive datasets at comparatively low cost while also strengthening stakeholder participation and stewardship (Dickinson et al., 2010, Chandler et al., 2017).

Fish frame and carcass donation programs have become an increasingly valuable component of recreational fisheries monitoring internationally, providing a cost-effective means of obtaining large numbers of biological samples such as otoliths, length measurements, sex data, gonads and tissue that would otherwise be expensive or logistically difficult to collect through conventional fishery-independent surveys (Fairclough et al., 2014). Such programs can substantially expand spatial and temporal coverage by drawing on samples from a wide range of fishing locations and seasons, while also generating direct information on the harvested component of the stock. In addition to their scientific value, donation programs can strengthen fisher engagement, stewardship and trust in management by involving recreational participants directly in data collection (Fairclough et al., 2014, White et al., 2026).

However, because these data are derived from retained fish donated voluntarily by anglers, they should be recognised as fishery-dependent samples that are subject to several forms of bias. Retention bias may occur where only legal-sized or preferred table fish are represented, while selective donation may arise if anglers are more likely to contribute unusually large or notable fish. Participation is often skewed toward highly engaged or avid fishers rather than the broader recreational sector, potentially creating self-selection bias. Samples may also be concentrated around accessible or highly populated fishing areas, and participation rates can vary through time, affecting temporal consistency. Consequently, best practice is to interpret donation-derived datasets alongside complementary information sources such as creel surveys, diary programs, fishery-independent surveys, and robust statistical methods that account for sampling limitations (Fairclough et al., 2014, White et al., 2026).

Such information is particularly relevant for Sand Flathead in Tasmania, where earlier analyses in this report identified strong regional variation in size structure, growth, age composition and sex ratios, with females increasingly dominating larger legal-sized classes. Under these conditions, size-based harvest regulations may create non-random removals from the stock, including disproportionate harvest of particular sexes or age classes. Understanding the composition of retained catches is therefore important for interpreting exploitation patterns, reproductive impacts, and rebuilding trajectories.

The Tassie Fish Frame Collection Program was established as a statewide citizen-science initiative to collect retained frames of key recreational species through a network of public drop-off locations. Sand Flathead were incorporated into the program in April 2021. This chapter evaluates donations received between 2021 and 2025, examining the spatial distribution of participation, length and age composition of retained fish, sex composition of harvested fish, and the utility and limitations of citizen-science fishery-dependent sampling as an ongoing monitoring tool. The program was publicised through social media and posters were distributed to drop-off locations around the state (Appendix Figure 80).

6.1.2 Methods

From April 2021, Sand Flathead donations were accepted through the Tassie Fish Frame Collection Program, a voluntary citizen-science initiative designed to obtain fishery-dependent biological samples from retained recreational catches. Recreational fishers donated fish frames (head, skeleton and associated tissues after filleting) through a network of approximately ten public drop-off locations distributed around Tasmania. Most collection sites were recreational fishing tackle stores, providing accessible donation points and opportunities for ongoing promotion of the program through local fishing communities.

Upon receipt, each frame was registered and, where available, associated capture information such as reported fishing location was recorded. For analytical purposes, donations were assigned to five broad reporting regions: east coast, southeast coast, northeast coast, northwest coast, and Flinders Island. Where location information was incomplete or uncertain, samples were retained in statewide summaries but excluded from regional analyses where appropriate.

Frames were processed in the laboratory to obtain available biological information. Total length (mm) was recorded where frame condition permitted reliable measurement. Sex was determined from retained gonadal or internal tissues when present, and gonad stage was noted where sufficiently intact material was available. Sagittal otoliths were removed where possible for age estimation. Otoliths were prepared, sectioned and read using the same ageing protocols applied to fishery-independent survey samples elsewhere in this report (5.1.2) to ensure consistency among datasets.

To evaluate how donated fish compared with the broader east coast population, size composition of frame donations was compared with fishery-independent survey samples from comparable years on the east coast. Comparisons were undertaken using both the full survey length-frequency distribution reported from each sample collection method and a truncated survey dataset restricted to fish at or above the minimum legal size limit (≥350 mm was used to ensure comparability across the temporal range of sample comparison), thereby allowing separation of harvest selectivity effects from broader population structure. Differences in length-frequency distributions between datasets were statistically assessed using two-sample Kolmogorov–Smirnov (KS) tests.

Because participation in the program was voluntary, fishery-dependent samples were not assumed to represent the full retained catch or underlying population structure. Instead, results were interpreted as indicators of retained harvest composition among participating fishers. Potential sources of bias include uneven regional participation, fisher retention preferences, minimum legal-size regulations, selective donation of notable fish, freezer storage effects prior to submission, and damage or incompleteness of frames that limited some biological measurements.

6.1.3 Results

Between April 2021 and December 2025, a total of 509 Sand Flathead frames were donated through the Tassie Fish Frame Collection Program. Contributions were highly uneven among regions, with the east coast providing 470 frames (92.3%of all samples). Remaining donations were limited, comprising 12 frames (2.4%) from the northeast coast, 11 (2.2%) from Flinders Island, 10 (2.0%) from the northwest coast, and 6 (1.2%) from the southeast coast.

Length was successfully estimated from most donated frames. Across all measured samples, females averaged 369 mm ± 1.6 SE, whereas males averaged 348 mm ± 7.4 SE, indicating females in retained catches were on average approximately 21 mm longer than males. Most donations fell between 330 and 400 mm, producing a relatively narrow size distribution centred above the minimum legal-size limit (Figure 48). Fish above 420 mm occurred less frequently but were represented more strongly compared with fishery-independent survey catches, while very small fish were uncommon. The largest fish donated was a 537 mm female from Flinders Island, with several additional fish exceeding 450 mm, primarily from northern and eastern Tasmania.

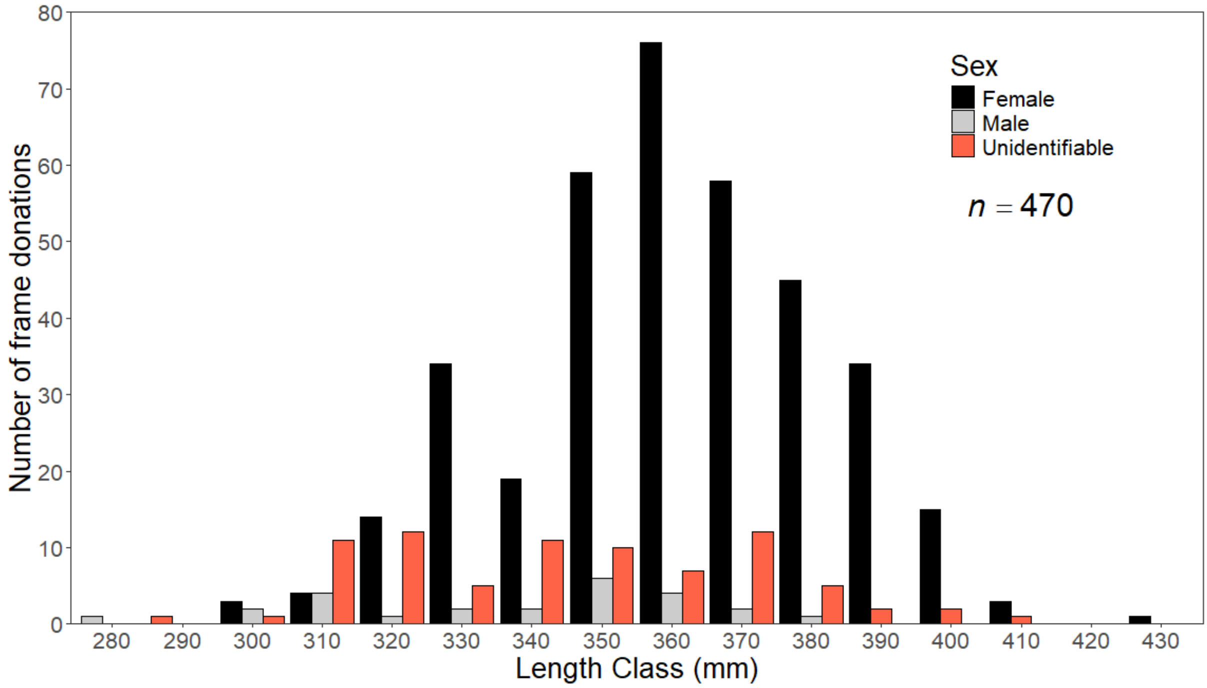


Figure 48. The number of Sand Flathead frames donated by recreational fishers to the Tassie Fish Frame Collection program from the east coast per length class (mm) from April 2021 to December 2025.

Comparison with fishery-independent east coast survey samples from comparable years showed clear differences in size composition (Figure 49; Table 18). Relative to the full survey dataset, donated fish were significantly shifted toward larger size classes and lacked the strong mode of sublegal and near-legal fish commonly observed in survey catches (KS test, $p < 0.001$). This was to be expected as most fish provided from the fishery-dependent samples were above the size limit.

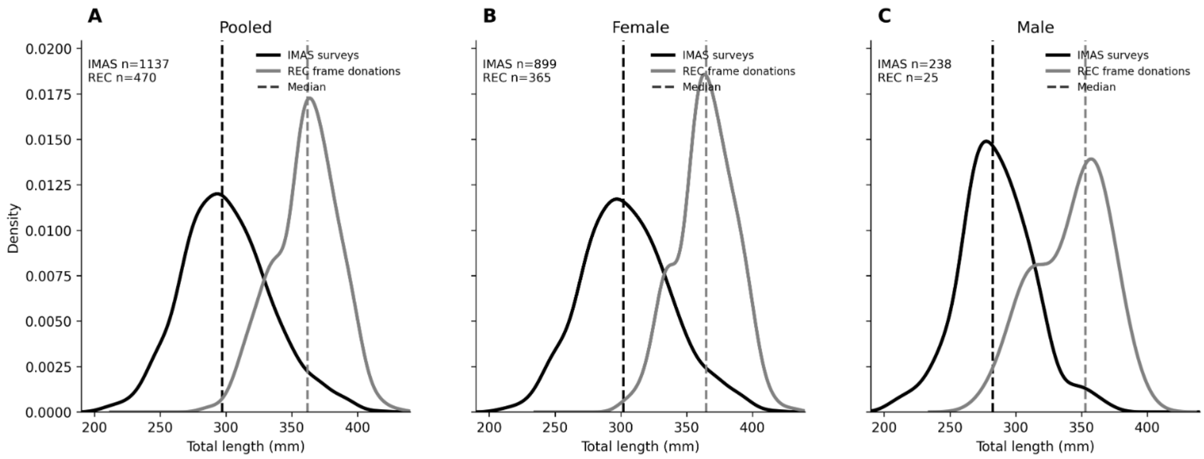


Figure 49. Length-frequency density distributions of sand flathead from the East Coast region, comparing fishery-independent survey data (IMAS_surveys) and fishery-dependent recreational frame donation data (REC_Frame). Panels show (A) pooled samples, (B) females, and (C) males. Solid lines represent kernel density estimates and dashed vertical lines indicate median lengths for each data source. Sample sizes (*n*) are shown within panels. Axes are standardised across panels to facilitate direct comparison.

Table 18. Results of Kolmogorov–Smirnov (KS) tests comparing length and age distributions between fishery-independent (IMAS_surveys) and fishery-dependent (REC_Frame) datasets for the East Coast region. KS statistic (*D*) and associated *p*-values are reported for pooled and sex-specific comparisons. Differences in median values (Δ median) are expressed as REC minus IMAS. All comparisons were statistically significant ($p < 0.001$).

Panel	Variable	KS statistic (D)	p-value	Δ Median (REC − IMAS)
Pooled	Length	0.704	**< 0.001**	+65 mm
Pooled	Age	0.258	**< 0.001**	+1 year
Female	Length	0.721	**< 0.001**	+63 mm
Female	Age	0.310	**< 0.001**	+1 year
Male	Length	0.718	**< 0.001**	+70.5 mm
Male	Age	0.552	**< 0.001**	+2 years

When survey data were truncated to include only fish at or above the prevailing minimum legal-size limit, differences in size composition between fishery-dependent and fishery-independent samples were substantially reduced to approximately 3 mm, and were no longer statistically significant (KS test, $p = 0.059$: Table 19; Figure 50). This indicates that, once both datasets were standardised to the harvestable component of the population, fish sizes were highly comparable between sampling methods, and that most of the original difference was attributable to the inclusion of sublegal fish in the fishery-independent survey catches (Figure 51).

Table 19. Kolmogorov–Smirnov (KS) test results comparing length distributions of sand flathead between fishery-independent surveys (IMAS_surveys) and fishery-dependent recreational frame donation data (REC_Frame) for the East Coast region. Results are shown for the full dataset and for legal-sized fish only (≥35 cm). The KS statistic (*D*), associated *P*-value, and differences in median length (Δ median; REC − IMAS) are reported. Reduction in Δ median following truncation provides a quantitative estimate of bias attributable to the exclusion of sublegal fish.

Dataset	KS statistic (D)	p-value	Δ Median (REC − IMAS)
Full data	0.704	**< 0.001**	+65 mm
Legal only (>35 cm)	0.153	0.059	+3 mm

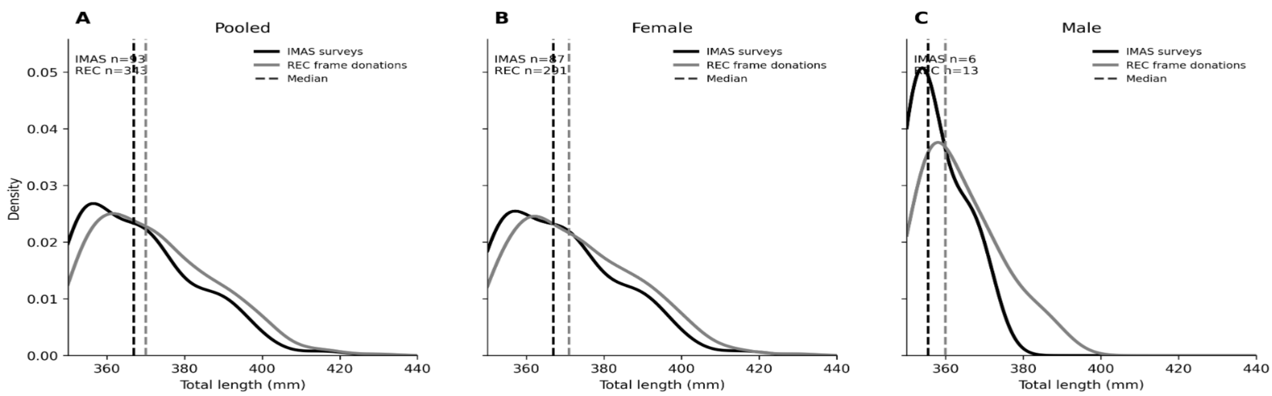


Figure 50. Length-frequency density distributions of legal-sized sand flathead (≥35 cm) from the East Coast region, comparing fishery-independent survey data (IMAS_surveys) and fishery-dependent recreational frame donation data (REC_Frame). Panels show (A) pooled samples, (B) females, and (C) males. Solid lines represent kernel density estimates and dashed vertical lines indicate median lengths for each data source. Sample sizes (n) are shown within panels, and axes are standardised to facilitate direct comparison. Restricting analysis to legal-sized fish reduces differences between datasets, highlighting the influence of sublegal fish on observed sampling bias.

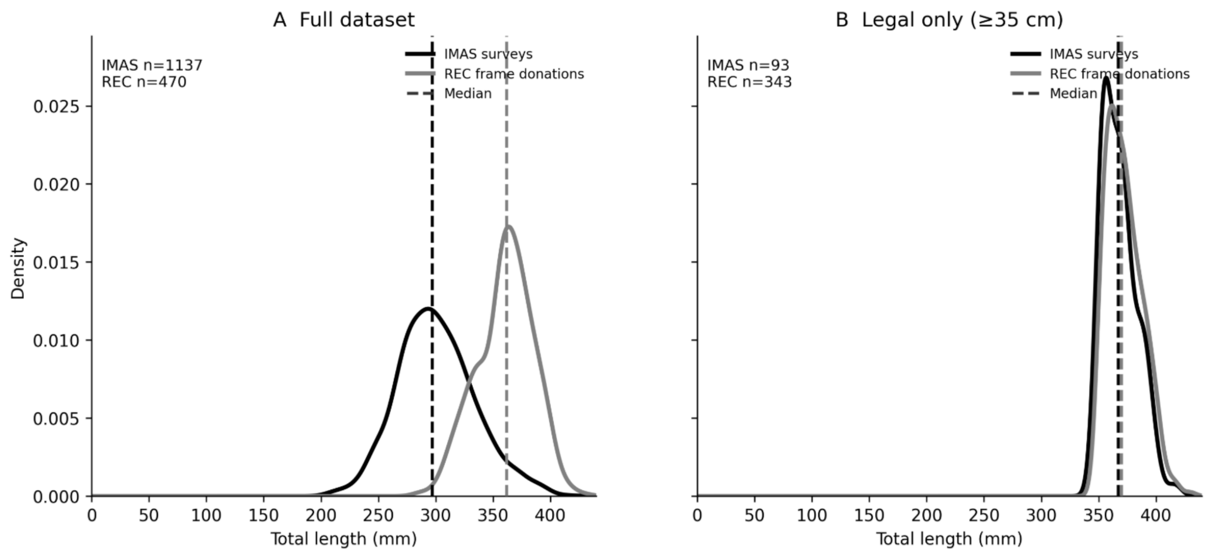


Figure 51. Effect of truncation to legal size on differences between fishery-independent and fishery-dependent length distributions. Length-frequency density distributions of sand flathead from the East Coast region are shown for (A) the full dataset and (B) legal-sized fish only (≥35 cm). Solid lines represent kernel density estimates for IMAS surveys (fishery-independent) and REC frame donations (fishery-dependent), with dashed vertical lines indicating median lengths. Sample sizes (n) are shown within panels. Truncation to legal size substantially reduces differences between datasets, demonstrating that much of the observed bias in fishery-dependent data arises from the absence of sublegal fish.

A small number of donated frames were estimated below the historical 320 mm minimum legal size (Figure 52). In total, 27 fish (5.3%) were measured below this threshold. Several were only marginally undersized, consistent with freezer shrinkage (e.g., Engel, 1974, Baltasar et al., 2021) or measurement uncertainty associated with incomplete frames. However, two of the donated fish were found to be 35 mm and 30 mm below the legal minimum size at the time of donation, indicating that at least a small proportion of undersized fish had likely been retained.

Otoliths suitable for ageing were obtained from 426 donations (83.7%), allowing age composition of retained catches to be examined. Most fish were concentrated between 4 and 9 years of age, indicating that harvest removals were dominated by mature mid-aged adults rather than young recruits or the oldest survivors in the population (Figure 54). Across all aged fish, females had a mean age of 6.3 years ± 0.1 SE, whereas males averaged 8.7 years ± 0.6 SE, indicating males in retained catches were older on average despite being smaller in length. The oldest fish donated was an 18.2-year-old male from the east coast, while several females older than 12 years were also represented.

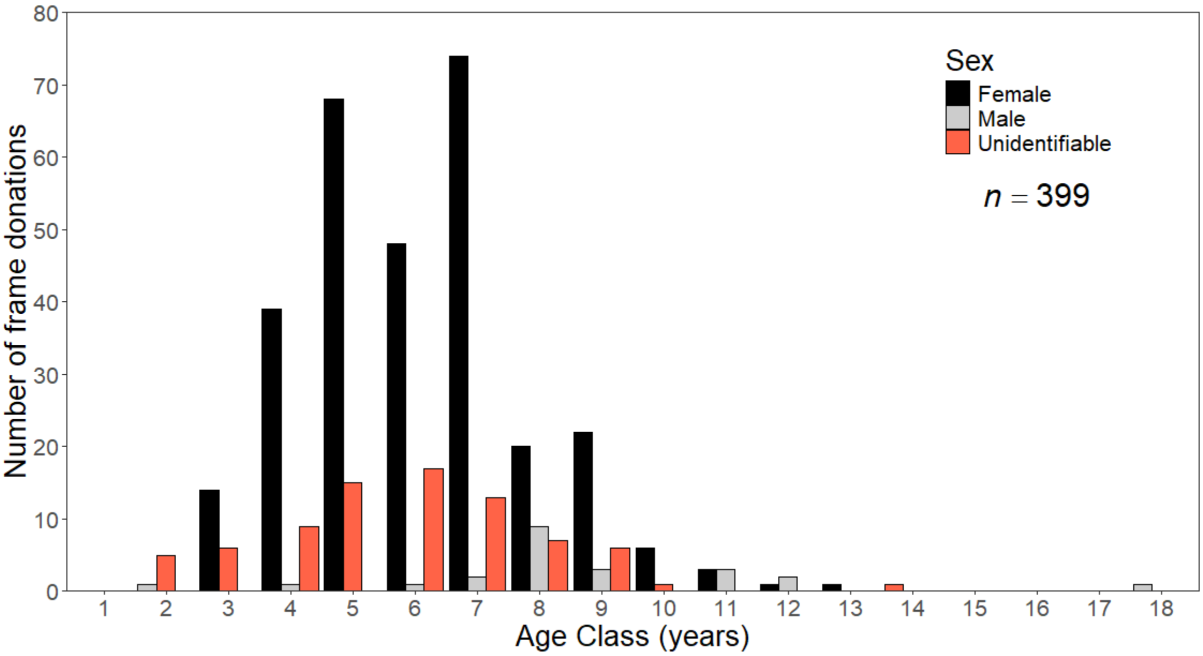


Figure 52. The total number of Sand Flathead frames donated by recreational fishers to the Tassie Fish Frame Collection program from the east coast per age class (years) from April 2021 to December 2025.

Sex was determined for 419 donations, of which 392 were female and 27 male. Excluding unsexed fish, females comprised 93.6% of all sexed samples, with males representing only 6.4% (Figure 52). Female dominance was evident across most retained size classes and became particularly pronounced above approximately 360 mm, where females accounted for the majority of larger fish (Figure 53). Males were uncommon throughout the sample and were largely restricted to smaller and intermediate legal-sized classes.

Joint interpretation of size and age distributions further highlighted strong sex-selective harvest patterns. Female donations displayed a modal size distribution centred around 350–380 mm (Figure 53) and a median age of approximately 6 years (Figure 54), indicating that retained females were generally larger but not especially old. In contrast, males had a lower median length of approximately 353 mm but a higher median age of 8 years, suggesting slower growth and lower representation in larger harvestable size classes. Unsexed fish tended to be smaller and younger, reflecting the greater difficulty of sex determination from damaged or incomplete frames.

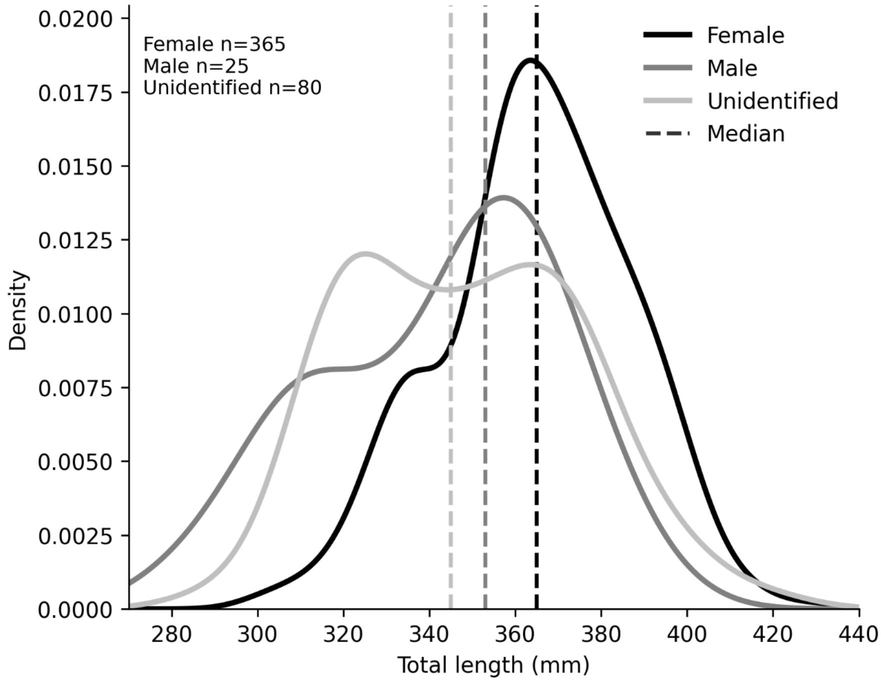


Figure 53. Length-frequency density distributions of sand flathead from recreational frame donation samples (REC_Frame) in the East Coast region. Distributions are shown separately for females, males, and unidentified individuals. Solid lines represent kernel density estimates and dashed vertical lines indicate median lengths for each group. Sample sizes (n) are provided within the panel. Axes are standardised to facilitate comparison among sex categories.

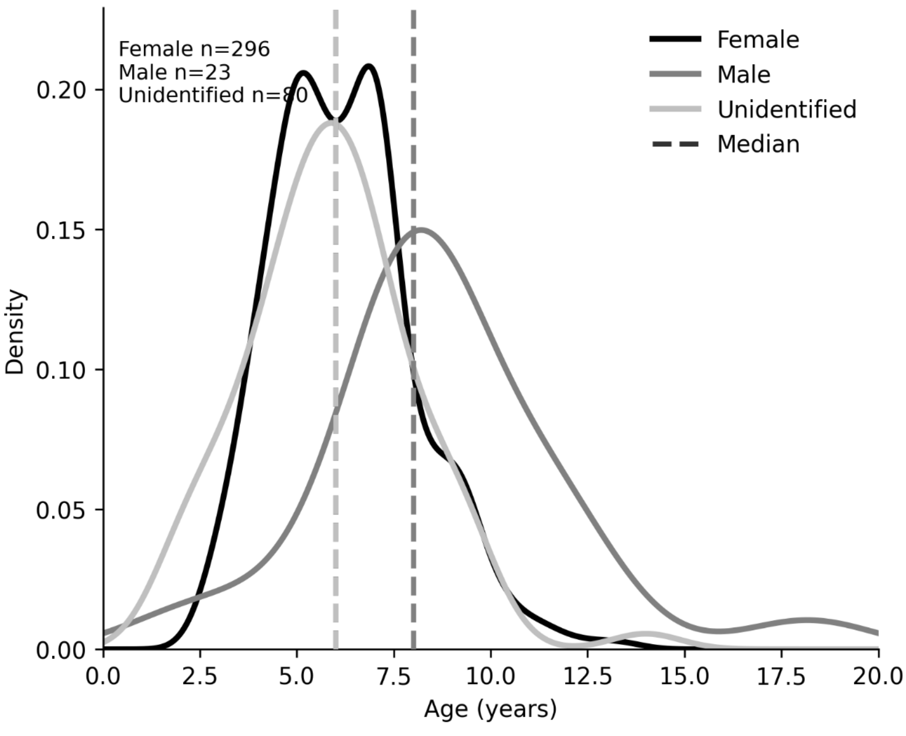


Figure 54. Age-frequency density distributions of sand flathead from recreational frame donation samples (REC_Frame) in the East Coast region. Distributions are shown separately for females, males, and unidentified individuals. Solid lines represent kernel density estimates and dashed vertical lines indicate median ages for each group (female/unidentified samples medians overlap). Sample sizes (n) are provided within the panel. Axes are standardised to facilitate comparison among sex categories.

6.1.4 Discussion

Fishery-dependent biological sampling through the Tassie Fish Frame Collection Program provided a valuable complementary perspective to the fishery-independent analyses presented elsewhere in this report. Whereas survey sampling described underlying stock structure, the frame collection program characterised the component of the population actually removed by recreational fishers. This distinction is important because retained harvest is rarely a random subset of the stock and is instead shaped by fisher behaviour, regulations, accessibility and biological selectivity.

The most striking result was the overwhelming dominance of females in donated harvest samples. This is highly consistent with earlier analyses showing that females attain larger sizes than males and increasingly dominate upper legal-sized classes. Under a minimum size limit, larger females become more vulnerable to retention, creating a strongly sex-selective harvest pattern. Similar outcomes have been documented in fisheries where sexual size dimorphism interacts with size-selective harvest processes to disproportionately remove one sex or particular demographic components of the stock (Kendall and Quinn, 2013, Uusi-Heikkilä, 2020).

This finding has important implications for Sand Flathead rebuilding. Removal of large females may reduce spawning biomass more than equivalent biomass removal distributed evenly across sexes, as larger and older females often contribute disproportionately to egg production and offspring quality (Berkeley et al., 2004b, Hixon et al., 2014). In depleted regions where large females are already scarce, continued female-selective harvest may therefore slow demographic recovery.

Length and age data further indicate that retained catches were concentrated within a relatively narrow demographic window, principally legal-sized fish aged approximately 4–9 years. This suggests current harvest pressure is focused on mature mid-aged fish, while smaller fish are largely protected by regulation and very large fish are less common in the retained catch. Such dome-shaped selectivity patterns are relevant to future stock assessment and management modelling.

The persistence of very large, donated fish, particularly the 537 mm female from Flinders Island, aligns closely with fishery-independent evidence that northern and northeastern Tasmania retain stronger demographic structure than south-eastern regions. Citizen-science harvest data therefore reinforce broader statewide patterns of regional variation rather than contradicting them.

Importantly, comparison with fishery-independent east coast survey data showed that much of the apparent difference in size composition was attributable to the presence of sublegal fish in survey catches rather than fundamental divergence between sampling methods. Donated samples were larger than the full survey population, as expected for retained catches, but once both datasets were truncated to fish at or above the minimum legal-size limit, differences were reduced to approximately 3 mm and were no longer statistically significant. This indicates that fish frame donations provide a close representation of the harvestable component of the stock, even though they do not represent the full standing population. Such agreement supports the utility of donation programs for monitoring retained catch structure when interpreted within the regulatory context of the fishery and conversely the representation of the fishery-independent survey of the size range of fish available in the population.

These findings remain consistent with well-established effects of size-selective fishing and harvest sampling, whereby retained catch disproportionately represents larger individuals because of minimum legal-size limits, gear selectivity and fisher behaviour (Ricker, 1969). Consequently, fish frame samples should be interpreted primarily as biological samples of realised harvest rather than direct representations of the full population. If used uncritically in stock assessment, they could inflate estimates of statewide size structure, growth potential or spawning biomass. However, when analysed alongside fishery-independent surveys and with appropriate recognition of selectivity, they can provide robust information on harvest composition and exploitation patterns (Rudd et al., 2018, Tagliarolo et al., 2021).

The program also demonstrated practical monitoring value. Donation-based biological sampling can provide substantial numbers of frames, otoliths and harvest-composition records at comparatively low cost. Similar cooperative carcass recovery programs in recreational fisheries have proven useful for obtaining age and demographic data that would otherwise be logistically difficult to collect (Fairclough et al., 2014). However, participation in the present study was strongly spatially uneven, with more than 90% of samples originating from the east coast. As with many volunteer-contributed datasets, submissions were inherently non-random because fishers selectively retained, processed and chose whether to donate fish. Citizen-science datasets commonly exhibit structured biases associated with who participates, where sampling occurs and what individuals choose to report or submit (Dickinson et al., 2010, Arazy and Malkinson, 2021). Accordingly, these data are best interpreted as indicators of retained harvest composition rather than unbiased statewide estimates of population structure.

The occurrence of some undersized donated fish is also notable. While freezer shrinkage and carcass damage may explain a proportion of cases, several fish were substantially below the legal minimum size. This suggests fish frame collections may also provide a useful auxiliary source of intelligence regarding compliance risk, warranting further exploration.

Overall, fishery-dependent sampling is unlikely to replace fishery-independent surveys, but it can materially strengthen monitoring programs when used in combination. Integrating fish frame collections with survey datasets can improve understanding of exploitation patterns, harvest selectivity and rebuilding progress, thereby providing more complete evidence base for future Sand Flathead management.

6.1.5 Conclusion

The Tassie Fish Frame Collection Program demonstrated that citizen-science fishery-dependent sampling can provide valuable biological information on retained recreational harvests of Sand Flathead. Donations were strongly concentrated on the east coast and revealed that retained catches were dominated by legal-sized, mid-aged females, indicating that current removals are highly structured rather than random.

Comparison with fishery-independent survey data showed that differences in size composition were largely explained by the inclusion of sublegal fish in survey catches. Once analyses were restricted to fish at or above the minimum legal-size limit, donated and survey samples were highly comparable. This indicates that fish frame collections can provide a realistic representation of the harvestable component of the stock, even though they do not describe the full population.

These results support earlier findings that females dominate larger size classes and indicate that current size-based harvest regulations likely generate non-random, female-selective removals from the stock. Such patterns may have important implications for spawning biomass and rebuilding, particularly in regions where large females are already depleted.

Although participation was spatially uneven, the program shows potential as a cost-effective complementary monitoring tool. Continued development could provide ongoing information on harvest composition, age structure, trophy fish occurrence and potential compliance issues. More broadly, combining fishery-dependent and fishery-independent datasets offers a stronger evidence base for future Sand Flathead assessment and management than either source alone.

6.1.6 Regional monitoring framework design

The integration of growth, length structure, age composition, sex ratio, and survey design analyses provides a strong basis for refining the future fishery-independent monitoring program for Sand Flathead. The objective should not be to minimise sampling effort alone, but to retain the capacity to detect biologically meaningful change, assess rebuilding progress, and maintain regionally relevant inputs for stock assessment.

A four-sector monitoring framework, with Flinders Island retained as a distinct reference region, is recommended:

Southeast: D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays
East: Great Oyster Bay and Mercury Passage
Northeast: St Helens and Bridport
North/Northwest: Tamar and Stanley
Flinders Island: retained separately as the clearest contemporary reference area for less depleted stock condition

This framework captures the major spatial gradients identified across the report. South-eastern Tasmania consistently showed the most depleted demographic structure, the east coast was generally intermediate, the northeast retained stronger size structure, and Flinders Island was clearly distinct, with larger fish, older age classes, and higher spawning potential. The north/northwest sector provides additional coverage of the northern and western components of the species' Tasmanian distribution.

The survey design analyses also show that precision is driven strongly by the number of independent sites sampled rather than simply the number of fish measured within sites. Accordingly, future survey optimisation should prioritise maintaining or increasing site replication within retained sectors, rather than concentrating effort only at historically productive locations. This is particularly important for detecting rebuilding in depleted regions, where local site effects and patchy size structure could otherwise obscure real population trends.

For monitoring frequency, annual sampling should be retained in the southeast because this is the highest-priority rebuilding region and the area where management sensitivity is greatest (Table 20). Annual or near-annual sampling should also be maintained in the east to preserve continuity with the long-term Great Oyster Bay time series and to track intermediate stock condition. The northeast and north/northwest sectors could be sampled annually where resources allow, but a biennial design may be acceptable if sufficient sites are sampled and biological data are maintained. Flinders Island should remain a standalone reference region, ideally sampled at least biennially, because it provides the clearest contrast to depleted regions and is important for interpreting growth, mortality, and rebuilding benchmarks.

Within this framework, some regional consolidation is possible. Mercury Passage appears to provide the most redundant information relative to Great Oyster Bay and could be sampled less frequently if resources are constrained. St Helens and Bridport show sufficient similarity to support sector-level monitoring, although at least one should be retained consistently and preferably both should be sampled periodically to detect effort displacement or emerging depletion. Tamar and Stanley can be treated as a north/northwest sector but reducing either region should be approached cautiously because recent trends differed, with Stanley showing declining mean size. The D’Entrecasteaux Channel and Frederick Henry–Norfolk Bays should both be retained wherever possible because they are long-term core regions, represent the most depleted part of the fishery, and are central to evaluating rebuilding outcomes.

Overall, the recommended framework balances biological realism, statistical power, and operational feasibility. It reduces unnecessary redundancy while preserving the spatial resolution required to evaluate rebuilding, detect effort displacement, protect less depleted regions, and provide regionally appropriate assessment inputs.

Table 20. Ranked decision framework for reducing monitoring regions.

Priority	Region	Monitoring role	Evidence	Risk if reduced	Recommendation
1	D'Entrecasteaux Channel	Core southeast rebuilding indicator	Highly depleted, long-term time series, strong management relevance	Very high	Retain annually
2	Frederick Henry–Norfolk Bays	Core southeast rebuilding indicator	Highly depleted, long-term time series, major recreational importance	Very high	Retain annually
3	Great Oyster Bay	Core east coast / intermediate indicator	Long-term time series and transitional stock condition	High	Retain annually or near-annually
4	Flinders Island	Reference region	Distinct size, age, growth, and spawning potential; least depleted benchmark	Very high	Retain separately, at least biennially
5	Bridport	Northeast indicator	Stronger size structure and useful contrast to depleted regions	Moderate	Retain, annual or biennial
6	St Helens	Northeast / east transition	Useful regional contrast; partly overlaps with Bridport	Moderate	Retain periodically or rotate with Bridport
7	Tamar	North/northwest indicator	Represents northern estuarine/coastal structure	Moderate	Retain if Stanley reduced
8	Stanley	North/northwest indicator	Recent decline in mean size suggests monitoring value	Moderate	Retain periodically; avoid full removal until trend clarified
9	Mercury Passage	East coast supplementary region	Similar to Great Oyster Bay; relatively redundant	Low	Sample less frequently or rotate if resources constrained

7 Objective 4: The reproductive biology of Sand Flathead around Tasmania

7.1.1 Introduction

Effective fisheries management depends on a robust understanding of the regenerative capacity of exploited populations. Central to this is accurate knowledge of key biological parameters, particularly reproductive traits such as size and age at maturity, spawning timing and duration, and growth dynamics (Quinn and Deriso, 1999). These parameters underpin stock assessment models and inform biological reference points designed to maintain spawning biomass above critical thresholds and prevent recruitment impairment (Deriso, 1987, Sissenwine and Shepherd, 1987, Mace, 1994). In the absence of reliable, contemporary biological information, management strategies risk being based on outdated assumptions regarding productivity and resilience.

Sand Flathead is a demersal temperate species distributed across southern Australia and is a key component of recreational fisheries in Tasmania. The species supports substantial fishing pressure, particularly in accessible embayments and coastal systems of the south-east, and recent assessments have highlighted concerns regarding truncated length structure and reduced abundance in some regions (Coulson et al., 2022). Given that reproductive potential is strongly influenced by the size and age structure of a population, changes in demographic composition may directly affect egg production and recruitment. Earlier chapters of this report further demonstrated persistent regional differences in size composition, age structure, growth, and rebuilding status, with south-eastern Tasmania consistently exhibiting the most depleted demographic structure. Given that reproductive potential is strongly influenced by the size and age composition of a population, such regional differences are likely to have direct implications for egg production, recruitment dynamics, and recovery capacity.

Previous studies by Jordan (1998, 2001) and Bani and Moltschaniwskyj (2008) described many aspects of the reproductive ecology of Sand Flathead in Tasmanian waters. However, these investigations were conducted in markedly different environments, including open marine waters off the south-east coast (Jordan, 1998, Jordan, 2001), a marine embayment on the mid-east coast, a semi-enclosed embayment on the north-east coast, and an estuary on the north coast (Bani and Moltschaniwskyj, 2008). Substantial spatial and temporal variability in reproductive investment, spawning duration, and size and age at maturity among locations was reported in the latter (Bani and Moltschaniwskyj, 2008).

For example, individuals from Coles Bay exhibited heavier gonads and a protracted spawning period of up to six months, whereas populations in Georges Bay displayed lighter gonads and a spawning season of approximately two months (Bani and Moltschaniwskyj, 2008). In the Tamar River, reproductive activity was minimal, suggesting that some sampled populations may not represent fully reproductive, open coastal stocks (Bani and Moltschaniwskyj, 2008). Size and age at maturity also differed between locations, with females in Georges Bay maturing at older ages and larger sizes than those in Coles Bay (Bani and Moltschaniwskyj, 2008). The length and age structure of some of these previously studied populations suggest they may not be indicative of open coastal populations of Sand Flathead (Coulson et al., 2022). For example, Georges Bay and the Tamar River populations sampled by (Bani and Moltschaniwskyj, 2008) consisted either of individuals attaining relatively small sizes at age or high proportions of small and young fish that did not mature (Bani and Moltschaniwskyj, 2008), raising concerns regarding the generality of length and age at maturity estimates derived from those systems. Furthermore, earlier studies were based primarily on seasonal sampling, limiting fine-scale resolution of spawning timing and duration. There have been no published studies examining contemporary reproductive biology of Sand Flathead from other regions of southern Australia, despite the species' broad distribution.

Since these earlier investigations, Tasmanian coastal waters have experienced measurable ocean warming (Hobday and Pecl, 2014) and increasing frequency of marine heatwave events (Oliver et al., 2018), while some regions have also been subjected to prolonged periods of elevated fishing mortality (Krueck et al., 2025). Both climatic and fishing pressures have the potential to alter key life-history characteristics, including growth rates, size and age at maturity, and spawning (Morrongiello et al., 2012, Poloczanska et al., 2013, Heino et al., 2015). Fishing-induced truncation of age structure may reduce reproductive output and resilience, while temperature-driven changes in environmental regimes can shift spawning timing and duration, with implications for recruitment success. Consequently, it is uncertain whether biological parameters estimated two to three decades ago remain representative of contemporary populations.

This uncertainty is particularly important in the context of the previous chapters of this report, which identified strong regional demographic structuring and evidence of depletion in south-eastern Tasmania. If maturity schedules, spawning timing, or reproductive investment also vary spatially or have shifted through time, then application of outdated or spatially pooled biological parameters could bias estimates of spawning biomass and rebuilding potential.

This study was undertaken to provide updated and regionally resolved estimates of the reproductive biology of Sand Flathead from three Tasmanian regions. Specifically, we quantify contemporary timing and duration of spawning and maturation schedules. By providing contemporary, region-specific biological parameters, this study aims to strengthen the evidence base underpinning stock assessment, harvest strategy development, and rebuilding management of Sand Flathead in Tasmanian waters, while evaluating whether reproductive characteristics have shifted over the past three decades in response to climatic and anthropogenic pressures.

7.1.2 Methods

7.1.2.1 Sampling and fish measurements

Sand Flathead were collected by line fishing in three regions, Frederick-Henry and Norfolk Bays (FH-NB), Great Oyster Bay (GOB) and Bridport (BP), in water depths of between 5 and 40 m (Figure 1; Figure 15). Up to 80 individuals were caught monthly from each region between August 2023 and July 2024 by line fishing from research vessels using a paternoster rig consisting of two size 3/0 hooks baited with Southern

Calamari (*Sepioteuthis australis*). Fish caught using this method tended to be longer than 200 mm, likely due to gear selectivity. Sand Flathead were also sampled from waters around Flinders Island (FI) using the same methods, but from a charter fishing vessel, in October 2023 and February 2024. Fish were stored on ice before being processed. A total of 3,363 Sand Flathead were retained from the four regions (i.e., FH-NB, GOB, BP and FI) during the 12-month reproductive biology sampling period (Table 21).

Samples of smaller (< 200 mm) Sand Flathead were collected using a small otter trawl and beam trawl in FH-NB between June and October. The otter trawl net consisted of 35 mm mesh in the body and 29 mm mesh in the pocket with mouth width of ~ 2.5 m. The beam trawl was 170 cm wide and consisted of 45 mm mesh in the body and 20 mm mesh in the pocket. Sampling was undertaking over soft sediment benthos at sites previously sampled by Jordan (1998, 2001), with trawls going for 7-10 mins at a speed of 1 knot.

The total length (TL) of all retained individuals was measured to the nearest 1 mm and total weight (TW) recorded to the nearest 0.1 g. Fish were aged using the methods described earlier in the report.

Table 21. Monthly samples sizes for female and male Sand Flathead from Frederick Henry and Norfolk Bays (FH-NB), Great Oyster Bay (GOB), Bridport (BP) and Flinders Island (FI).

	Month	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Female	FH-NB	33	24	33	56	55	44	52	43	36	38	46	47
	GOB	58	46	47	39	58	42	65	45	89	61	66	69
	BP	55	47	45	39	38	28	28	26	39	40	48	40
	FI				206				107				
Male	FH-NB	37	37	47	58	23	36	31	37	44	42	34	34
	GOB	22	41	24	41	29	38	17	36	11	19	14	11
	BP	26	35	38	38	46	53	57	29	41	42	33	40
	FI				98				46				

7.1.2.2 Spawning season and duration

The sex of each fish was determined by macroscopic examination of the gonads following (Jordan, 2001) (Table 22). The gonads were removed and weighed to the nearest 0.01g. Mean monthly gonadosomatic indices (GSI) were calculated for female and male Sand Flathead with lengths greater than or equal to the L_{50} value reported by (Jordan, 1998) (i.e., 235 and 210 mm for females and males, respectively), using the equation $GSI = GM/TW \times 100$, where GM is wet gonad mass and TW is total weight of fish. The prevalence of the females and males with gonads at each developmental stage in each month was used in conjunction with monthly trends exhibited by the GSI to define the timing and duration of the spawning period of Sand Flathead.

To compare potential reproductive output among regions, the standardised mean gonad masses (GMs) were calculated for females and males with gonads at stages V and VI during peak spawning months in all regions, i.e., October-December (Coulson et al., 2019). The peak spawning mean GMs for female and male Sand Flathead in each region were standardised for a common *TL* using ANCOVA, with region as the fixed factor, the natural logarithm (ln) of *TL* as the covariate and ln *GM* as the dependent variable. Mean monthly *GM*s were back-transformed before plotting. The standardised TLs were 354 and 302 mm for females and males, respectively.

Table 22. Macroscopic staging criteria used for female and male Sand Flathead.

Stage	Category	Female	Male
I.	Virgin	Small strap with rounded edge, less than 3/4 length of body cavity. Pink, firm texture.	Flattened and ribbon like, less than3/4 length of body cavity.
II.	Maturing virgins/resting	Virgin: at least ¾ of body length, pink and glassy. Recovering: as long as body cavity, bloodshot and flabby at posterior.	Virgin: at least ¾ of body length, flattened and ribbon like. Recovering: as long as body cavity, slightly bloodshot and ribbon like.
III.	Developing	Almost length of body cavity, opaque and becoming yellow. Ova not discernible.	Almost length of body cavity, firm, larger and creamy pink.
IV.	Late Developing	Full length of body cavity, opaque and yellowish pink. Individual ova discrete.	Full length of body cavity, less firm and more rounded.
V.	Ripe	Full length of body cavity and swollen, occupying all available space. Ovary and ova becoming transparent.	Full length of body cavity and swollen, occupying all available space. Pinkish white and soft.
VI.	Running Ripe	Eggs express with slight pressure. Ovary pinkish, clear and granular.	Testes exude milt with gentle pressure on belly. Very soft.
VII.	Spent	Slack and bloodshot. Few residual oocytes present.	Testes broad, flaccid and bloodshot, little residual milt present.

7.1.3 Results

The mean monthly GSI for female Sand Flathead in FH-NB were 2.2 between January and August and increased to between 3.5 and 5.7 from September-December (Figure 55). In GOB and BP, the mean monthly GSIs for females were elevated (> 4) between August and November and July and October, respectively. The mean monthly GSI for females at Flinders Island in October and February was 4.6 and 1.8, respectively. The mean monthly GSIs for male Sand Flathead followed almost identical trends to that of their females (Figure 55).

The percentage of females with stage IV (mature) gonads was > 50% between September and December in FH-NB and between July and December and in March in GOB (Figure 56). The proportion of females with stage IV gonads in Bridport was > 50%

between July and November while 87% of females collected from Flinders Island in October possessed IV gonads. While the proportion of males with stage IV gonads in each month followed a similar pattern to their females, in GOB and Bridport the monthly percentage of males with mature gonads was > 50% over an extended period, i.e., July - February and June - December, respectively (Figure 56). Almost 100% of males caught in October at Flinders Island possessed mature gonads.

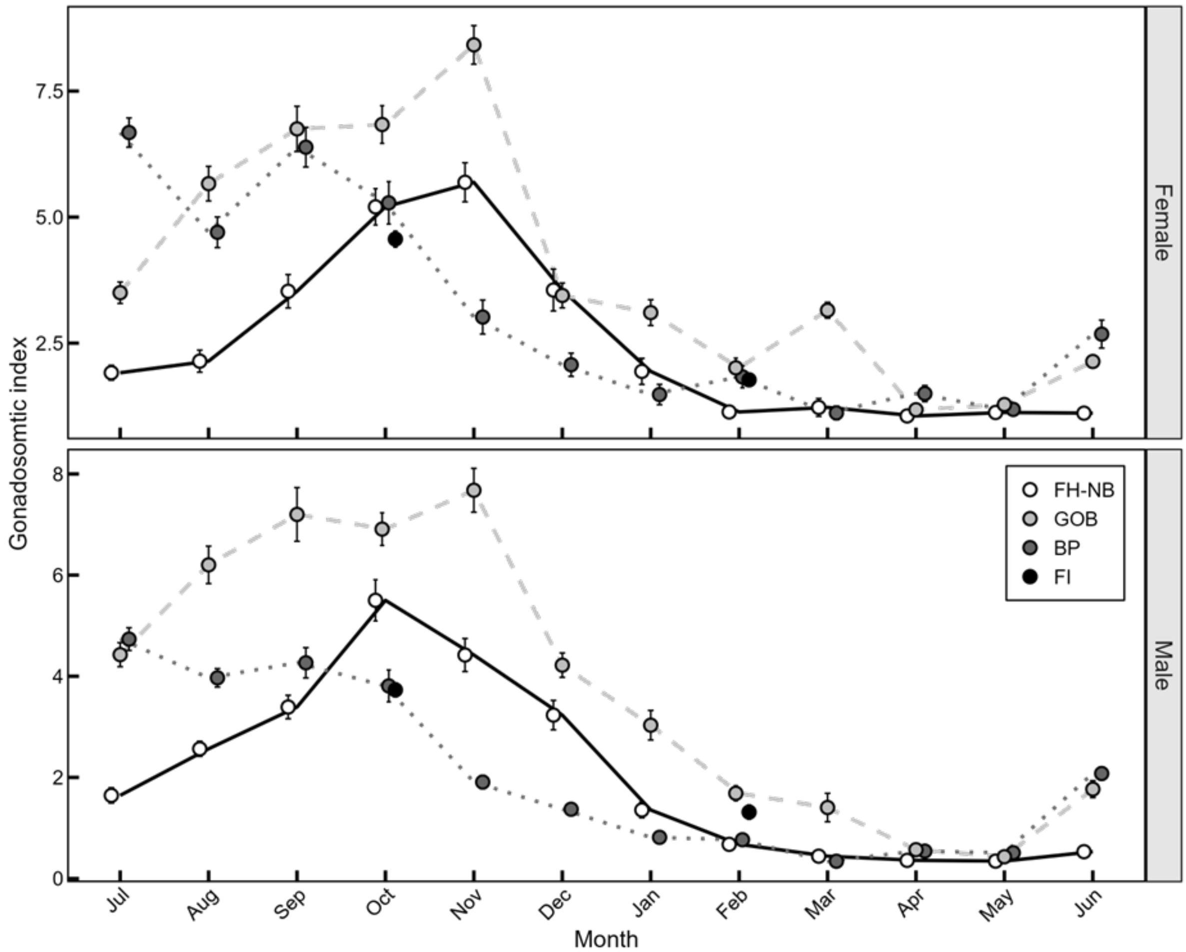


Figure 55. Mean monthly gonadosomatic indices (GSI) ± 1 SE for female and male Sand Flathead from Frederick Henry and Norfolk Bays (FH-NB), Great Oyster Bay (GOB), Bridport (BP) and Flinders Island (FI). Note, mean monthly GSIs for females and males from Flinders Island were only calculated for October and February. Monthly sample sizes are provided in Table 21.

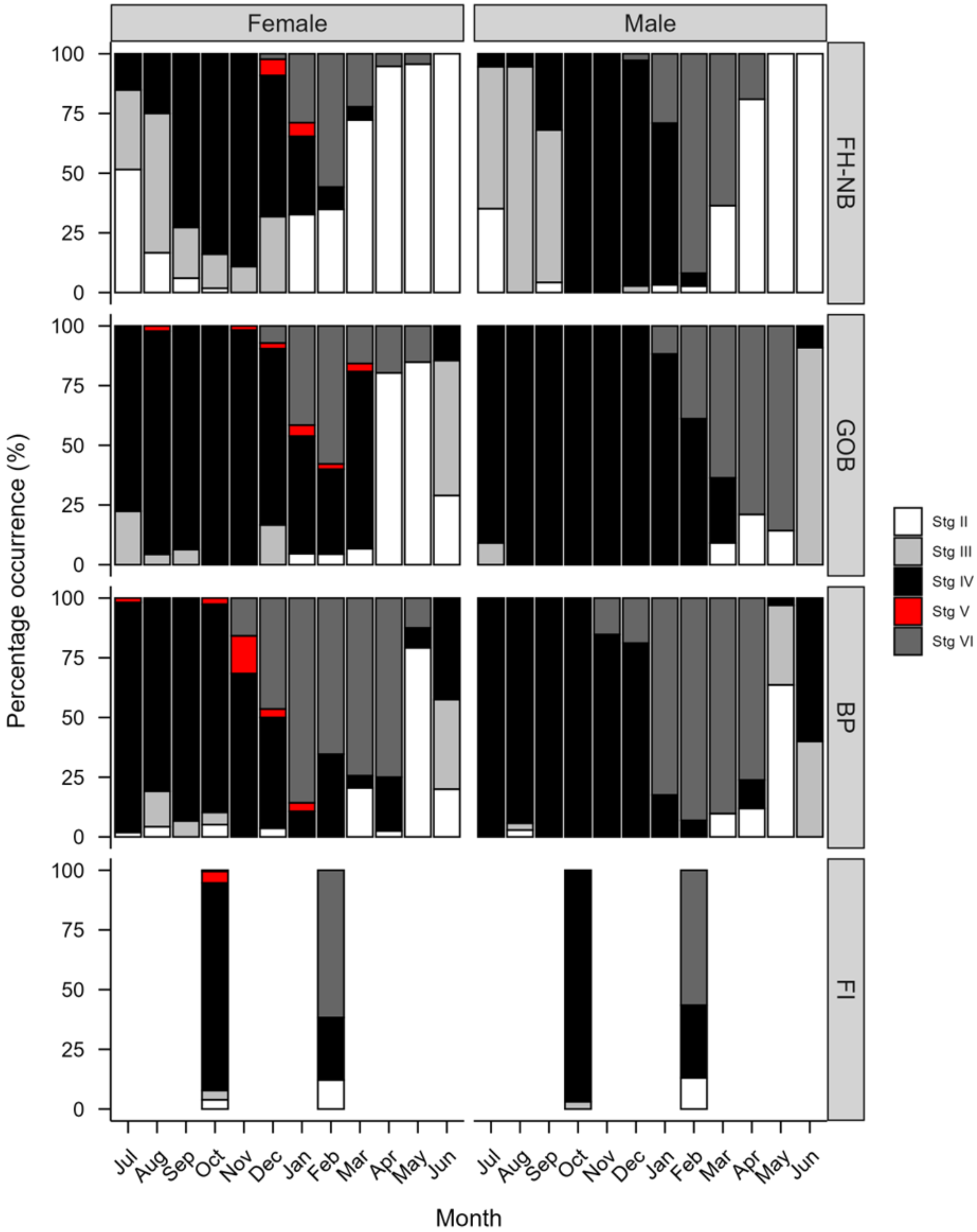


Figure 56. Monthly percentage frequencies of occurrence of sequential stages in the gonadal development of female and male Sand Flathead from Frederick Henry and Norfolk Bays (FH-NB), Great Oyster Bay (GOB), Bridport (BP) and Flinders Island (FI). Monthly sample sizes are provided in Table 21.

The mean standardised weights for stage V/VI gonads of female Sand Flathead from FH-NB, GOB and BP during the peak spawning period (October - December) were 15-17 g (Figure 57), and thus not significantly different ($p > 0.05$) from each other. In contrast, the mean standardised gonad weight (12 g) for stage V/VI gonads of female

Sand Flathead from that same period from FI, noting that samples were only collected in one of those months (October), was significantly lower than the other three regions ($p < 0.05$). The mean standardised weight for stage V/VI gonads of male Sand Flathead from FH-NB was significantly lower ($p < 0.05$) than that for males from GOB, both of which were significantly higher ($p > 0.05$) than the mean standardised weight for stage V/VI gonads of males from BP and FI (Figure 57). The mean standardised weight for stage V/VI gonads of males from these latter two regions were not significantly different ($p > 0.05$).

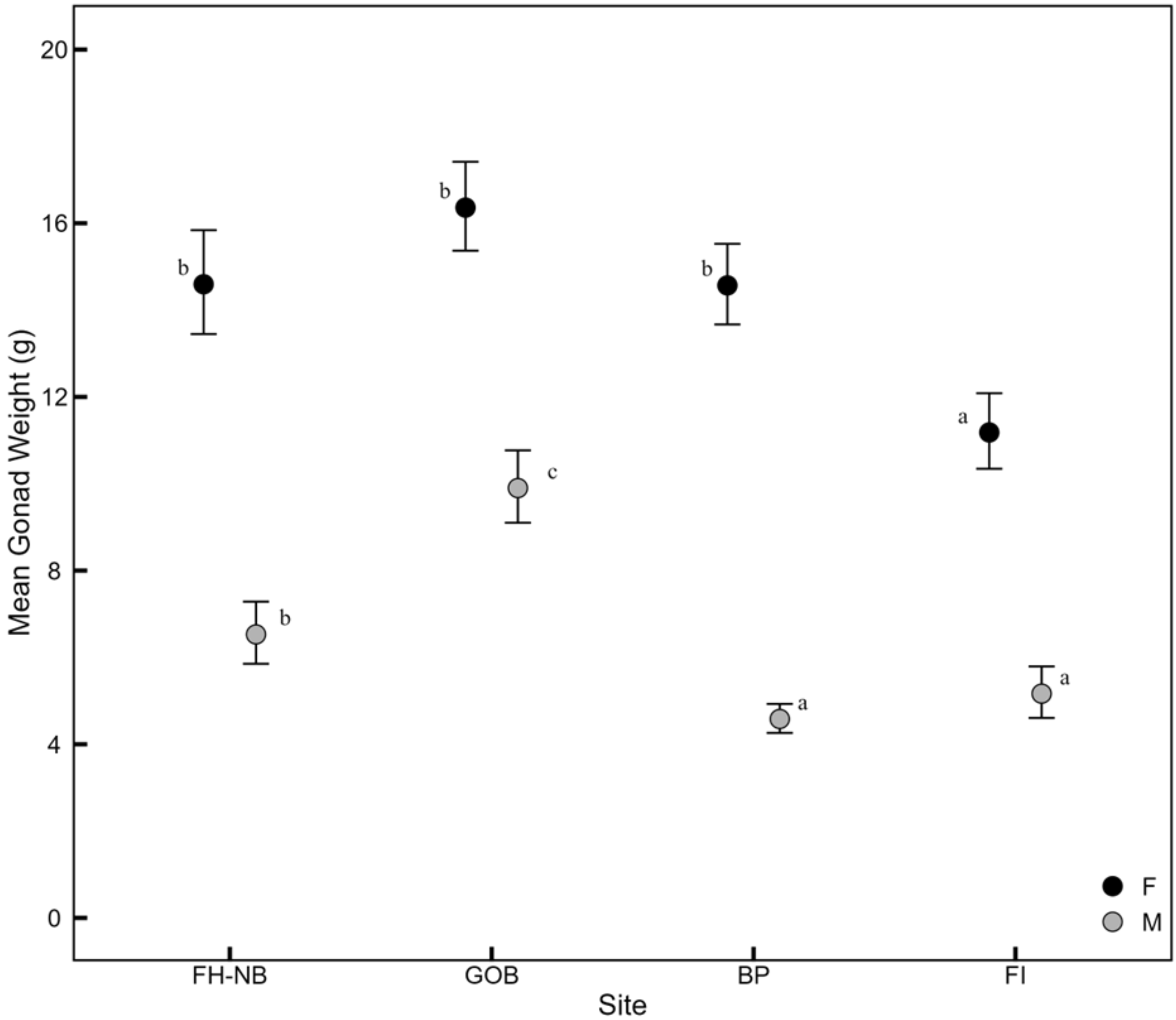


Figure 57. Mean standardised gonad weight ± 95% CI for female and male Sand Flathead from Frederick Henry and Norfolk Bays (FH-NB), Great Oyster Bay (GOB), Bridport (BP) and Flinders Island (FI) during peak spawning months (i.e., October-December). Gonad weights were calculated for a standard total length of 354 mm for females and 302 mm for males. Identical letters indicate mean gonad weights are not significantly different while differing letters indicate a significant difference in those weights.

7.1.3.1 Maturation

The vast majority of female and male Sand Flathead caught by line fishing during the spawning period were mature across all four regions (Figure 58; Figure 59). The smallest mature females were 215 mm in FH–NB, 218 mm in GOB, 255 mm in BP, and 252 mm in FI. For males, the smallest mature individuals measured 218 mm in FH–NB, 192 mm in GOB, 232 mm in BP, and 221 mm in FI. The youngest mature females were 2.9 years (FH–NB), 1.9 years (GOB), 2.8 years (BP), and 2.9 years (FI), while males matured at similar ages, with the youngest individuals recorded at 2.9, 1.9, 2.9, and 3.0 years in the same regions.

A total of 63 small (< 200 mm) Sand Flathead were collected by trawl in FH–NB between June and August, with strong winds limiting sampling during the spring months (September–November). Fish ranged in length from 22 to 219 mm. Individuals in the 0+ and 1+ age classes measured 22–168 mm and 162–219 mm, respectively, while a single 2+ fish measured 209 mm. All 0+ fish possessed either sexually indistinguishable gonads or stage I (virgin) gonads. Most 1+ fish had stage I or stage II (immature) gonads, although three individuals, all males, had reached stage III (maturing), as indicated by the presence of sperm.

When these small, young individuals were incorporated with line-fishing data for FH–NB, preliminary estimates of length and age at 50% maturity were 224 mm and 2.4 years for females, and 201 mm and 2.3 years for males.

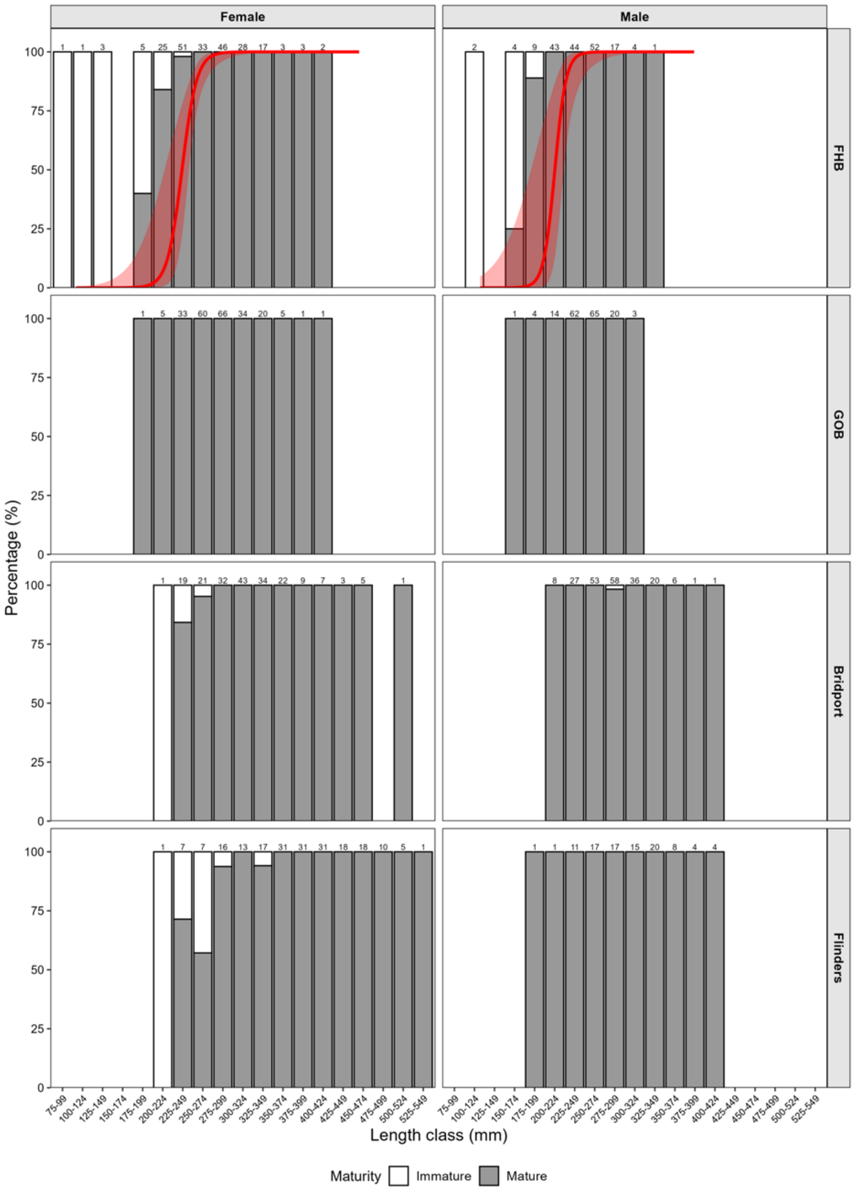


Figure 58. Percentage frequencies of occurrence of female and male Sand Flathead with immature and mature gonads in sequential 25 mm length classes in samples obtained during the peak spawning period, i.e., August to December. Sample sizes for each length class are shown.

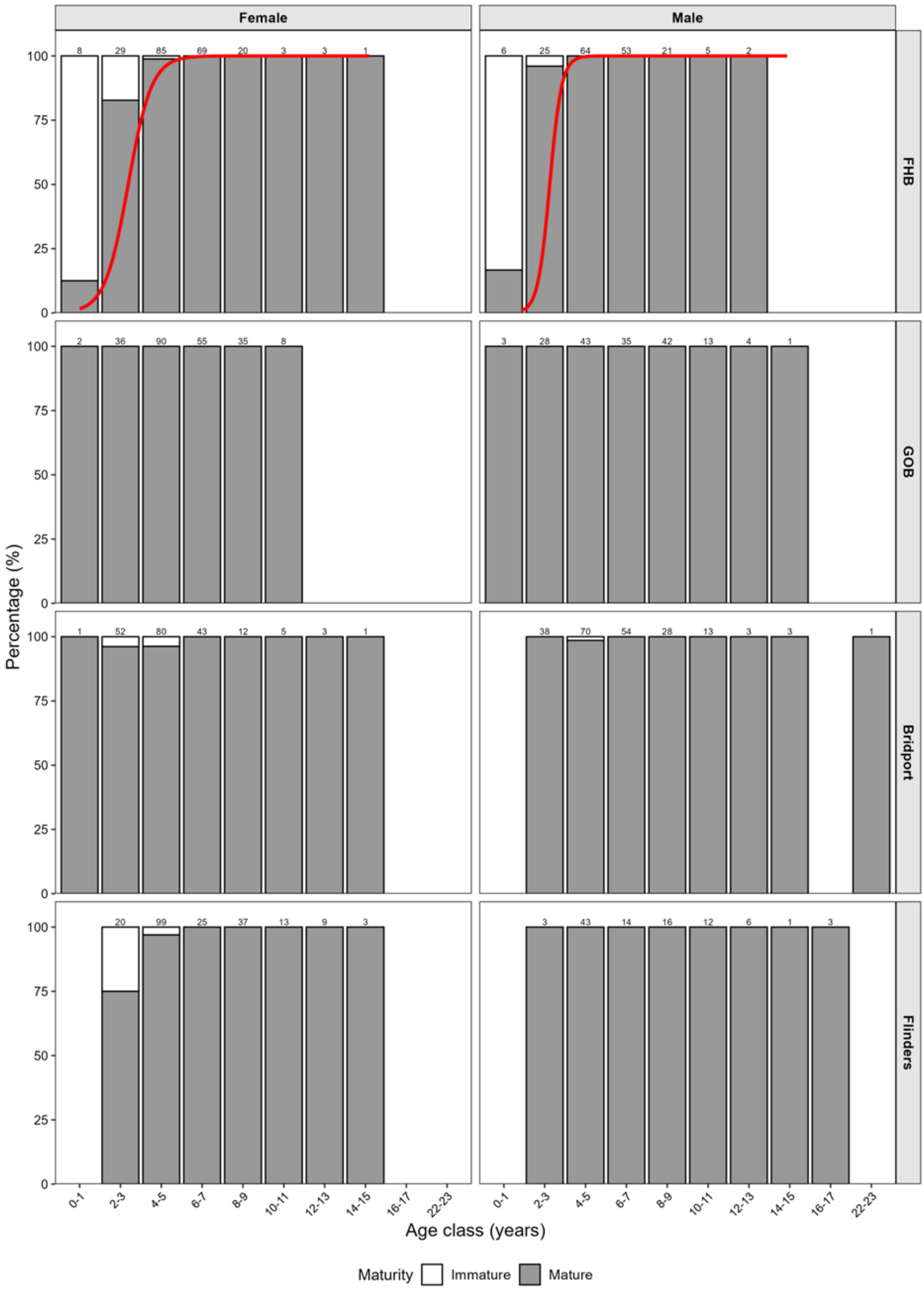


Figure 59. Percentage frequencies of occurrence of female and male Sand Flathead with immature and mature gonads in sequential 2-year age classes in samples obtained during the peak spawning period, i.e., August to December. Sample sizes for each age class are shown.

7.1.4 Discussion

7.1.4.1 Reproductive timing and spawning dynamics

This study provides the first contemporary, regionally standardised assessment of the reproductive biology of Sand Flathead in Tasmanian waters since the foundational studies of Jordan (1998, 2001), and Bani and Moltschaniwskyj (2008). The results demonstrate that Sand Flathead remains an early maturing, prolonged batch-spawning species characteristic of temperate batch-spawning marine fishes, but with clear spatial variation in reproductive timing among Tasmanian regions. The regionally variable timing and protracted spawning season are consistent with life-history traits that will influence recruitment success and population productivity, likely including prey availability, and favourable temperature and hydrodynamic conditions (Jordan, 1998, Koopman et al., 2004, Bani and Moltschaniwskyj, 2008, Jenkins, 2010, Lowerre-Barbieri et al., 2011). These findings improve the biological evidence base for stock assessment and rebuilding management, particularly given the broader report evidence of regional depletion, truncated size structure, and reduced spawning potential in south-eastern Tasmania.

Across all regions examined, gonadosomatic indices and gonad staging indicated that spawning activity generally extended from late winter through early summer, with peak reproductive activity concentrated between October and December. However, the duration and apparent onset of spawning differed among regions.

Frederick Henry and Norfolk Bays exhibited the most compressed reproductive season, with more than half of sampled females mature primarily between September and December. In contrast, Great Oyster Bay and Bridport displayed earlier onset and more prolonged spawning activity, with mature females common from July onward and elevated reproductive activity extending into November or December. Flinders Island samples were temporally limited, but the high proportion of mature fish in October and predominance of spent fish by February indicate that spawning was well advanced in spring and largely complete by late summer.

These regional differences are broadly consistent with earlier Tasmanian studies that reported spawning seasons ranging from two to six months depending on location (Jordan, 2001), while also suggesting that open coastal populations may sustain reproductive activity for longer than some enclosed embayments or estuarine systems. This distinction is important because several historical maturity estimates were derived from semi-enclosed systems that may not fully represent contemporary coastal populations.

The observed spatial variation in spawning timing is consistent with environmental gradients around Tasmania. Northern and northeastern regions typically experience earlier spring warming and longer persistence of elevated water temperatures than more southerly embayments, while local productivity cycles and hydrodynamic conditions may also differ. Seasonal increases in temperature and photoperiod are widely recognised as key reproductive cues in temperate fishes (Lam, 1983, Pankhurst and Munday, 2011).

Jordan (2001) similarly noted that spawning of Sand Flathead intensified with spring warming and coincided with seasonal increases in east coast productivity. Earlier onset and longer spawning seasons in Great Oyster Bay and Bridport may therefore reflect more favourable thermal or trophic conditions than Frederick Henry and Norfolk Bays. Such environmental forcing is biologically relevant because reproductive timing can strongly influence larval feeding success, transport pathways, and ultimately recruitment strength (Cushing, 1990, Lowerre-Barbieri et al., 2011).

These findings are particularly relevant in the context of warming Tasmanian waters and increasing marine heatwave frequency (Jordan, 2001). Ongoing environmental change has the potential to alter spawning phenology, larval survival windows, and regional productivity, reinforcing the need for continued monitoring of reproductive timing through time.

Preliminary estimates of length and age at 50% maturity in Frederick Henry and Norfolk Bays were approximately 224 mm and 2.4 years for females, and 201 mm and 2.3 years for males. These values are broadly consistent with earlier estimates from open coastal Tasmanian populations reported by Jordan (2001), who estimated female and male L_{50} values of approximately 247 mm and 217 mm, respectively, with ages at maturity of 2.6 and 2.5 years.

Although the contemporary estimates were modestly smaller and younger, differences were not large and should be interpreted cautiously given the preliminary nature of the current estimates and limited sampling of smaller immature fish. Nonetheless, the available evidence suggests that maturity schedules in open coastal Tasmanian populations have remained broadly stable over the past two to three decades.

This contrasts with substantially older ages at maturity reported from Georges Bay by Bani and Moltschaniwskyj (2008), where females matured at approximately 5.2 years. Earlier chapters of this report demonstrated that Georges Bay fish exhibit relatively small size-at-age and atypical demographic structure compared with open coastal populations. Similarly, the Tamar estuary was dominated by immature fish, suggesting it functions primarily as juvenile habitat. Together, these observations reinforce that reproductive parameters derived from enclosed or nursery-dominated systems should not be assumed to represent statewide coastal populations.

While maturity schedules are important, they represent only one component of stock reproductive capacity. Contemporary fisheries science increasingly recognises that reproductive potential is strongly influenced by the size and age structure of the spawning stock, not simply the proportion mature (Lowerre-Barbieri et al., 2017). Larger and older females often produce disproportionately more eggs and offspring with enhanced survival potential.

This principle is especially relevant for Sand Flathead because females attain substantially larger sizes than males. Earlier chapters of this report showed that fish above 320 mm are predominantly female, and fish above 350 mm are almost exclusively female in many Tasmanian regions. Consequently, size-selective fishing that removes larger fish can disproportionately reduce female spawning biomass even where overall abundance remains moderate.

The persistence of truncated size structure in south-eastern Tasmania therefore has implications beyond reduced catch quality or mean size. It likely reflects diminished reproductive capacity and lower resilience to poor recruitment years. This aligns with the broader BOFFFFs concept, whereby preservation of big, old, fat, fecund female fish can materially enhance stock productivity and stability (Hixon et al., 2014).

The reproductive characteristics identified in this study suggest that Sand Flathead possesses several life-history traits associated with moderate resilience to exploitation, including relatively early maturation and a prolonged spawning season. However, resilience should not be interpreted as immunity to depletion. Earlier chapters documented substantial demographic truncation and depleted stock status in south-eastern Tasmania, demonstrating that even relatively productive species can decline when sustained fishing pressure removes larger spawning fish faster than they are replaced.

The recent introduction of a slot limit in Tasmanian waters (excluding Flinders Island) is strongly supported by the reproductive evidence presented here. Such measures allow fish to spawn across multiple seasons before harvest while also protecting the largest individuals, which are predominantly female and disproportionately valuable to stock reproductive output. International experience with harvest-slot regulations similarly shows that well-designed harvest windows can help maintain broader size structure and reproductive capacity Jordan (2001).

The identified spawning period also provides useful biological context for future management. While reproductive activity may begin earlier in some northern regions, peak statewide spawning appears concentrated in spring to early summer, particularly October to December. This period may warrant consideration in future harvest strategy discussions if seasonal protection of spawning biomass is contemplated.

Most importantly, rebuilding success should not be judged solely by abundance metrics. Recovery of upper size classes, increased representation of large females, and restoration of regionally appropriate spawning potential are likely to be equally important indicators of stock rebuilding.

Several priorities emerge from this work. First, explicit modelling of reproductive timing against environmental drivers such as temperature, photoperiod, and productivity would improve understanding of climate sensitivity. Second, continued regional monitoring is needed to determine whether spawning phenology or maturity schedules shift through time under changing environmental or fishing conditions. Third, incorporation of region-specific reproductive parameters into future stock assessment models would improve estimates of spawning biomass and rebuilding potential.

7.1.5 Conclusion

This study provides the most contemporary and regionally comparable assessment of Sand Flathead reproductive biology in Tasmania to date. Sand Flathead remains an early maturing, asynchronous batch-spawning species with a prolonged reproductive season, but important spatial variation exists in the timing and duration of spawning activity across regions. Open coastal populations exhibited maturity schedules broadly consistent with earlier historical estimates, suggesting relative stability in this key life-history trait over recent decades.

However, reproductive capacity is determined by more than maturity schedules alone. The strong sexual size dimorphism of Sand Flathead means that larger fish are disproportionately female, making preservation and rebuilding of upper size classes central to sustaining spawning biomass. In this context, the truncated size structures documented elsewhere in the report, particularly in south-eastern Tasmania, likely represent reduced reproductive potential as well as diminished fishery quality.

By providing updated, region-specific reproductive parameters, this chapter strengthens the biological foundation for stock assessment, harvest strategy development, and rebuilding management of Sand Flathead in Tasmanian waters. Continued monitoring of spawning dynamics and restoration of large female biomass will be central to securing the long-term productivity and resilience of this important recreational fishery.

8 Objective 5: Investigate movement and connectivity of Sand Flathead within Tasmania

8.1 Otolith microchemistry

8.1.1 Introduction

Advances in spectral analysis technologies, such as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), have enabled low-cost, fast, reliable, and precise measurement of micro chemical composition of calcifying structures such as bones (Limbeck et al., 2015). In aquatic systems, site specific environmental chemistry is influenced by physical characteristics (e.g., currents, geology, etc), as well as biological inputs and terrestrial runoff, including from anthropogenic sources. Fish absorb elements through their gills, digestive tract and skin, which are subsequently incorporated into the calcifying matrix during osteogenesis (Kerr et al., 2014). Therefore, elemental signatures in fish bones can at least partially reflect an individual's environment and dietary history (Izzo et al., 2018).

The otoliths of teleost fish are composed of highly crystallised aragonite, which is permanently mineralised and is therefore not susceptible to reworking or leaking after formation (Kerr et al., 2014). If elements are incorporated proportionally to their abundance in the environment, these signatures can be used as natural tags to identify presence and movement across distinct geographic regions. Otoliths show accretionary growth and are commonly used for age determination, helping build an established sclerochronology. These characteristics make otoliths ideal for analysing microchemical signatures throughout the lifetime of an individual. This ecological timeframe can complement knowledge from conventional tagging (short term trends) and population genetics (long term population trends), providing a potential valuable resource for management. In fact, elemental analysis of hard structures in fish has been successfully used to aid in stock discrimination (Nazir and Khan, 2021), identification of ontogenetic movement and trophic patterns (Sturrock et al., 2012), and even validation of ageing (Moreno and et al., 2018).

Sand Flathead are an important recreational fishery species and are widespread across Tasmania, occurring across a variety of habitats. Therefore, variables like proximity to shore, freshwater runoff, localised biogeochemistry and even anthropogenic inputs have the potential to produce distinct environmental fingerprints that can be used to study the geographic origin, movement and connectivity of individuals and to help inform management strategies.

This question is particularly relevant in the context of previous chapters of this report. Fishery-independent surveys demonstrated persistent regional differences in size structure, with south-eastern Tasmania supporting consistently smaller and more truncated populations than northern and northeastern regions. Growth analyses similarly identified marked regional differences in size-at-age, while reproductive assessments suggested spatial variation in spawning timing and demographic composition. Collectively, these findings indicate strong spatial structuring, but do not resolve whether such patterns arise from largely discrete regional populations, partial mixing among regions, or common recruitment followed by localised fishing effects.

Improved understanding of movement and connectivity is therefore central to defining biologically meaningful management units and interpreting rebuilding trajectories across Tasmania.

This study was motivated by the important need to better understand connectivity and discrimination of Sand Flathead across regions in Tasmania. The main goal was to develop a robust protocol for elemental analysis of Sand Flathead otolith samples (recent and historical) and conduct a pilot study to determine the potential of this technique to aid in the management of the species.

The specific objectives of this component were:

- To develop a sample preparation and analytically protocol for reliable LA-ICP-MS analysis of Sand Flathead otoliths. This includes testing the core assumptions of LA-ICP-MS analysis, such as verifying internal consistency within the samples, optimizing ablation parameters and refining the target element list.
- To compare multiple analytically techniques and develop prototype predictive model (for pilot samples) to discriminate origin of Sand Flathead based on microchemical signatures.
- To verify the potential for using Sand Flathead otoliths for the retrospective analysis of lifelong patterns of movement and ecology on the species.

8.1.2 Methods

8.1.2.1 Sample collection and pilot design

Otolith samples were obtained from the historical collection at IMAS. Otoliths are collected yearly from multiple regions across the state as part of regular fishery-independent population monitoring. See Objective 3 in this report for details on fish capture and otolith extraction methods.

For the pilot study a factorial design was used which included two main areas (North and South), each with a marine (FHB-Frederick Henry Bay (S) and TC-Badger beach (N)) and an estuarine site (DC-D’Entrecasteaux Channel (S) and TE-Tamar estuary (N)). To explore the effects of inter-annual variability in environmental conditions and ontogenetic variability, individuals that belonged to the same cohort for each year/site (based on estimated age) were chosen (estimated birth years 2016 and 2018) except the Tamar estuary (only 2018 samples were available). A single otolith (left sagittal) was used for analysis except for four individuals from FHB, where the second sagittal otolith was also included to verify internal consistency and test the effect of different sample preparation procedures (see below).

8.1.2.2 Sample preparation

To develop a consistent method for reliable analysis and reduce the risk of surface contamination in samples, a series of sacrificial otoliths were analysed to test different preparation methods. Using a 50% bleach solution to clean the otolith did not influence the chemical composition of the sample (determined by comparing sister otoliths, where one was treated with bleach and the other was not). The final protocol was as follows:

- Otoliths were carefully cleaned of any soft tissue and placed in an individually labelled tissue cassette.
- Samples were immersed in a 50% bleach solution (sodium 150 hypochlorite 42 g L^{-1}; sodium hydroxide 9 g L^{-1}) for 5 minutes for cleaning.
- Samples were rinsed in a running water bath for 30 minutes and air dried for 24 to 48 hours in a covered laminar flow cabinet (LFC) to provide a particle free environment.
- Dry otoliths were embedded in a two-part clear-casting polyester resin (Gemmasta Deluxe GS6D) and left to cure.
- Otoliths were sectioned along the transversal plane to expose the centrum using a low speed Isomet saw with a diamond blade saw (Isomet, Bruehler, Lake Bluff, IL, USA) at approximately 240 rpm with a 75 g load weight.
- Sectioned otoliths were rinsed in dH_2O and embedded into a round resin mount in groups of five with the exposed section facing downwards.
- Each mount was wet polished using sandpaper with increasingly finer grit sizes (100 to 10,000).
- To remove surface contamination from the polishing process, samples were cleaned in dH_2O and sonicated twice in 10-minute cycles (35 seconds on, 5 seconds off) using a sonication probe (Qsonica) at 50% amplification.
- Samples were air dried in the LFC and stored in a vacuum glass container until analysis (Figure 60).

Figure 60. Photograph of whole mounted Sand Flathead otoliths prepared for LA-ICP-MS using the protocol developed here. Otoliths of similar sizes were embedded together and polished to expose the individual centra.

8.1.2.3 Elemental analysis

The microchemical composition of otoliths was analysed using a NewWave NWR213-ESI laser system coupled to a quadruple ICP-MS housed at the Centre for Ore Deposits and Earth Sciences (CODES) analytical laboratory, University of Tasmania. Ablation spots were programmed using the inbuilt camera. For each otolith two replicate spots were placed each at the origin (representing the natal origin) and at the edge (representing the capture location). For the four individuals with a second available otolith, a transect was programmed extending from the edge on the long side to the origin and across to the opposite edge (Figure 61).

Ablation parameters were consistent between runs, i.e., beam size was 43 μm diameter moving at 10 $\mu m\ s^{-1}$ (transects only), laser refresh rate was 5Hz with 87 mJ intensity. For each spot, analysis consisted of a pre-ablation run (to clean the sample surface), a 28 s blank (to measure background concentration levels), and a 60 s ablation run. Reference materials were ablated after every 15 ablation runs to account for instrumental drift and precision (i.e., United States Geological survey MAC3 and BCR-2, National institute of standards and technology 612, and Durango apatite) ((Jochum et al., 2005), (Pearce et al., 1997) respectively). Detection thresholds were calculated for each isotope and only those consistently above detection limits were kept for further analysis. Raw count data was processed for data reduction using an in-house macro (Centre for Ore Deposits and Earth Sciences, University of Tasmania). The average background levels in the pre-analysis blank were subtracted from the counts and values were corrected for instrumental drift. Counts were normalised using Ca^{43} as an internal standard and concentrations were converted to molar ratios (element: Ca $\mu mol\ mol^{-1}$).

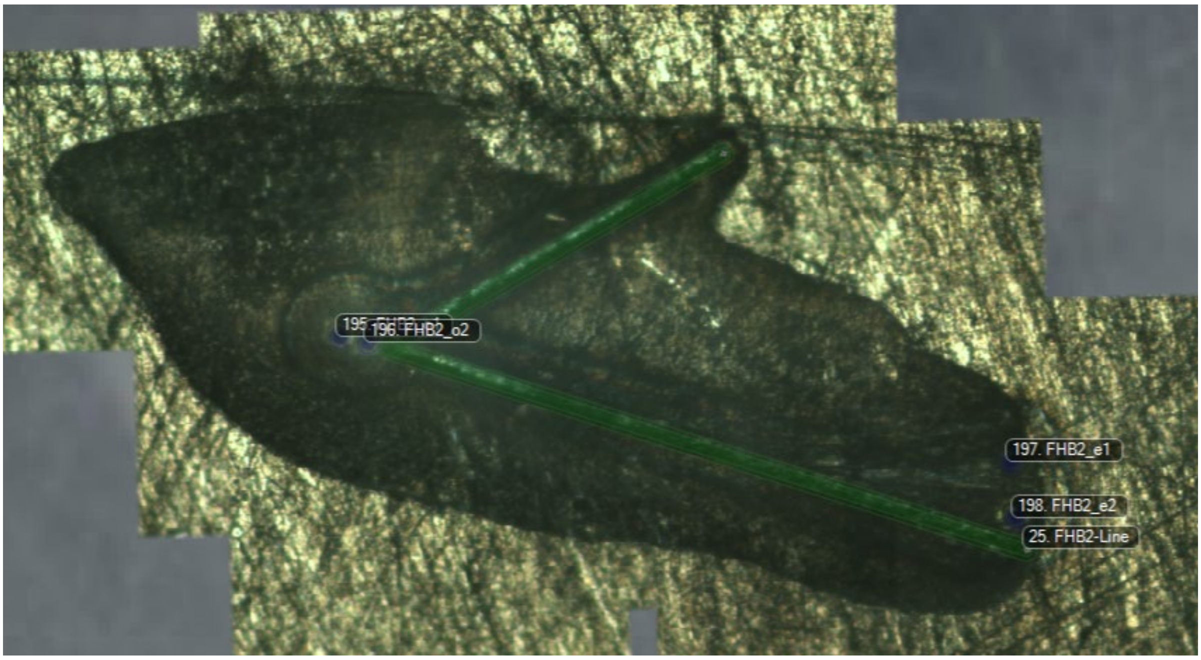


Figure 61. Example of laser ablation transects across the otolith surface from the point of natal origin to the edge (capture) across different axes.

8.1.2.4 Data analysis

Statistical analysis and data manipulation were conducted using R statistical software (Team et al., 2018). All permutational multivariate analysis were conducted using 10,000 permutations.

Time resolved concentrations were visualised to confirm that the ablated material was homogeneous and that there were no signs of contamination (Figure 62). Element reads were stable within all ablation runs, so a mean time resolved value of each element was calculated for each spot. Replicates were internally consistent

(PERMANOVA, *F*=0.094, *p*=0.928), so the element concentrations across both replicates were averaged.

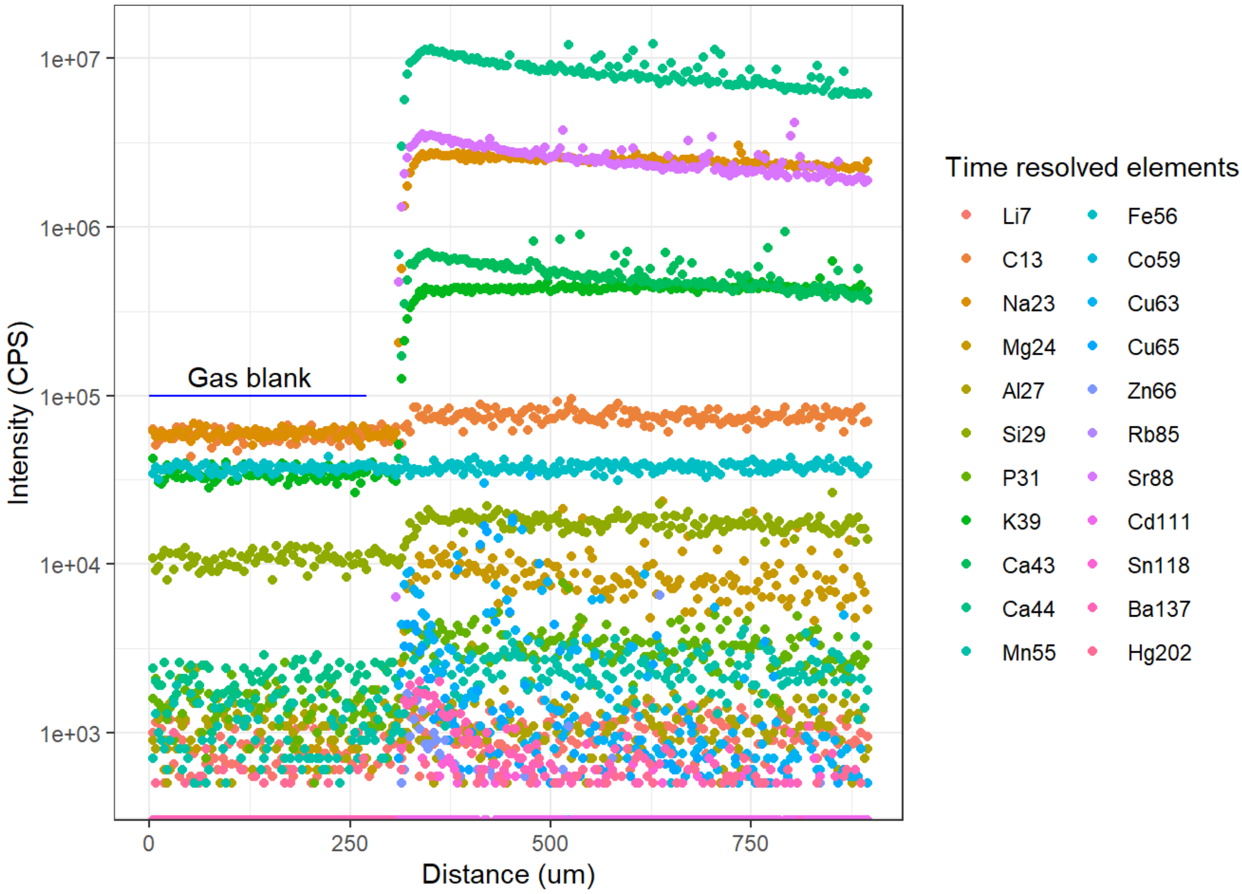


Figure 62. Example of time resolved (signal in counts per second vs. ablation depth) for a single ablation spot in a Sand Flathead otolith. The gas-blank shows the pre-ablation background levels.

Differences in multivariate elemental signature between sites were analysed using permutation analysis of variance (PERMANOVA). A pairwise PERMANOVA post-hoc test was conducted using a Bonferroni correction. Site specific ranked dissimilarities were explored using analysis of similarity (ANOSIM). To understand what elements were responsible for the differences between sites, similarity percentage analysis (SIMPER) and indicator species analysis were used.

To explore the potential for using elemental signatures to discriminate location of origin we compared a variety of available techniques (k means clustering, NDMS, Random Forest (supervised and unsupervised) and linear discriminant function analysis (LDFA)). All techniques showed good classification accuracy (>60%), however, LDFA consistently produced the best results through testing and was chosen as the primary analysis for the rest of the study. LDFA models were trained using elemental signatures from the capture region. Given the large differences between element: Ca concentrations, the data were standardised by column centering. Regression coefficients were calculated for all element/site combinations. To determine the proportional contribution and significance of the different elements towards discrimination, R^2 and p statistics from the package “flipMultivariates” were used.

To explore the possible effect of biological traits (i.e., sex, size, stage of maturity and birth year) on elemental concentrations, a multivariate GLM with latent variables was fitted using the 'boral' package (40,000 permutations). The model assumed a multivariate normal distribution and was fitted using a Bayesian Markov Chain Monte Carlo (MCMC) method. The Bayesian posterior distribution of the response specific coefficients for each covariate was calculated (95 % HDP intervals) and plotted to determine if the modelled response significantly differed from zero. To evaluate how well the model captured the data structure, Dunn-Smith residuals were inspected (Hui, 2016).

Lifelong concentrations of element: Ca ratios were plotted using a 5-point moving average for the four otoliths were transects were ablated. Additional isotope: isotope ratios that could provide insight into biological processes or anthropogenic signatures were also calculated (e.g., Sr: Ba, Pb: Pb).

8.1.3 Results

Otoliths from 30 individuals were analysed (M=12, F=18). All fish were captured between January and March 2021 to control for seasonal variation in environmental conditions. At the time of capture individuals ranged in size between 199–280 mm TL. Individuals were estimated to be either 3 or 5 years old at the time of capture.

The limit of detection was estimated for all elements analysed (Table 23). Hg was excluded from analysis since Mercury gas is used as a carrier in the ablation process and contamination in the lased cell can occur. Concentrations of Al, Cd, Pb, Fe and Pb were consistently below the detection limit and were therefore excluded from further analysis.

Table 23. Mean limit of detection (LOD) for all elements included in the analysis shown as PPM. Elements marked with * were consistently below LOD and were removed from subsequent analysis.

ELEMENT	LIMIT OF DETECTION (PPM)	REMOVED
INTERNAL STANDARD		
CA_{43}	10.9	
MULTI-ELEMENT TARGETS		
LI_{7}	0.09	
NA_{23}	1.3	
MG_{24}	0.17	
AL_{27}	0.18	*
SI_{29}	35.7	
P_{31}	3.9	
K_{39}	1.06	
MN_{55}	0.1	
FE_{56}	0.76	*
CO_{59}	0.01	
CU_{65}	0.04	*
ZN_{66}	0.02	
RB_{85}	0.01	
SR_{88}	0.003	

CD_{111}	0.007	*
SN_{118}	0.02	
BA_{137}	0.001	
PB_{206}	0.006	*
PB_{208}	0.006	*

8.1.3.1 Differences between regions

Multi-element chemical signatures in the capture region of otoliths differed significantly by location (*F* = 5.207, *p* > 0.002). However, post-hoc pairwise analysis showed that only Channel vs TamarEst, NorFred vs TamarEst had significant differences (*F* = 18.248, 19.757, *p* = 0.012, 0.018 respectively). The ANOSIMs R statistic was 0.2 (with 0 being completely homogeneous and one being completely dissimilar), suggesting that dissimilarities between groups were only moderate, but not likely to be caused by random chance alone. SIMPER and indicator species analysis showed that Mg, Mn and Na were significantly associated with the Tamar Estuary and were the main contributors towards the observed dissimilarities.

LDFA is a type of supervised machine learning method that allowed the use of prior knowledge of the capture location of individuals to train a model that maximizes the distance between sites. Based on standardised elemental concentrations of the capture region (Model A), the mean cross-validated classification accuracy was very high (93%) with only 2 of 30 sites being misclassified (Table 24; Figure 63). Interestingly, despite being the site with the most distinct elemental signatures, TE showed the lowest accuracy (80%), with the DC and TC sites having a classification accuracy of 100% (Figure 64). However, due to the small number of samples per category, this pilot model should only be considered as proof of concept and is unlikely to represent a robust estimator. All elements contributed to discrimination; however, Mn, Mg, Sr and Na explained the largest proportion of the variance within each site.

Table 24. LDFA model for site discrimination based on chemical signatures from the capture region of Sand Flathead otoliths (Model A). The mean contribution to linear discriminant analysis for each element:site combination is presented, with the colour indicating strength and direction of the correlation. Discriminator performance is described by R^2, which represents the proportion of variance for each element that is explained by the categories.

	Channel n: 9	NorFred n: 8	TamarCoast n: 8	TamarEst n: 5	R-Squared	*p*
X7Li	0.76	0.93	1.06	1.04	0.16	.397
X23Na	0.93	0.95	0.97	**1.12**	0.43	**.002**
X24Mg	**0.57**	0.60	0.88	**1.70**	0.65	**< .001**
X29Si	0.96	0.96	1.00	1.03	0.16	.632
X31P	0.90	0.99	0.97	0.66	0.09	1.000
X39K	0.99	0.93	1.03	0.89	0.08	1.000
X55Mn	**0.29**	0.54	0.62	**1.89**	0.64	**< .001**
X59Co	1.00	0.82	0.74	1.03	0.08	1.000
X66Zn	0.85	0.71	1.06	0.95	0.10	1.000
X85Rb	0.89	0.78	1.04	0.81	0.05	1.000
X88Sr	**1.11**	0.96	0.94	**0.72**	0.38	**.019**
X118Sn	0.95	0.99	1.01	0.96	0.06	1.000
X137Ba	1.07	0.92	0.98	0.76	0.18	.419

n = 30 cases used in estimation; null hypotheses: two-sided; multiple comparisons correction: False Discovery Rate correction applied simultaneously to the entire table

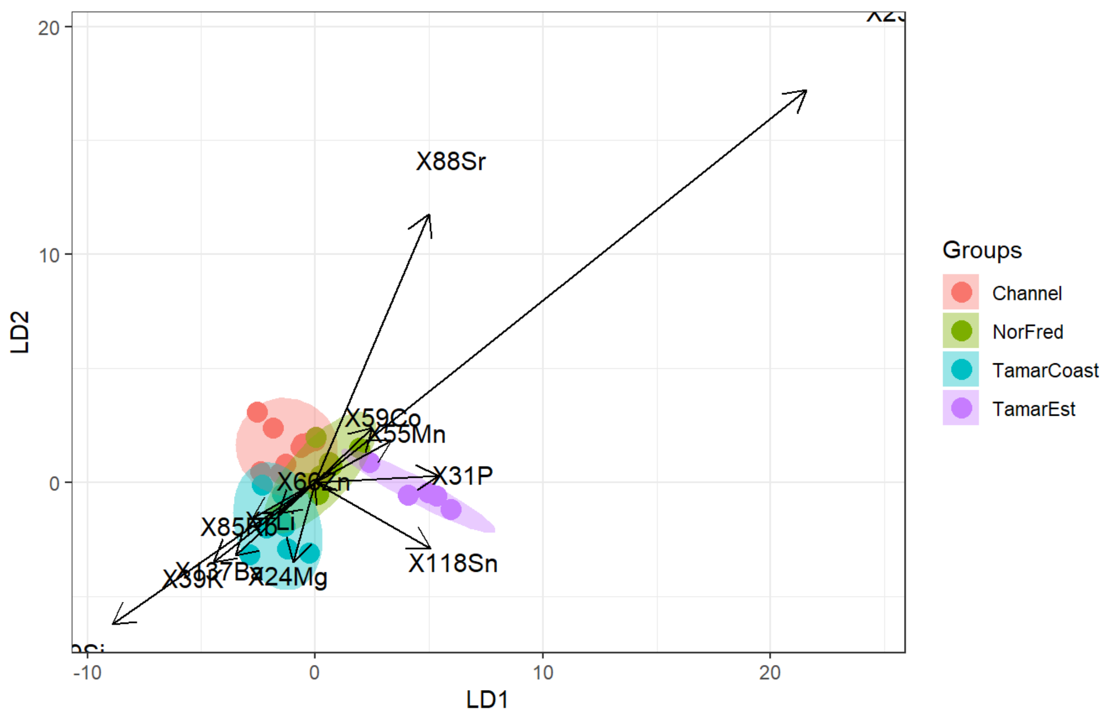


Figure 63. Ordination biplot based on LDFA (Model A) showing observed site differences (based on capture region) between sand Flathead otoliths in relation to elements used in LA-ICP-MS. The axes show the 2 main linear discriminants.

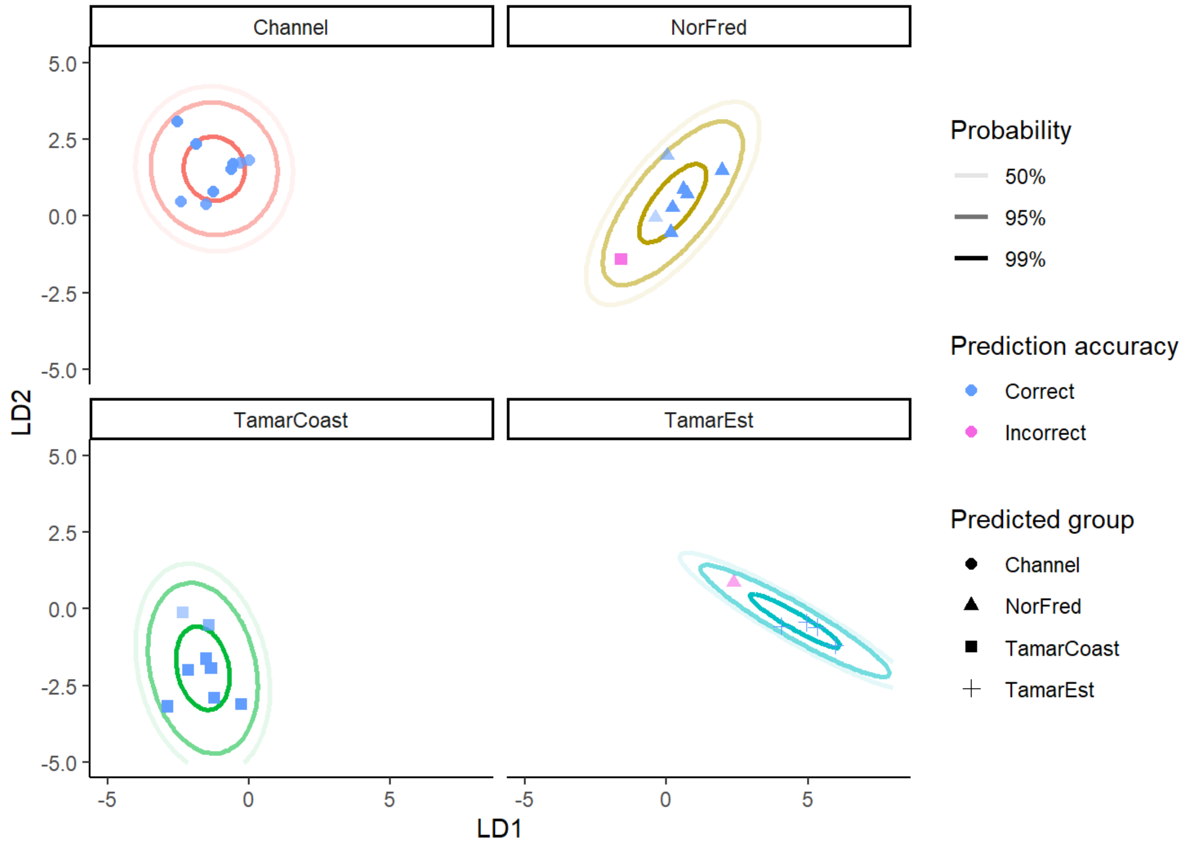


Figure 64. Predicted site classification based on LDFA (Model A) for otolith capture region microchemistry and trained on known capture site. Solid colour lines denote classification probability areas in 2D space. Blue points show correctly classified individuals. Red points show incorrectly assigned individuals, and the shape legend indicates their true site of capture.

A separate model was fitted to the elemental data from the otolith's origin (Model B). Cross-validated classification accuracy declined to 70%, with FHB and TE showing the largest drop, with 50 and 60% accuracy respectively (Table 25; Figure 65). In this model Li, P, Zn and Ba contributed the most towards discrimination. Two individuals from the TE were classified as from DC and individuals from FHB were classified as originating from all the other sites (Figure 66). Using the model trained on the capture location data (Model A) to predict location based on data from the otoliths origin resulted in a further decline in prediction accuracy to 30%.

Table 25. LDFA model for site discrimination based on chemical signatures from the origin region of Sand Flathead otoliths (Model B). The mean contribution to linear discriminant analysis for each element:site combination is presented, with the colour indicating strength and direction of the correlation. Discriminator performance is described by R^2, which represents the proportion of variance for each element that is explained by the categories.

	Channel n: 9	NorFred n: 8	TamarCoast n: 8	TamarEst n: 5	R-Squared	*p*
X7Li	1.03	0.95	0.99	0.82	0.13	1.000
X23Na	0.99	0.97	0.99	0.98	0.03	1.000
X24Mg	0.86	0.90	0.97	1.11	0.09	1.000
X29Si	0.98	1.05	0.89	0.95	0.12	1.000
X31P	0.45	0.45	0.43	1.25	0.14	1.000
X39K	0.95	0.97	0.98	0.98	0.01	1.000
X55Mn	0.73	0.88	0.97	1.00	0.06	1.000
X59Co	0.56	0.76	0.33	0.74	0.05	1.000
X66Zn	0.30	0.67	0.18	1.00	0.12	1.000
X85Rb	0.87	1.06	0.94	0.86	0.07	1.000
X88Sr	0.95	0.97	1.01	0.99	0.08	1.000
X118Sn	0.96	1.03	0.97	0.94	0.09	1.000
X137Ba	0.56	0.99	0.40	0.97	0.13	1.000

n = 30 cases used in estimation; null hypotheses: two-sided; multiple comparisons correction: False Discovery Rate correction applied simultaneously to the entire table

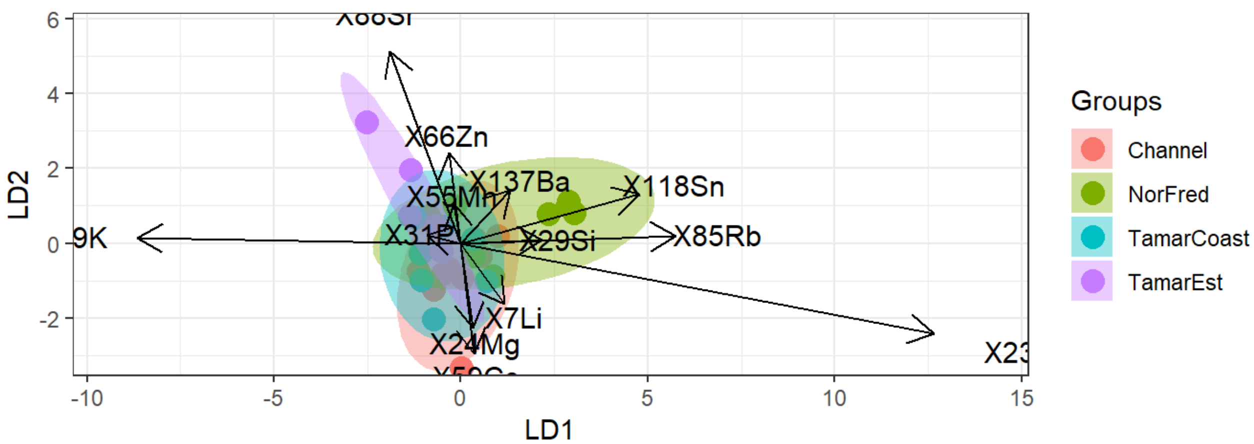


Figure 65. Ordination biplot based on LDFA (Model B) showing observed site differences (based on capture region) between sand Flathead otoliths in relation to elements used in LA-ICP-MS. The axes show the 2 main linear discriminants.

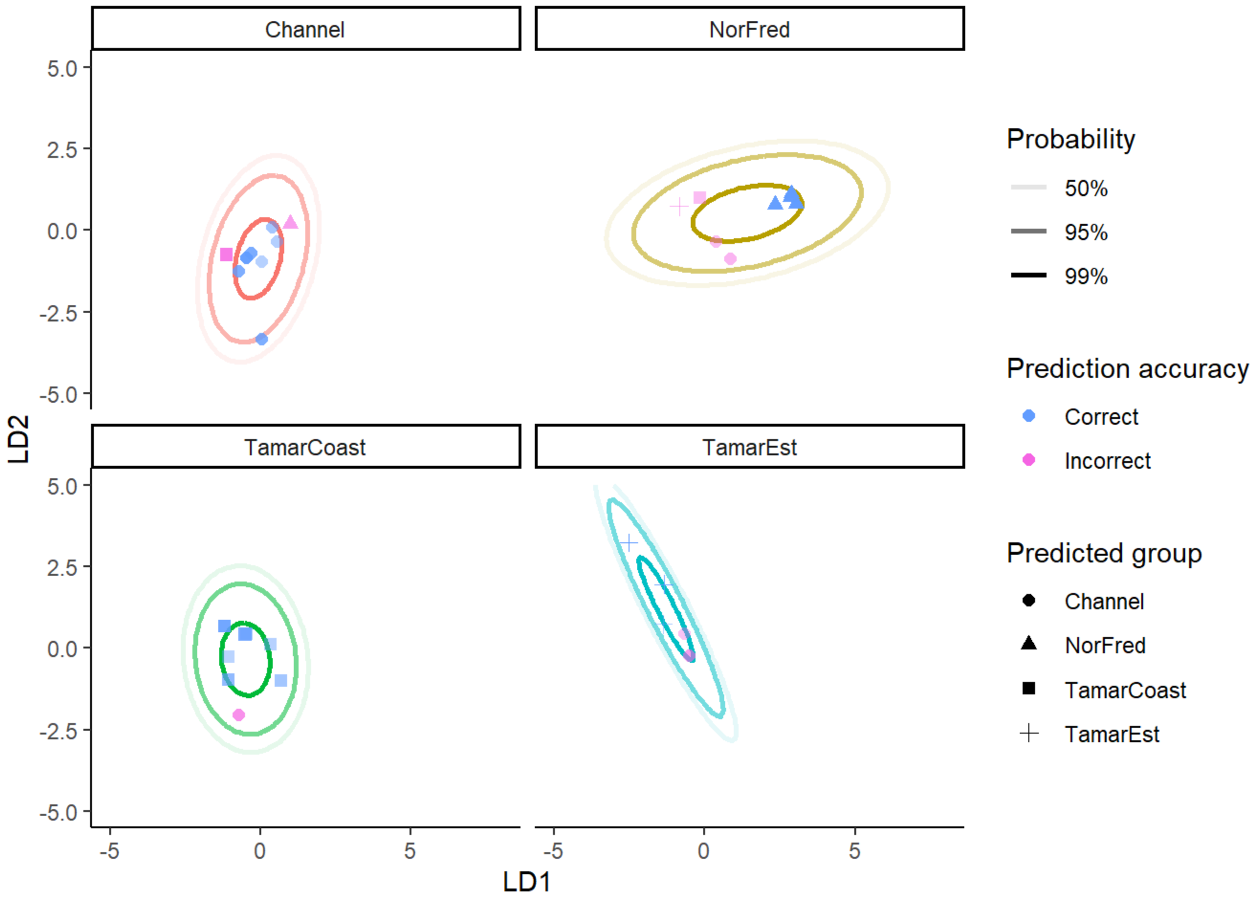


Figure 66. Predicted site classification based on LDFA (Model B) for otolith origin microchemistry and trained on known capture site. Solid colour lines denote classification probability areas in 2D space. Blue points show correctly classified individuals. Red points show incorrectly assigned individuals, and the shape legend indicates their true site of capture.

The model-based approach produced a similar ordination plot to the LDFA when no environmental covariates were included and concentration data was de-scaled (unconstrained ordination) (Figure 67). To explore the effects of the covariates, the untransformed element data was used, but given the different scales across the covariate matrix, all covariates were de-scaled (Figure 68). Therefore, the element specific regression coefficients can be interpreted as a proportional response in concentration to changes in the covariates. Si, K and Sr show a significant response by sex. Si and Sr also showed significant responses related to ontogeny (age, size, stage of maturity). Interestingly, Sr was higher in females and showed an overall increase with size and age, while Si showed the opposite, i.e., higher levels in males with a general decline in concentrations as length and age increased.

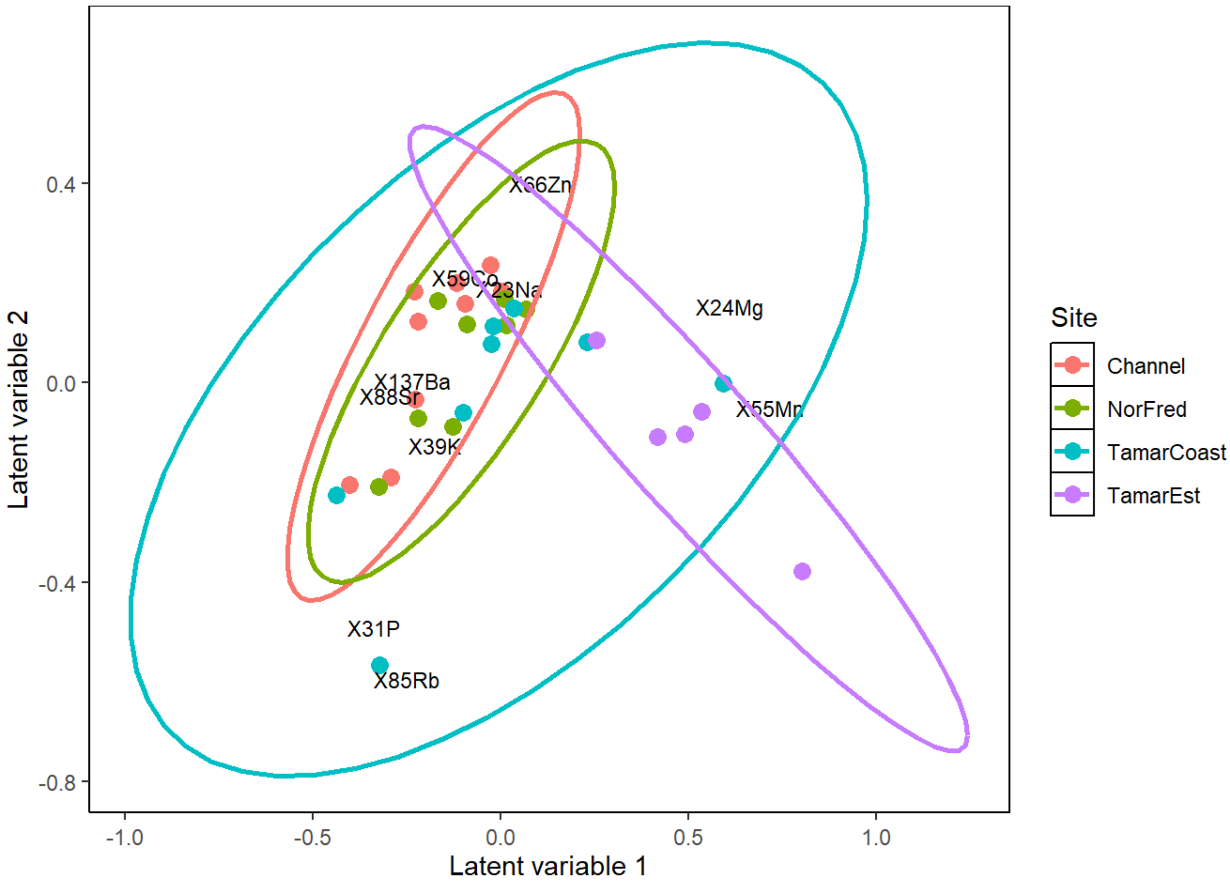


Figure 67. Model based unconstrained ordination of Sand Flathead otolith (capture region) microchemistry based on posterior median estimates. The axes show the 2 main latent variables. The legend notes site classification based on known region of origin of samples.

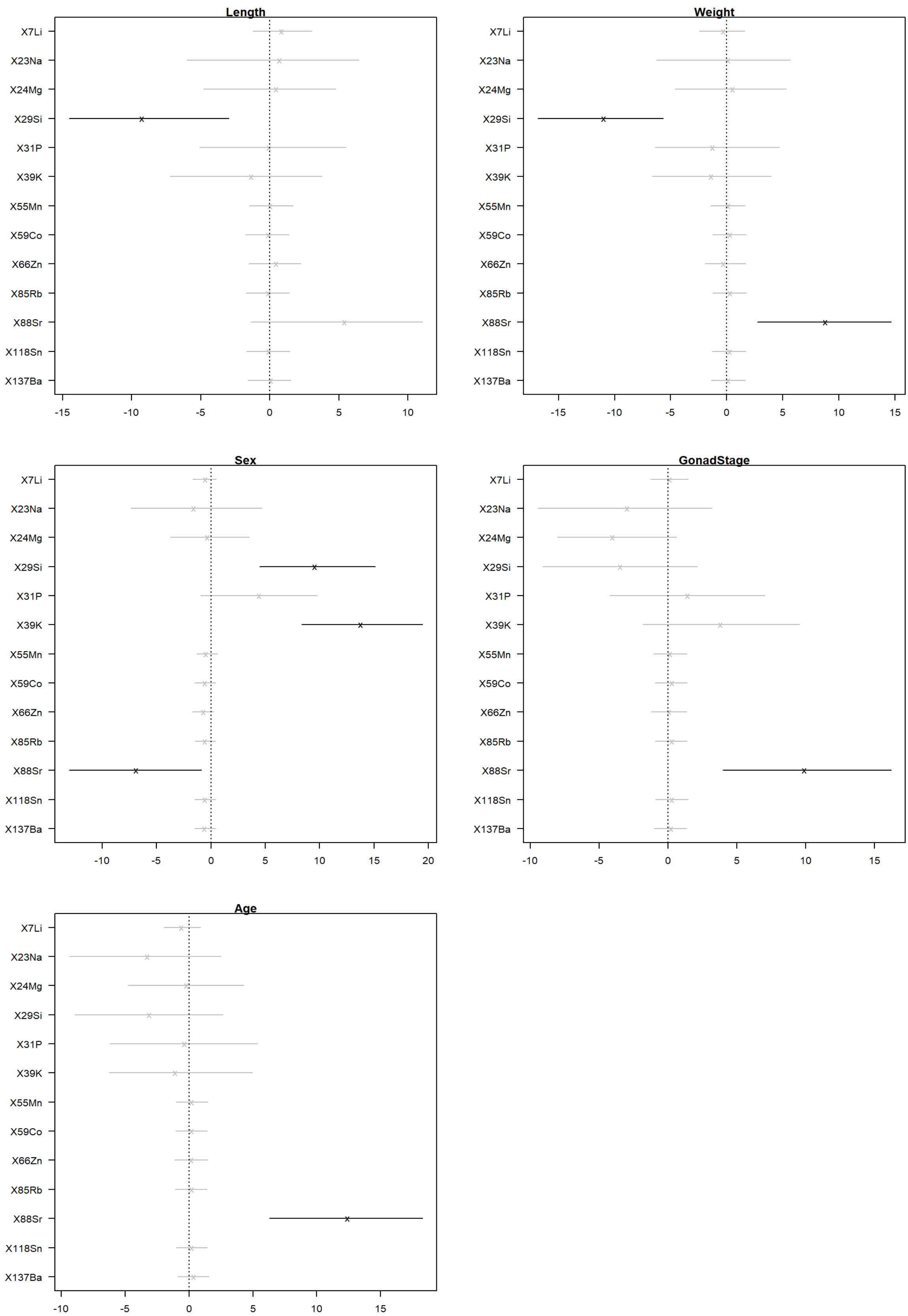


Figure 68. Caterpillar plot showing the point estimates for the multivariate negative binomial glm coefficient (*) of different traits on the microchemical signature of Sand Flathead otoliths (capture region) and the HDS (Bayesian) 95 % CI (lines),

Ablation transects started at the edge of the otoliths long plane (used for the ageing of this species), moving towards the centroid and afterwards back towards the edge in one of the shorter planes. Accordingly, data moving away from the centroid on both planes should represent a mirror image of each other (with the short plane slightly compressed). Lifelong element: Ca ratios for the four otoliths in which transects were ablated were plotted and visualised. There was no evidence of surface contamination and despite the shorter dwell time at each given site (compared with spots), elemental concentrations along the two different planes of the otolith appeared to have internally consistent patterns (Figure 69). However total concentrations differed between planes, likely due to differences in the matrix caused by the different rates of growth. This suggests that Sand Flathead otoliths could be suitable for retrospective analyses of movement (if the same plane is used) and could provide insights into larval stages, recruitment processes, bioaccumulation and maternal offloading of heavy metals.

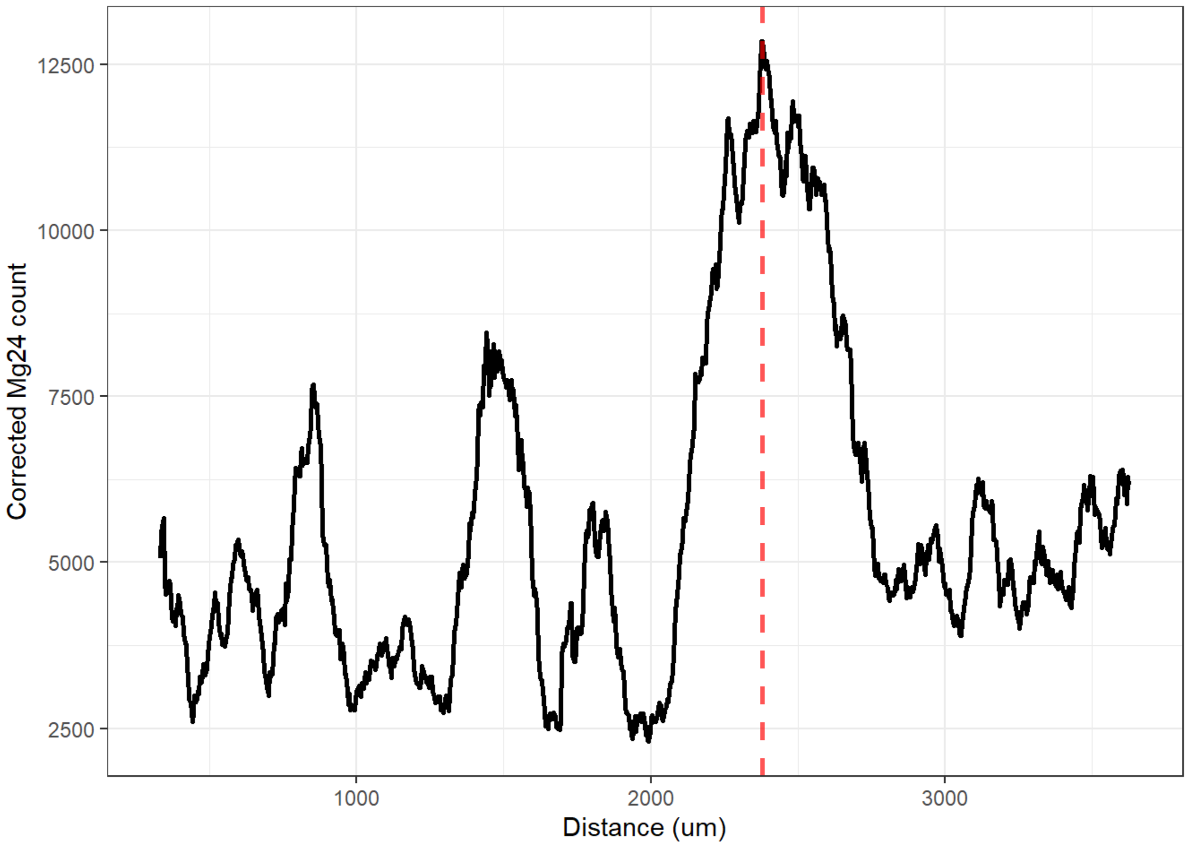


Figure 69. Corrected Mg:Ca counts for an ablation transect along a Sand Flathead otolith. The transect ran along the long growth axis of the otolith towards the origin (---) and then back towards the edge on a different (shorter plane).

8.1.4 Discussion

This study demonstrates strong proof of concept that otolith multi-element signatures can be used to investigate spatial structure, movement and connectivity of Sand Flathead within Tasmania. To our knowledge, this represents the first application of otolith microchemistry to the species and provides an important new line of evidence for interpreting the regional demographic differences identified elsewhere in this report. Previous chapters demonstrated persistent spatial variation in size structure, growth trajectories and reproductive dynamics among Tasmanian regions. The present results suggest that at least some of this regional structuring may reflect biologically meaningful differences in environmental history, movement pathways, or partial population connectivity rather than sampling artefacts alone.

The LA-ICP-MS protocol developed here generated stable and internally consistent elemental data across both spot and transect analyses, supporting the suitability of Sand Flathead otoliths for retrospective chemical analysis. Capture-edge signatures differed significantly among sampled locations, and supervised classification using linear discriminant function analysis achieved high cross-validated assignment success (~93%) using a 13 element:Ca ratio suite. This level of discrimination is notable given that all sampled sites were marine, where environmental chemistry can often be more homogeneous than in estuarine or freshwater systems. Otolith chemistry has been widely used for stock discrimination in marine fishes, but assignment success is often strongest where strong salinity gradients exist (Campana, 1999). The present findings therefore indicate that Tasmanian coastal environments contain sufficiently distinct geochemical fingerprints to support management-relevant discrimination even within fully marine settings.

Among the sampled regions, clearer separation of inshore and offshore habitats suggests that local hydrography, freshwater influence, productivity, or anthropogenic inputs may contribute to site-specific chemical signatures. Elements such as Sr and Ba are often associated with salinity and water-mass differences, whereas Mn, Zn, Li and other trace elements may reflect localised redox conditions, catchment inputs, or subtle oceanographic gradients (Sturrock et al., 2012, Izzo and et al., 2018). Although the mechanistic basis for several discriminatory elements remains uncertain, the results reinforce the value of multi-element approaches rather than reliance on a small number of traditional tracers.

A particularly important finding was that core (origin) signatures were less reliably assigned to capture-defined site groups than edge signatures. Capture-trained models performed poorly when applied to core material, and within-site heterogeneity was evident among individuals collected from the same adult habitat. This pattern is consistent with fish recruiting from multiple nursery areas, experiencing movement during juvenile stages, or occupying chemically variable early-life habitats prior to settlement into adult populations.

This interpretation has direct relevance to the broader report. Earlier chapters identified strong regional differences in adult demographic structure, particularly between south-eastern Tasmania and northern or northeastern regions. The otolith core results suggest that adult populations may not be formed solely by local self-recruitment but instead may include mixtures of fish from multiple early-life origins. Such source mixing is common in coastal marine fishes and can substantially influence resilience, local depletion risk, and rebuilding potential (Kerr et al., 2010, Secor, 2015).

These findings also illustrate the complementary role of otolith chemistry relative to conventional tagging and genetics. Tagging studies generally resolve shorter-term movement of marked individuals, whereas genetics often reflects longer-term gene flow across generations. Otolith chemistry can bridge this gap by reconstructing environmental exposure over the life of individual fish and identifying movement or habitat transitions at ecologically meaningful timescales (Campana, 1999).

The study also identified measurable associations between selected elemental ratios and biological covariates including size, age and sex. This is an important result because many discrimination studies implicitly assume that otolith chemistry reflects environmental exposure alone. In reality, elemental incorporation can also be influenced by growth rate, ontogeny, physiology and reproductive condition (Sturrock et al., 2015). Failure to account for these processes may bias assignment models or obscure true spatial signals.

Application of a Bayesian hierarchical framework therefore represents a valuable methodological advance. By modelling multiple elements simultaneously while incorporating explanatory covariates, this approach provides a pathway for separating biological from environmental drivers of elemental variation. Such model-based methods are increasingly recommended in otolith chemistry studies because they improve inference beyond purely distance-based or ordination approaches (Kerr et al., 2014).

From a fisheries perspective, these findings are highly relevant. Earlier chapters of this report identified strong and persistent regional differences in stock condition, with south-eastern Tasmania exhibiting smaller fish, truncated size structure, and lower spawning potential than northern regions. A key uncertainty has been whether these patterns reflect largely independent regional populations or are buffered by movement and recruitment exchange among regions.

The present pilot study suggests that Sand Flathead likely exhibits a combination of localised adult structure and partial connectivity, rather than complete statewide mixing or complete regional isolation. If confirmed through larger studies or molecular work, this has important management implications. Local depletion may not be rapidly offset by immigration if adult movement is limited, while replenishment may depend partly on variable recruitment supply from connected nursery areas. This supports the broader report conclusion that regionally explicit management remains appropriate, particularly for depleted south-eastern Tasmania.

Otolith chemistry may also provide an independent means of evaluating the four-sector management framework developed in previous chapters (Southeast, East, Northeast, North/Northwest). If fish within sectors share stronger chemical similarity than fish among sectors, this would provide additional biological support for those proposed reporting and assessment units.

Several priorities emerge before operational application is possible. First, larger baseline libraries across multiple sites and years are required to quantify temporal variability in signatures and improve model transferability. Second, pairing transect chemistry with age estimates would allow movement histories to be placed on an annual timescale. Third, targeted sampling of juvenile habitats could directly test nursery-source contributions to adult populations. Fourth, experimental studies examining temperature, salinity and physiological controls on element incorporation would improve mechanistic interpretation. Finally, integration of otolith chemistry with tagging, genetics and demographic survey data would provide the strongest multi-evidence understanding of connectivity.

8.1.5 Conclusions

This pilot study demonstrates that otolith microchemistry measured using LA-ICP-MS can provide a powerful and scalable tool for investigating spatial structure, movement and connectivity of Sand Flathead within Tasmania. Multi-element otolith signatures at the capture edge differed significantly among sampled sites, and high classification success (~93%) indicates that distinct environmental fingerprints exist at management-relevant spatial scales, even among marine habitats.

In contrast, weaker discrimination of core signatures suggests mixed recruitment sources and/or early-life movement prior to establishment in adult habitats. These patterns are not readily resolved by conventional tagging or genetics alone, highlighting otolith chemistry as a valuable complementary approach for reconstructing life-history connectivity.

Associations between elemental composition and biological covariates further demonstrate that robust application will require consideration of both environmental and physiological drivers of incorporation. Nonetheless, the results clearly establish proof of concept that otolith chemistry can contribute to management of Sand Flathead by improving understanding of stock structure, nursery connectivity and regional population dynamics.

In the context of this report, the findings complement previous evidence of strong regional differences in growth, reproduction and stock status, suggesting that Tasmania's Sand Flathead population is spatially structured but not necessarily demographically isolated. Expansion to a larger, temporally replicated otolith baseline library would provide a valuable next step toward operational assignment models and improved region-specific management of this important recreational fishery.

8.2 Conventional T-bar tagging

8.2.1 Introduction

Understanding fish movement is fundamental to fisheries management because spatial behaviour influences habitat use, local depletion risk, rebuilding potential, exposure to fishing pressure, and the scale at which management measures are most effective (Fogarty and Botsford, 2007). Tag-recapture studies remain one of the most practical and widely applied tools for quantifying realised movement, residency, growth and survival in exploited fish populations (Fogarty and Botsford, 2007, Goddard et al., 2024).

For Sand Flathead in Tasmania, movement information has been limited. Previous acoustic telemetry work in the Derwent estuary tracked a small number of individuals and suggested relatively localised movement behaviour (Tracey et al., 2020), but no broad-scale statewide conventional tagging program had previously been undertaken. This knowledge gap is important in the context of earlier chapters of this report, which documented persistent regional differences in stock condition, size structure, growth and reproductive characteristics. Whether such patterns are maintained by limited adult movement, offset by redistribution among regions, or influenced primarily by local recruitment has remained uncertain.

Conventional tagging provides a complementary perspective to the otolith microchemistry analyses presented in the previous section. Whereas otolith chemistry can infer lifetime environmental histories and early-life connectivity, tag-recapture studies provide direct evidence of realised movement and site fidelity of individual fish after release. Together, these approaches help resolve connectivity across ecologically relevant timescales.

Accordingly, a statewide T-bar tagging program was implemented to investigate movement patterns of Sand Flathead in Tasmania, generate baseline recapture data, and establish a longer-term platform for future mark-recapture analyses.

8.2.2 Methods

Tagging was undertaken between 2021 and 2024 during fishery-independent surveys and dedicated field trips, including University of Tasmania student training and work-experience activities. Captured fish were measured to the nearest millimetre total length and tagged externally with Hallprint T-bar anchor tags inserted between the first and second pterygiophores of the second dorsal fin. Fish smaller than 200 mm total length were considered unsuitable for T-bar tagging and were released untagged.

Release position was recorded using latitude and longitude coordinates. Each tag carried a unique identification number, the letters IMAS, and a contact telephone number to facilitate public reporting. For recaptured fish, the tag number, recapture date, location, fish length, fish fate (retained or released), and reporter details were recorded.

Recapture distance was calculated as the straight-line distance between release and recapture locations. Time at liberty was defined as the number of days between tagging and recapture.

8.2.3 Results

Between 2021 and 2024, a total of 4,126 Sand Flathead were tagged across Tasmania (Table 26). Tagging effort was concentrated in south-eastern Tasmania (2,298 fish; 55.7%), followed by the northeast coast (878; 21.3%), east coast (522; 12.7%) and north/northwest coast (425; 10.3%). Only three fish were tagged at Flinders Island.

Table 26. The number of Sand Flathead tagged per region with a T-bar tag between 2021 and 2024.

Region	Number of fish tagged	Number of fish recaptured
SEC	2,298	7
EC	522	4
NEC	878	2
NWC	425	0
FI	3	0

A total of 13 tagged fish were subsequently recaptured and reported, representing a preliminary reporting rate of 0.32% over the study period. Recaptures were recorded from the southeast coast (7 fish), east coast (4 fish) and northeast coast (2 fish), with no reported recaptures from the north/northwest coast or Flinders Island (Table 27).

Time at liberty ranged from 1 to 673 days (median = 64 days). Four fish (31%) were recaptured within six days of release, while six fish (46%) were recaptured after more than 100 days at liberty. Length change between tagging and recapture varied from −2 mm to +50 mm, reflecting measurement variability, somatic growth, or both (Table 27).

Reported movement distances were generally small (Figure 70). Twelve of the 13 recaptured fish were reported from the same local bay, beach or coastal area in which they had been tagged, indicating little net displacement during time at liberty. The maximum observed movement was approximately 13 km by an east coast fish recaptured 673 days after release. Most other recaptures were within a few kilometres of the release location.

Collectively, these preliminary results indicate strong local residency or repeated return to capture areas for many tagged Sand Flathead.

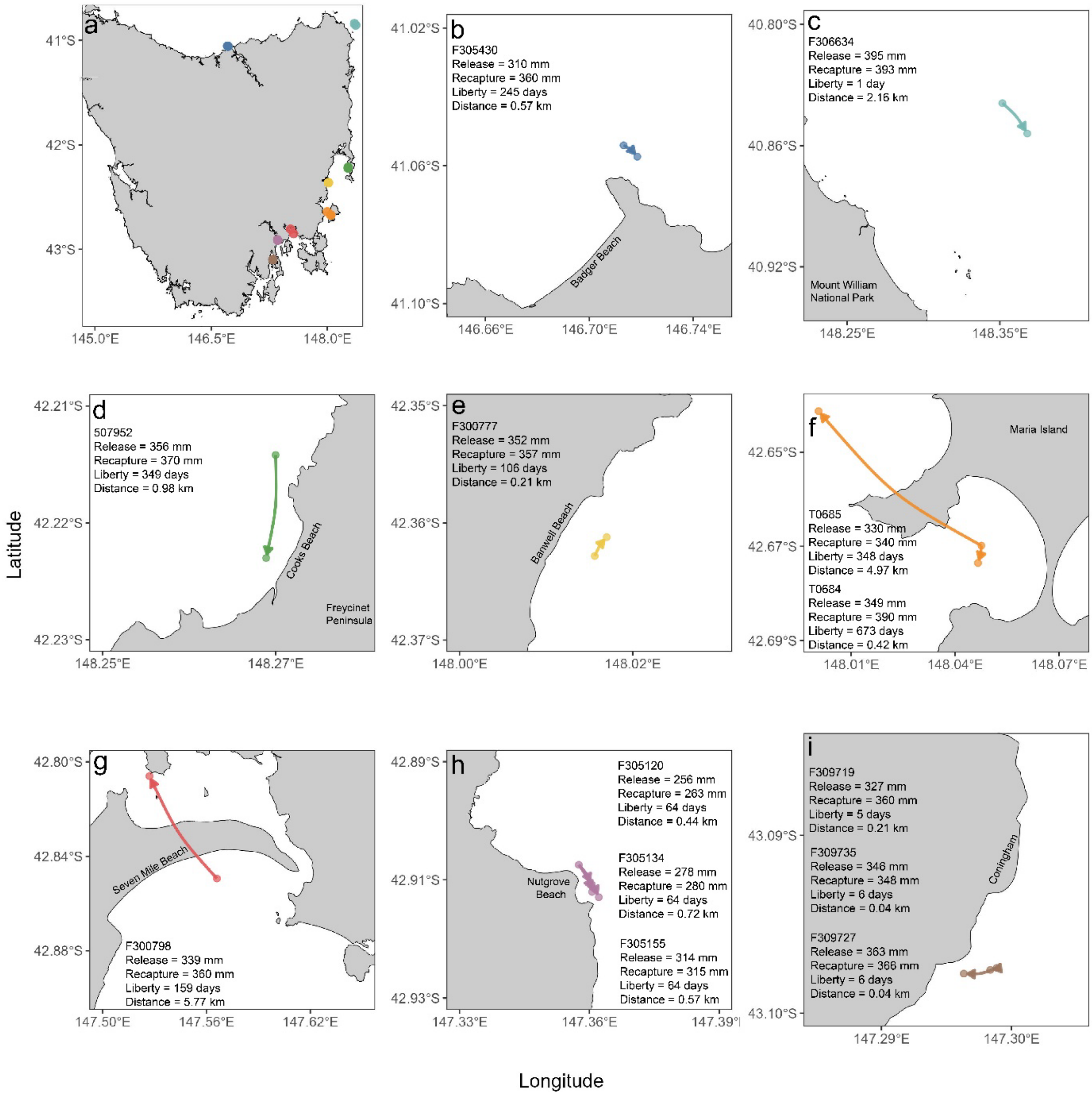


Figure 70. Reported recaptures of Sand Flathead from 2021 until 2024 (a). Releases and recaptures are coloured by location, with arrows indicating the overall direction of movement between release and recapture. Distance is the straight line distance between release and recapture (km). Movements are grouped by region, namely Tamar (b), Eddystone (c), Great Oyster Bay (d, e), Maria Island (f), Seven Mile Beach (g), Sandy Bay (h) and D'Entrecasteaux Channel (i), with colours being consistent between overall recaptures map (a) and focused movement plots. The time at liberty (days) and release and recapture lengths (mm) are highlighted in each panel.

Table 27. Details of the 13 tagged Sand Flathead that were recaptured between 2021 and 2024.

Tag ID	Region	Length at tagging (mm)	Length at recapture (mm)	Days at liberty
T0685	EC	330	340	348
T0684	EC	349	390	673
507952	EC	356	370	349
F300777	EC	352	357	106
F300798	SEC	339	360	159
F305120	SEC	256	263	64
F305134	SEC	278	280	64
F305155	SEC	314	315	64
F309719	SEC	327	360	5
F309735	SEC	346	348	6
F309727	SEC	363	366	6
F305430	NEC	310	360	245
F306634	NEC	395	393	1

8.2.4 Discussion

This study provides the first statewide conventional tagging assessment of Sand Flathead movement in Tasmania and offers valuable early evidence that adult fish often display limited spatial displacement over periods ranging from days to nearly two years. Although recapture numbers remain modest, the consistency of the reported pattern is notable: almost all recaptured fish were taken in the same local area in which they were released. This is consistent with earlier acoustic telemetry studies on Sand Flathead (Tracey et al., 2020).

These findings align with previous movement studies of flathead species in Australia. Dusky Flathead (*Platycephalus fuscus*) tagged in New South Wales estuaries were predominantly recaptured within their tagging estuary, with relatively few individuals moving among systems (Gray and Barnes, 2015). Acoustic telemetry studies of Dusky Flathead in the Gippsland Lakes also found high residency within local regions (Hindell, 2008), while Blue-spotted Flathead (*Platycephalus caeruleopunctatus*) in Jervis Bay occupied comparatively small home ranges and showed strong site attachment (Fetterplace et al., 2016). The present study suggests Sand Flathead may exhibit similar behavioural tendencies.

The results are particularly relevant when considered alongside previous chapters of this report. Fishery-independent surveys identified persistent regional differences in size structure, with south-eastern Tasmania characterised by smaller fish and truncated upper size classes relative to northern and northeastern regions. Growth and reproductive analyses similarly demonstrated spatial variation in demographic traits. If adult Sand Flathead exhibit relatively limited movement, then these regional differences are unlikely to be rapidly homogenised by redistribution of older fish among areas. This means local depletion may persist unless rebuilding occurs through improved local survival, local spawning output, or incoming recruitment rather than large-scale adult immigration. Such a pattern supports the broader conclusion that regionally explicit management is appropriate, particularly for depleted south-eastern Tasmania.

This interpretation complements the otolith microchemistry findings presented in the preceding chapter. Otolith chemistry suggested mixed early-life environmental histories and some degree of broader connectivity, whereas conventional tagging indicates relatively localised adult movement. Together, these results are consistent with a life history in which dispersal may occur primarily during larval or juvenile stages, followed by stronger adult residency.

The overall recapture reporting rate (0.32%) was low relative to some longer-running tagging programs for larger or more intensively targeted species (Gray and Barnes, 2015; Goddard et al., 2024). However, several factors likely contributed to this outcome. First, the present program operated for only four years, limiting the period over which fish could be recaptured and reported. Second, many Sand Flathead are likely released without tag reporting or may not be encountered by fishers after release. Third, tag shedding, natural mortality, or unreported retention may also reduce apparent recapture rates. Consequently, the current results should be interpreted as an early baseline rather than a final estimate of recapture probability or survival.

Importantly, the recapture of some fish after more than 600 days at liberty suggests that at least some tagged fish survived capture, handling and tag insertion for extended periods, supporting the practicality of the method for longer-term monitoring.

The statewide tagging program has now established an important platform for future movement analyses. As additional fish are tagged and reporting awareness increases, recapture numbers should rise, allowing more robust estimation of movement kernels, growth increments, regional exchange rates, and survival.

Future priorities include increasing tag deployment in underrepresented northern and offshore regions, continued engagement with recreational and charter fishers to maximise reporting, and integration of tagging data with otolith chemistry and survey datasets. Such combined approaches offer the strongest pathway to resolving movement ecology and informing spatially explicit management of Sand Flathead.

8.2.5 Conclusion

The first statewide T-bar tagging program for Sand Flathead in Tasmania provides preliminary but informative evidence that adult fish often exhibit strong local residency, with most reported recaptures occurring close to release locations despite liberty periods extending to nearly two years. Maximum observed movement was modest (~13 km), suggesting that broad-scale adult redistribution may be limited.

In the context of earlier chapters, these findings imply that regional differences in stock condition are unlikely to be quickly offset by movement of adults among areas. Recovery of depleted south-eastern populations may therefore depend more on local rebuilding processes than immigration of larger fish from healthier northern regions.

When considered alongside otolith microchemistry evidence of broader early-life mixing, the emerging picture is of a spatially structured stock with greater connectivity during early life stages and more localised residency as adults. Continued expansion of the tagging program will provide increasingly valuable evidence to refine management units, evaluate rebuilding trajectories, and support sustainable management of this important Tasmanian recreational fishery. The tag-recapture program is also being widely publicised through social media (Figure 71), with a Tag Lottery carried out every six months with fishers receiving a reward if drawn in the lottery. Furthermore, to acknowledge their contribution and to encourage the public to participate in reporting recaptured fish, regular updates on recaptured fish are also publicised through social media (Figure 72). As part of the 2022-204 project, recreational and charter fishers around the state are being involved in the tagging program in an effort to boost tag numbers and increase reported recaptures (e.g., Goddard et al., 2024).

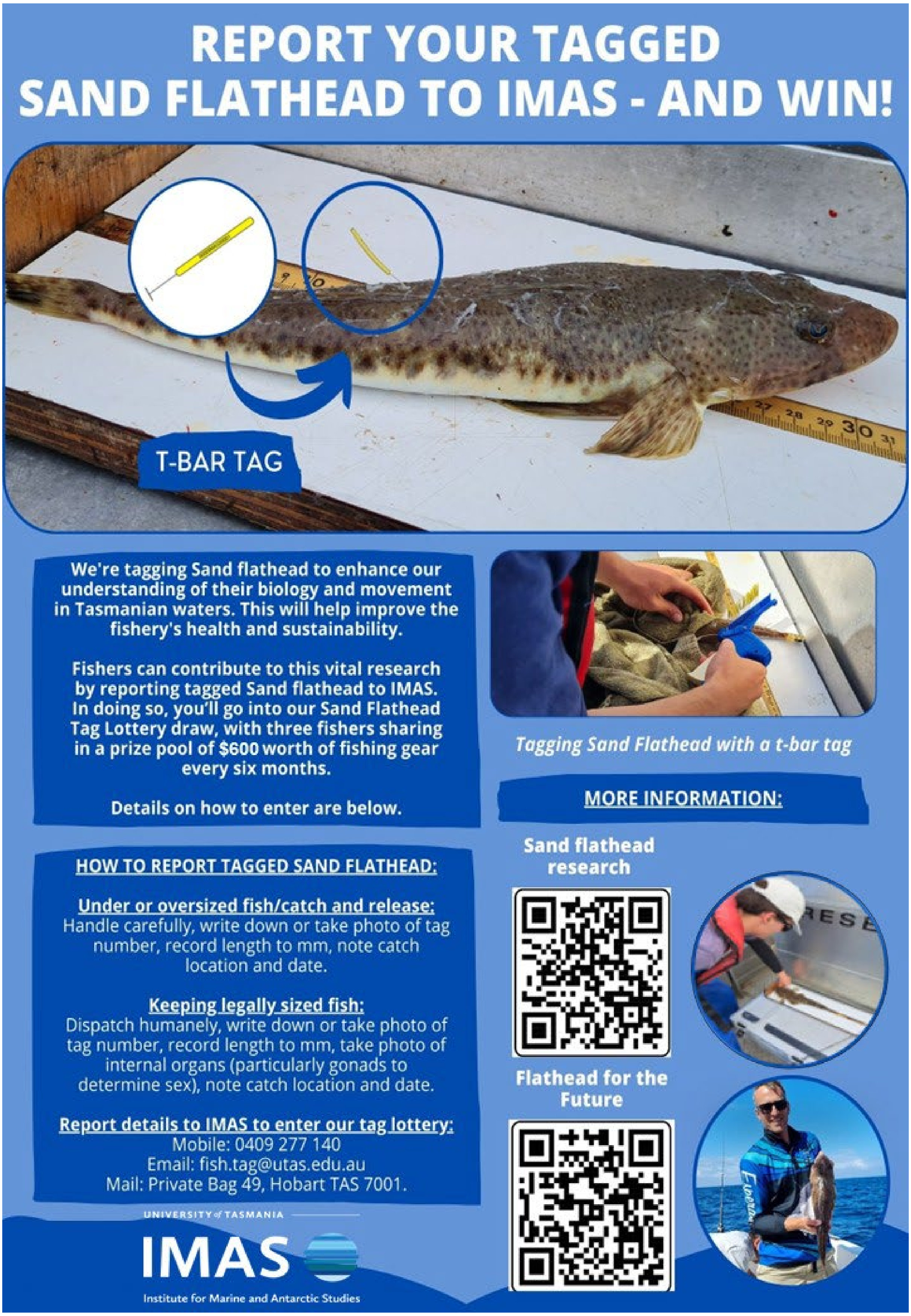


Figure 71. Sand Flathead Tag Lottery poster used to promote the tagging program and the reporting of recaptured fish.

Institute for Marine and Antarctic Studies - IMAS
July 11 ·

Thanks to the amazing efforts of recreational fishers, we've had 10 tagged Sand Flathead recaptured and reported to IMAS so far this year!

Your tagged Sand Flathead reports help us gather valuable insight into how these fish grow and move around Tasmania.

Last week we revealed the three winners of the IMAS Sand Flathead Tag Lottery! Check out the results:
Dylan Faulkner's fish was tagged on the 30/10/2024 in Lime Bay, Norfolk Bay and measured 349 mm. He caught the fish on the 19/03/2025 in Lime Bay. The fish measured 360 mm, growing 11 mm over 5 months.
Kai Bold's fish was tagged on the 25/03/2025 in Apollo Bay in the D'Entrecasteaux Channel. Kai caught this fish only 10 days later (04/04/2025) whilst fishing in Apollo Bay.
Reinhard Hemm's fish was tagged on the 31/03/2025 near Taroona during an IMAS student field trip that was tagging Sand Flathead in the Derwent Estuary. Reinhard caught this fish 41 days later in the same location.

IMAS staff have been tagging Sand Flathead around the state for 2 years now (check out the images to see where and how many Sand Flathead have been tagged).

If you catch a tagged Sand Flathead, make sure you call the mobile number on the tag to report the details of the fish. You'll then go into our next lottery which will be drawn in December this year!

Check out the details on how to report a tagged Sand Flathead below

(1): A Sand Flathead recaptured by Dylan Faulkner. Credit: Dylan Faulkner. (2) Report your Tagged Sand Flathead to IMAS and win. Credit: IMAS (3) The locations of the 10 recaptured Sand Flathead. Credit: IMAS. (4) Sand Flathead tagging numbers around Tasmania. Credit: IMAS.

Tassie Fish Frame Collection Program

Nick Hill and 15 others   1 comment   6 shares

Figure 72. An example of a social media post highlighting several recaptured and reported Sand Flathead.

9 Objective 6: Develop a quantitative region-age-sex structured fishery assessment model for Sand Flathead

9.1.1 Introduction

Robust quantitative stock assessment is central to modern fisheries management because it provides the analytical basis for estimating stock status, fishing mortality, reproductive capacity, and rebuilding trajectory (Beverton and Holt, 1957, Hilborn and Walters, 1992). For Sand Flathead in Tasmania, the need for such assessment has increased markedly over recent decades as concerns have emerged regarding declining catch quality, reduced availability of larger fish, and persistent perceptions of local depletion in historically important fishing grounds (Tracey et al., 2023, Krueck et al., 2025). Earlier chapters of this report provide multiple independent lines of evidence consistent with substantial regional decline, particularly in south-eastern Tasmania. Historical reconstruction identified the long-term erosion of fish size and fishing quality. Fishery-independent surveys documented the resulting persistent truncation of length and age structure over the last 15 years. Biological analyses showed reduced representation of larger females in heavily exploited areas, and movement studies suggested limited adult redistribution among regions. Collectively, these findings indicate that the present condition of the stock requires formal quantitative evaluation

The need for quantitative assessment was first recognised in Tasmania through concerns about declining catches and potential overfishing, which prompted the establishment of fishery-independent surveys in 2012 (Ewing et al., 2014). The first formal stock status classification, undertaken for 2014–15 using an initial four-year survey time series, assessed Sand Flathead as 'Transitional Depleting'. At that time, low relative abundance of legal-sized fish and declining catch rates were interpreted as evidence of high fishing mortality and possible future depletion of south-eastern populations (Emery et al., 2016). However, fishing mortality had not yet been estimated directly, and no benchmark information from lightly exploited regions was available to evaluate biomass depletion.

Subsequent annual assessments based on longer survey time series reached similar conclusions, noting that fishing pressure remained high and that the stock was at risk of recruitment overfishing (Emery et al., 2017, Moore et al., 2018). A major methodological advance occurred in the 2017–18 assessment, when age-based catch curve analyses were first used to estimate fishing mortality. These analyses indicated that, for females, fishing mortality substantially exceeded natural mortality across sampled regions, and the stock was reclassified as Depleting under revised status categories (Moore et al., 2019). The classification as Depleting was retained in the following years as continued shortages of legal-sized fish and elevated mortality estimates suggested ongoing pressure (Krueck et al., 2020, Fraser et al., 2021).

Historically, the development of a comprehensive (integrated) stock assessment model for Sand Flathead suitable to inform management strategy evaluation (MSE) has been constrained by the nature of the fishery. Catch by the commercial sector was modest in scale during recent decades and has now ceased, while the recreational sector has accounted for most removals but lacks a continuous long-term catch and effort time series suitable for standard surplus production or integrated age-structured models. This challenge is common in recreationally dominated and mixed-use fisheries, where removals may be substantial but monitoring systems are often intermittent, survey-based, or behaviourally confounded (Post et al., 2002, Cooke and Cowx, 2004, Cooke and Cowx, 2006). In such fisheries, catch-per-unit-effort data can also be affected by fisher learning, technological improvement, localised targeting, regulatory change, and hyperstability, whereby catch rates remain relatively high despite declining abundance (Hilborn and Walters, 1992, Walters and Martell, 2004). These limitations mean that the application of standard assessment approaches used in large commercial fisheries was not feasible for Sand Flathead.

In contrast, one of the major strengths of the Tasmanian Sand Flathead dataset is the extensive fishery-independent survey program and associated biological sampling developed over the past decade. The statewide survey expansion implemented in 2021 substantially improved the assessment base by adding six new regions and providing, for the first time, comparative information from northern, eastern, and relatively lightly exploited areas, specifically Flinders Island. These expanded data enabled estimation of regional selectivity and life-history parameters and supported the transition from age-based mortality estimation to length-based approaches better suited to the species' substantial plasticity in length-at-age. Earlier chapters of this report showed that fishing pressure has strongly altered size composition in some regions, particularly through the loss of larger fish. This finding is important because length composition can itself contain substantial information on stock status in size-selective fisheries. Length-based assessment methods use the relationship between growth, natural mortality and the mean length of fully grown individuals to contrast observed size structure against an expected unfished size structure. The outcomes allow us to infer fishing mortality and reproductive capacity and have become increasingly valuable where detailed catch histories are unavailable or uncertain (Hordyk et al., 2015a, Hordyk et al., 2015b, van Gemert et al., 2021).

The comprehensive application of length-based assessment methods to the Sand Flathead fishery led to a substantial reassessment of stock condition. Inclusion of length-converted catch curve analyses and alternative spawning biomass depletion models indicated that spawning biomass in many regions was below the globally adopted limit reference point of 20% of unfished levels. On this basis, Sand Flathead was reclassified from Depleting to Depleted in 2022 (Fraser et al., 2022). The 2022 stock assessment was subject to an international expert review in 2023 along with the fishery-independent sampling program and the objectives of this FRDC project (Hyder, 2023). Subsequent independent assessments supported the conclusion that the species remained depleted across much of Tasmania (Krueck et al., 2025), although year-to-year trends remained difficult to estimate and annual revised outputs reflected improved parameterisation rather than further stock deterioration.

The classification as a depleted stock triggered a statewide rebuilding response. In 2023, commercial fishing for Sand Flathead in State waters was closed. Recreational possession limits were substantially reduced, with the most restrictive limits applying in south-eastern Tasmania. The minimum legal size was increased from 32 to 35 cm, and a maximum legal size of 40 cm was introduced across most regions. These measures were explicitly intended to reduce fishing mortality, protect larger spawning fish, and initiate rebuilding of depleted regional components.

A second major conclusion of the preceding chapters was that Sand Flathead in Tasmania should not be treated as a single homogeneous stock. Persistent regional differences were evident in size structure, age composition, growth, reproductive timing, and contemporary condition. South-eastern Tasmania, particularly the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays, consistently exhibited the most truncated demographic structure, whereas northern and northeastern regions generally retained larger fish and wider age composition. This regional heterogeneity indicates that statewide averaging may obscure local depletion and overstate condition in heavily fished areas.

Accordingly, this chapter describes a quantitative stock assessment framework for Sand Flathead that explicitly recognises both the strengths and limitations of the available data. The assessment is based on an equilibrium length-based modelling framework derived from established fishery theory (Beverton and Holt, 1957, Walters and Martell, 2004, Hordyk et al., 2015a, Hordyk et al., 2015b). This framework has been applied in annual Sand Flathead assessments since 2022, with parameter values progressively refined as new biological and survey information became available. In each assessment year, model configuration and parameterisation reflected the best available evidence at the time, consistent with accepted fisheries management practice under uncertainty (Hilborn and Walters, 1992, FAO, 1996). The current chapter builds on that progression by applying the most contemporary biological information generated through earlier objectives of this report, using region- and sex-specific length- and age-based methods to estimate fishing pressure and spawning potential, and explore uncertainty through sensitivity analyses. Rather than seeking false precision from incomplete data, the objective is to provide a transparent and biologically grounded diagnosis of stock status that can support management decisions and advise the next steps of ongoing work needed to advance integrated stock assessment modelling methods in the context of FRDC2022-204 ("Filling the knowledge gaps to recover Tasmania's favourite recreational fishery") to enable future management strategy evaluation (MSE) in direct support of the Sand Flathead rebuilding program.

9.1.2 Methods

9.1.2.1 Assessment objectives and conceptual basis

The stock assessment framework for Sand Flathead was developed following review and integration of all major information sources available for the fishery, including commercial logbook records, periodic statewide recreational harvest estimates, expanded fishery-independent surveys, contemporary biological sampling, and the life-history analyses generated through earlier objectives of this report. The aim was to establish the first independent, regionally resolved and sex-informed quantitative assessment for Sand Flathead in Tasmania that was consistent with the realities of the available data and the biological characteristics of the species. The model framework was first presented in Krueck et al. (2023) and has been updated in Sand Flathead stock assessment reports since as new biological information has been collected.

Stock classification was aligned conceptually with the national Status of Australian Fish Stocks (SAFS) framework, in which stock condition is interpreted primarily in relation to the risk of recruitment impairment. Under this approach, a stock is considered at increasing biological risk where spawning biomass or reproductive capacity has been reduced to levels that may no longer sustain reliable replenishment. Because direct estimates of unfished spawning biomass are rarely available in data-limited fisheries, relative indicators such as spawning potential ratio (SPR) or biomass relative to an assumed unfished state are commonly used as practical proxies for stock status.

Recruitment impairment occurs when the mature adult population (spawning biomass) is depleted to a level where it might no longer ensure the reproductive capacity for stock rebuilding. Notably, recruitment impairment is difficult to measure directly without robust estimates of juvenile abundance under unfished conditions. Thus, a high risk of current or future recruitment impairment is commonly assumed unless estimates of stock status, represented, for example, by the relative spawning biomass or spawning potential ratio compared to assumed unfished conditions, are likely to remain above the limit reference point (e.g., 90% probability that spawning biomass is >20% of unfished levels).

9.1.2.2 Fishery Context and Available Data Sources

Commercial catch and effort data were examined to provide historical and recent context for the fishery. Commercial Sand Flathead catches were historically reported through compulsory logbooks within the Tasmanian Scalefish Fishery and were summarised by fishing year (1 July to 30 June), consistent with long-standing Tasmanian reporting practice and the seasonal nature of the fishery. Effort was standardised as vessel days fished, which reduced inconsistencies associated with alternative effort units, while catch-per-unit-effort summaries were based on geometric mean daily catch rates to better reflect the log-normal distribution typically observed in fisheries catch data However, commercial removals represented only a minor proportion of contemporary harvest and the commercial fishery has now ceased. Recreational harvest is dominant, but statewide recreational surveys are periodic rather than annual. Consequently, fishery-dependent data were considered informative for context and trend interpretation, but insufficient as the primary basis of conventional catch-and-effort stock assessment models.

The principal strength of the Sand Flathead evidence base was therefore the fishery-independent survey program established in 2012 in response to concerns regarding declining availability of legal-sized fish. The original survey encompassed three key southern and eastern Tasmanian regions using fishing gear and targeting methods representative of the recreational fishery. In 2021 the survey network was expanded substantially through inclusion of additional east and north coast regions, and Flinders Island was later incorporated as a further survey area most likely to represent near-unfished conditions.

Earlier chapters demonstrated that these survey data were highly informative of status. In the most heavily fished regions, fish often remained numerically present but were dominated by smaller individuals with very limited representation of larger or older fish. This observation indicated that abundance alone would be an incomplete measure of condition and that biological structure, particularly the persistence or loss of upper size classes, was central to understanding stock status.

9.1.2.3 Assessment Framework and Model Selection

Several candidate methods suitable for data-limited fisheries were initially considered, including the Length-Based Spawning Potential Ratio (LBSPR) assessment approach (Hordyk et al., 2015a), the Length-Based Bayesian Biomass estimation (LBB) method, catch-curve approaches, and integrated mixed-effects models. Following review of model suitability and data characteristics, the principal assessment emphasis was placed on LBSPR, supported by complementary mortality analyses. LBB was also evaluated during model development and produced broadly similar depletion signals, but LBSPR provided the clearest linkage to reproductive capacity and widely recognised to infer biological reference points for management

Length-based methods were selected because earlier analyses showed that age-based approaches were confounded by the historical truncation of size structure. In heavily exploited regions, some older fish persisted primarily because they had remained below vulnerable harvest sizes for much of their life, meaning age alone no longer reflected historical biomass or spawning potential. By contrast, the loss of larger fish was one of the clearest and most consistent statewide indicators of fishing impact. Length-based approaches were therefore considered more biologically meaningful for Sand Flathead than methods relying principally on catch histories or age composition.

9.1.2.4 Biological Parameterisation and Reference States

Parameterisation of the assessment drew directly on earlier objectives of this report and standard theoretical approaches. In brief summary, the sex-specific instantaneous rate of natural mortality (*M*) was parameterised according to a recent meta-analysis by assuming 1.5% adult survival until the maximum observed age available from the Sand Flathead survey data (Dureuil and Froese, 2021). L_∞, L_{50}, L_{95}, SL_{50}, *and* SL_{95} were estimated using established methods as implemented in the “TropFishR” package in R (Mildenberger et al., 2017). L_∞ and *k* were also estimated using the “nls2” function in R to fit the standard von Bertalanffy growth function (VBGF) to survey data. The parameter space for VGBF fitting of k was determined by assuming credible *M/k* ranges between values of 1 and 2 (the default and median estimated value is 1.5). The parameter space for L_∞ was determined based on prior L_∞estimates using the PW regression, as implemented in the TropFishR package. Length thresholds for inclusion of data points in PW regressions were specified according to prior estimates of SL_{95} (i.e., full gear selectivity). An L_∞ range between 0.5 and 2 times the PW estimate of L_∞ was then used for VGBF fitting. The parameter space for t_0 was restricted to values between 0 and -10% of t_{max}. If gear selectivity (SL_{50}) indicated an introduction of bias in the length at age of young fishes available from the survey data, t_0 was fixed to 0.

TropFishR was further used to estimate the instantaneous rate of total annual mortality (*Z*) from catch curves, including 95% confidence intervals. Values of *Z* were then used to infer the long-term fishing mortality *F* ($F = Z - M$), and relative fishing mortality (*F*/*M*). An *F*/*M* value of 1, where fishing mortality equals natural mortality, is commonly used as a threshold for overfishing. However, lower *F*/*M* values of 0.87 and 0.5 have been recommended for teleosts to ensure that *F*/*M* does not exceed the fishing mortality supporting maximum sustainable yield or does not violate the precautionary principle, respectively (Froese et al., 2016). Notably, as indicated above, mortality estimates from catch curves represent long-term trends.

Because fishing pressure had removed many large fish from several Tasmanian regions, direct estimation of unfished growth and size parameters from depleted areas was considered unreliable. Flinders Island, where large fish remained common and fishing pressure appeared comparatively low, was therefore used as an important reference source for plausible unfished size structure and growth expectations. Complementary approaches, including Powell-Wetherall regressions and von Bertalanffy growth modelling, were used to parameterise and cross-check these assumptions.

The principal outputs of the assessment were fishing mortality relative to natural mortality (F/M) and spawning potential ratio (SPR). Fishing mortality relative to natural mortality provides a comparative measure of exploitation pressure, while SPR estimates the reproductive output expected under current fishing relative to an assumed unfished population. LBSPR uses observed length composition together with growth, mortality, maturity and selectivity parameters to infer the level of fishing pressure most consistent with the contemporary size structure of a stock. In practical terms, heavily exploited populations are expected to contain fewer large mature fish and lower lifetime egg production than lightly exploited populations, making SPR a practical proxy for reproductive capacity in data-limited fisheries. A value of SPR/SPR_0 = 0.2 (i.e., 20% of unfished levels) is widely recognised as the ‘replacement level’, where fish populations might persist at current levels, but have little ability to rebuild, or they might decline further over time. The default target reference points for SPR are 40%-50% of unfished levels (SPR/SPR_0 = 0.4-0.5), where reproductive output and recruitment is expected to result in maximum sustainable ecologic or economic returns (MSY and MEY, respectively).

9.1.2.5 Regional Assessment Units and Sensitivity Analyses

Consistent with earlier chapters, the stock assessment was undertaken using regional units rather than a pooled statewide stock. Fishery-independent surveys demonstrated that statewide averaging masked major biological contrasts between depleted south-eastern Tasmania and stronger northern components. The principal units of inference therefore comprised stock condition estimates for two locations in Southeast Tasmania (D’Entrecasteaux Channel and Frederick Henry–Norfolk Bays), two locations on the East Coast (Great Oyster Bay and Mercury Passage), three locations in Northeast Tasmania (Bridport, St Helens and Flinders Island), and two locations in North/Northwest Tasmania (Tamar and Stanley). Notably, as described above, data from Flinders Island provided the default reference base for life history parameter estimation due to the relatively low fishing pressure in this most remote location.

Given the unavoidable uncertainty associated with data-limited fisheries assessment, sensitivity testing formed a central component of the framework. Alternative scenarios were used to examine the influence of growth assumptions, natural mortality, reference baselines, pooled versus regional structures, and plausible recent reductions in fishing pressure following management reform. Outputs were therefore interpreted as evidence-weighted ranges and comparative patterns rather than false precision from single point estimates.

9.1.3 Results

9.1.3.1 Trends in catch and effort

Sand Flathead has been distinguished from Tiger Flathead in commercial fishery statistics since 2007/08. Previous assessment reports reconstructed commercial catches of Sand Flathead at up to almost 15 t, with peak reported commercial harvest of 13 t in 2008/09 (Ziegler and Lyle, 2010, Krueck et al., 2020, Fraser et al., 2021a). By contrast, total commercial harvest in the 2023/24 fishing year was only 0.4 t, due in part to the commercial fishery closure for Sand Flathead (Sharples et al., 2024) (Figure 73A). Before the closure, most commercial catch was taken by handline, Danish seine and beach seine.

Commercial removals were minor relative to the recreational fishery according to statewide recreational fishing surveys conducted since 2000/01 (Lyle, 2005, Lyle et al., 2009, Lyle et al., 2014, Lyle et al., 2019, Tracey et al., 2024). In 2022/23, the recreational harvest of Sand Flathead was estimated at 125.8 t (Tracey and Stark, 2024), which represented approximately 99% of the estimated total harvest (recreational and commercial combined) for that season (Figure 73A). Recreational catch was concentrated in the more populated regions of Tasmania, particularly south-eastern Tasmania. In 2017/18, just over half of recreational catch was derived from the southeast coast, with the central east coast and northwest coast also contributing substantially. In 2022/23, the southeast coast again accounted for just over half of statewide recreational catch, contributing 57% of the total estimate.

Prior to closure, commercial catch and effort were concentrated primarily on the east coast, southeast coast and northwest coast (Figure 74). Commercial handline CPUE showed a declining trend over time, accompanied by a decline in commercial handline effort (Figure 73B; Figure 73C). However, spatial breakdowns showed that regional heterogeneity in catch, effort and CPUE was considerable (Figure 74; Figure 75), indicating that statewide trends alone are unlikely to provide a reliable proxy for stock condition in this fishery.

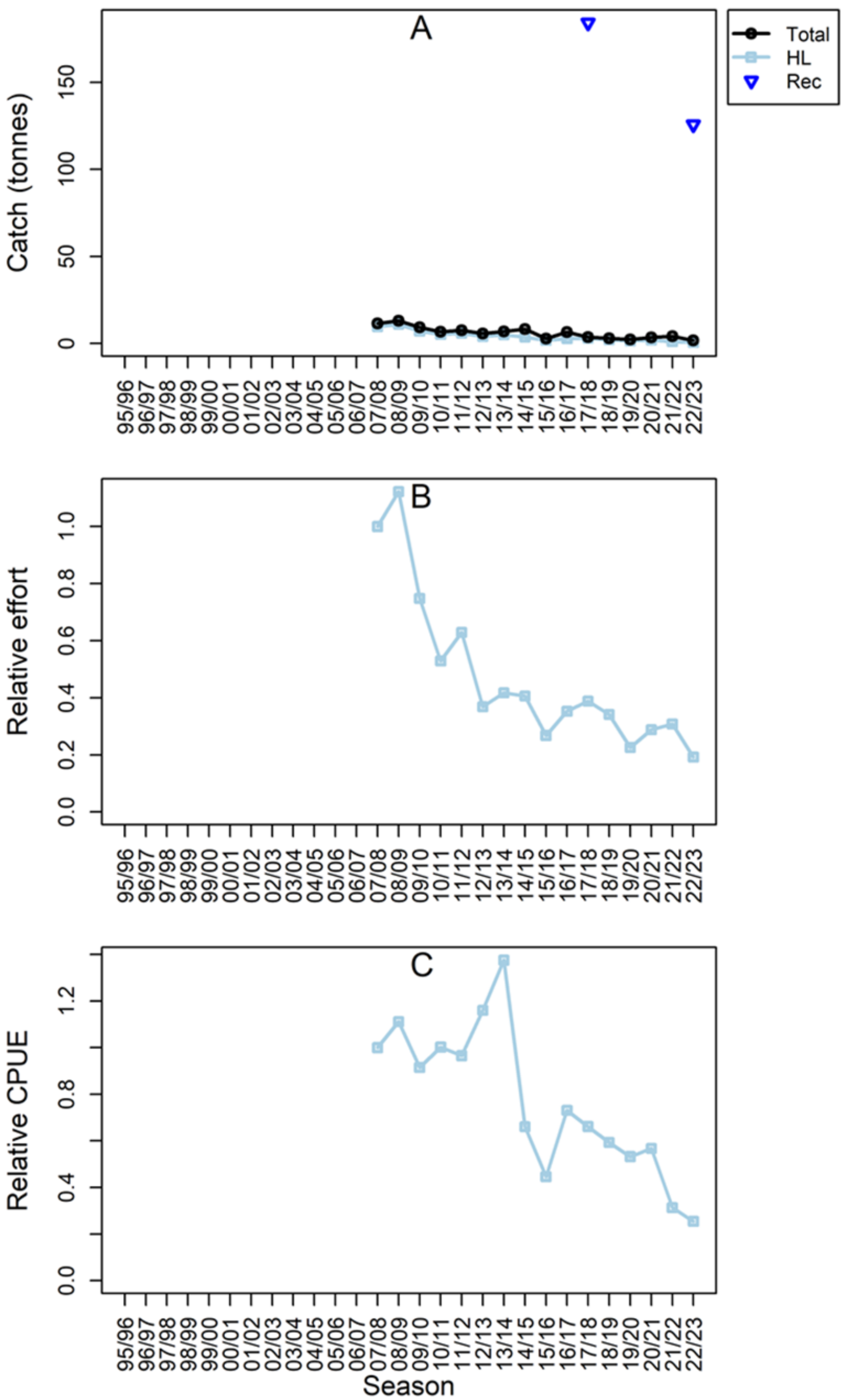


Figure 73. (A) Annual commercial Sand Flathead catch (t) by gear (dark blue triangles represent recreational catch estimates); (B) annual commercial effort for main gear type(s) based on days fished relative to 2007/08; and (C) annual commercial catch per unit effort (CPUE) based on weight per days fished relative to 2007/08. HL = handline, Rec = estimated recreational catch.

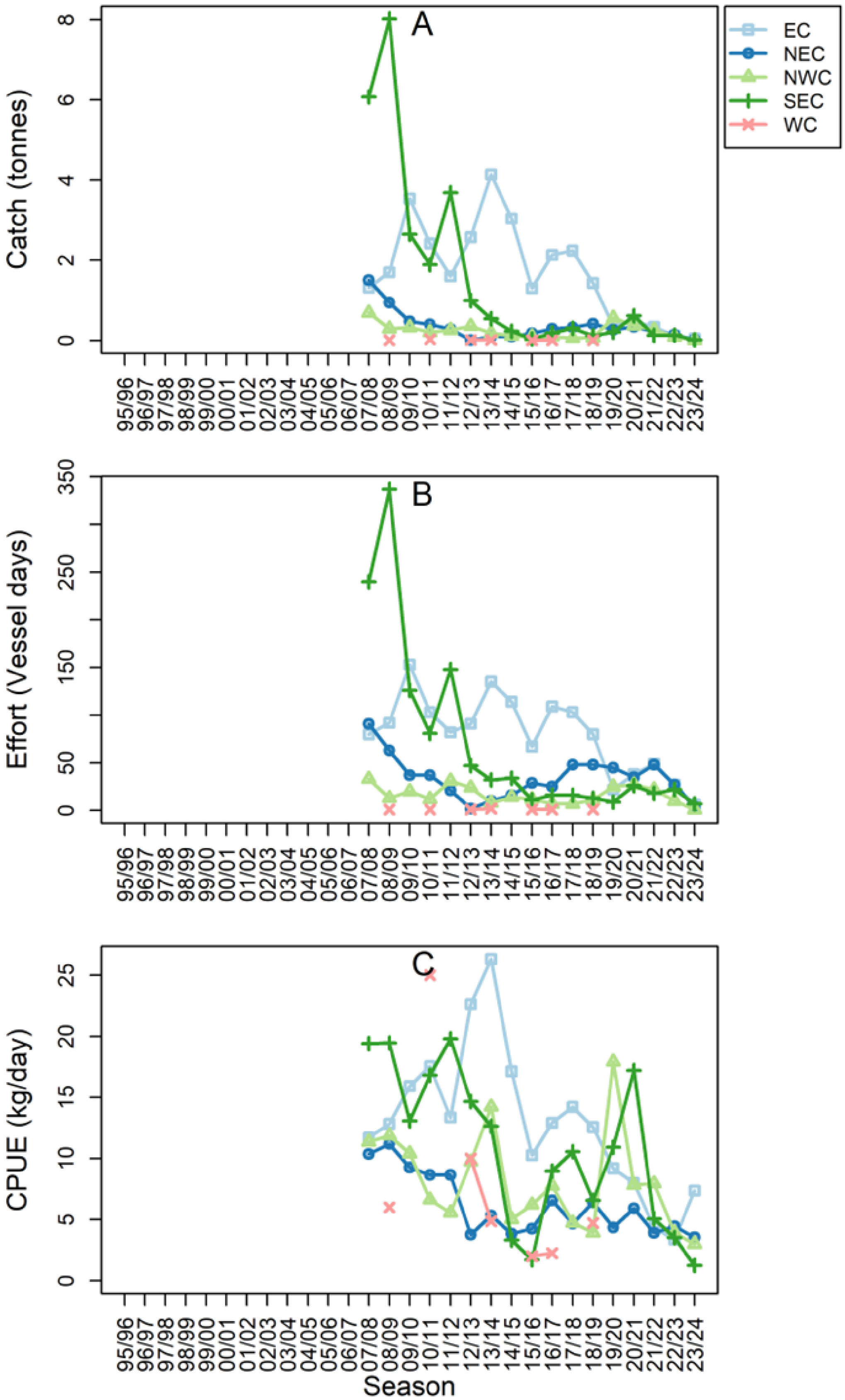


Figure 74. Regional commercial Sand Flathead catch (A), effort (B), and catch per unit effort (CPUE) (C) recorded for handline gear. EC = east coast, NEC = northeast coast, NWC = northwest coast, SEC = southeast coast, WC = west coast.

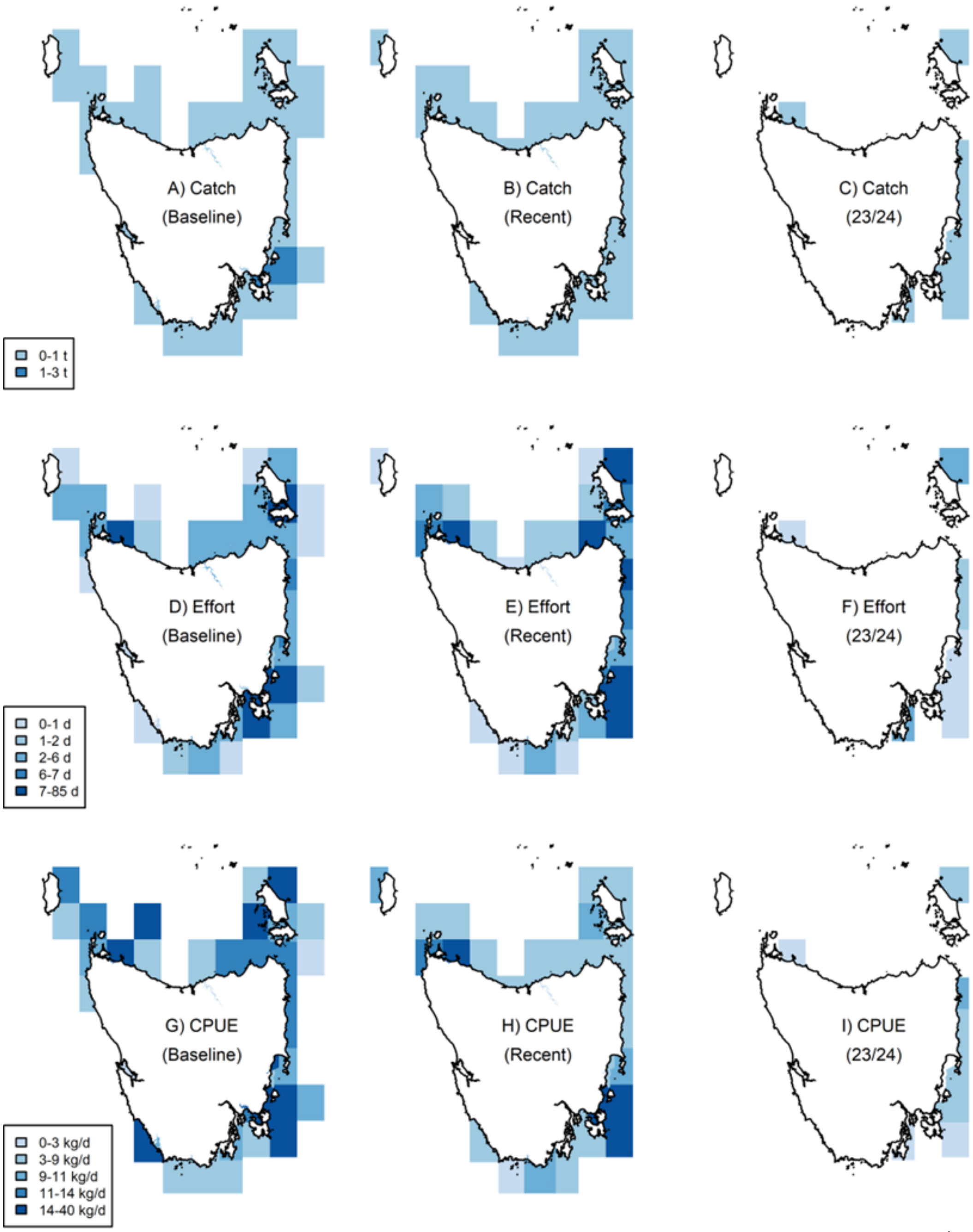


Figure 75. Sand Flathead commercial catches (t), effort (fishing days), and CPUE (kg/day) by fishing block for all main gear types combined. 'Baseline' data represent the average per fishing block across the ten-year period from the reference year (2007/08 to 2016/17 for this species). 'Recent' data represent the average per fishing block across the last five fishing seasons (2018/19 to 2022/23). '23/24' represent data from the 2023/24 fishing season.

9.1.3.2 Baseline life-history scenarios for length-based assessment

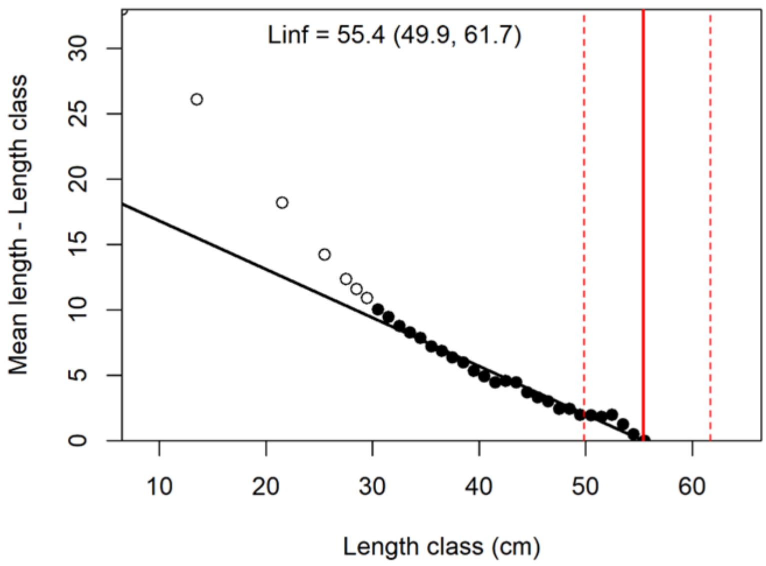
Assessments were undertaken using females only because Sand Flathead exhibit pronounced sexual dimorphism, with females attaining substantially larger sizes and dominating the upper size classes that contribute disproportionately to reproductive output. As demonstrated throughout this report, females comprise most fish above legal harvest sizes and therefore experience the greatest exposure to size-selective fishing mortality. In contrast, males mature earlier, remain smaller on average, and contribute differently to population biomass and spawning dynamics. Modelling sexes jointly would therefore mask the component of the population most vulnerable to harvest and most influential to stock productivity. Focusing assessment on females provides a more precautionary and biologically meaningful estimate of reproductive output, fishing pressure, depletion risk, and rebuilding potential, particularly in a fishery where removal of larger females is likely to have disproportionate consequences for egg production and long-term resilience.

For the assessment outcomes presented below, asymptotic length (L_∞) was re-estimated using the expanded survey dataset, including additional size and age information from Flinders Island, where Sand Flathead populations are considered comparatively lightly fished. Powell–Wetherall regression for female fish from Flinders Island returned an estimate of L_∞ = 54.4 cm, closely aligned with the estimate from direct von Bertalanffy growth function (VBGF) fitting to the same data (52.7 cm) (Figure 76A; Figure 76B). These estimates were also highly consistent with the corresponding estimate used in the 2024 assessment, and all fell within the Powell–Wetherall confidence interval of 49.9–61.7 cm.

To capture this uncertainty in growth and asymptotic size, four alternative life-history scenarios were carried forward into subsequent mortality and depletion analyses (Table 28). These comprised a default scenario based on Flinders Island data (L_∞ = 54.4 cm; k = 0.18; M = 0.26; M/k = 1.44), a fast growth scenario (L_∞ = 49.9 cm; k = 0.30; M/k = 0.87), a slow growth scenario (L_∞ = 61.7 cm; k = 0.15; M/k = 1.86), and an additional SEC baseline scenario based on pooled data from the three traditionally surveyed south-eastern and eastern regions (L_∞ = 49.8 cm; k = 0.15; M/k = 1.73) (Table 28; Figure 76B). The SEC baseline scenario was included to represent the alternative possibility that growth in south-eastern Tasmania differs naturally from Flinders Island, while acknowledging that growth estimates from the southeast may themselves be biased by long-term size truncation.

The default estimate of female natural mortality (M = 0.26) was slightly lower than the values used in the previous two assessments (0.28–0.30), reflecting a new maximum recorded age of 16 years for females in the 2025 dataset. This updated estimate implies a slightly lower background mortality and therefore slightly greater vulnerability to fishing pressure than previously assumed.

A)



B)

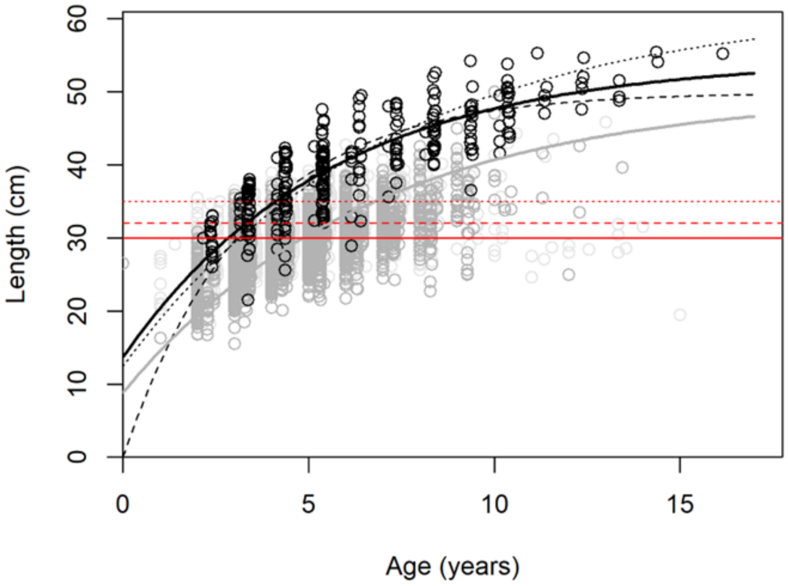


Figure 76. A) Powell-Wetherall regression to estimate the asymptotic length (L_∞) of female Sand Flathead based on data from lightly fished survey sites on Flinders Island. Filled circles highlight data for individuals ≥ 30 cm in length, which was representative of the estimated length of "full" gear selectivity (≥ 95% of individuals). Red vertical lines mark the estimate of L_∞ (solid) and associated confidence intervals (dashed). (B) Alternative fits of the von Bertalanffy growth function (VBGF) to estimate L_∞ and the associated growth coefficient (*k*). The black solid line represents the "best estimate" scenario (default assumption) while the dashed and dotted black lines represent the alternative "fast growth" and "slow growth" scenarios, respectively, all based on fits to the black dots which represent the assumed baseline data from Flinders Island. The solid grey line represents an alternative baseline assumption by fitting the VBGF to length-at-age data from the consistently surveyed south-east coast ("SEC") region (dark grey dots), where fishing is more intense. The light grey dots represent data from other survey sites across the state. Red lines represent the long-term initial (solid: 30 cm), previous (dashed: 32 cm) and current (dotted: 35 cm) minimum size limit.

Table 28. Key parameters used for length-based assessments of stock status and trends. L_∞: infinite or asymptotic length; *k*: von Bertalanffy growth rate; *M*: instantaneous rate of natural mortality; *M/k*: the ratio between natural mortality and growth determines the shape of the estimated unfished length-frequency distribution. All results represent females only.

Scenario	L_∞	***k***	***M***	**M/k**
"Default"	54.4 cm	0.18 (t_0 =-1.6)	0.26	1.44
"Fast growth"	49.9 cm	0.3 (t_0 = 0)	0.26	0.87
"Slow growth"	61.7 cm	0.15 (t_0 =-1.5)	0.26	1.86
"SEC baseline"	49.8 cm	0.15	0.26	1.73

9.1.3.3 Long-term mortality estimated from length-based catch curves

Length-based catch curves estimated a high long-term total mortality in the traditionally surveyed southeast and east coast regions (pooling data for D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays, and Great Oyster Bay). Under the default scenario, total mortality was estimated at *Z* = 1.51 (95% CI: 1.26–1.76), equivalent to approximately 78% annual mortality of adult fish (Table 29). Subtracting the estimated natural mortality yielded a fishing mortality of *F* = 1.25 (95% CI: 1.00–1.50), corresponding to long-term annual mortality from fishing of approximately 71% (95% CI: 63–78%). Fishing mortality therefore accounted for about 91% of total annual adult female mortality in these traditionally sampled south-eastern and eastern areas. Relative fishing mortality was estimated at *F/M* = 4.81 (95% CI: 3.85–5.77), far above commonly invoked sustainability thresholds of F/M < 1 and thus also above more precautionary teleost thresholds proposed in the literature (Table 29).

When survey data from all additional east and north coast sites were pooled with Flinders Island, estimated long-term fishing mortality was markedly lower, with Z = 0.52, F = 0.26, and F/M = 1.00 (Table 29). However, this pooled outcome masked substantially higher fishing mortality in all regions other than Flinders Island. When Flinders Island data were excluded from the pooled analysis, estimated long-term mortality increased to *Z* = 1.28, *F* = 1.02, and *F/M* = 3.92 (Table 29).

Flinders Island itself returned an estimate of *Z* = 0.27 (95% CI: 0.21–0.33), very close to the independently estimated female natural mortality of *M* = 0.26, indicating that fishing mortality there was likely to be very low. This result was consistent with the use of Flinders Island as the preferred reference for comparatively lightly fished female life-history parameterisation.

Table 29. Estimates of long-term total mortality (*Z*), fishing mortality (*F = Z-M*), and fishing mortality relative to natural mortality (*F/M*) based on length-based catch curves using fishery-independent survey data between 2023 and 2025. Results for the southeast coast region represent females from three traditionally sampled survey sites (D'Entrecasteaux Channel, Frederick Henry and Norfolk Bays and Great Oyster Bay). All results state 95% confidence intervals in brackets.

Region	***Z***	***F***	***F/M* (Target: 0.5-1)**
Pooled - all regions	0.52 (0.46–0.58)	0.26 (0.2–0.32)	1.00 (0.77–1.23)
Pooled - Flinders excluded	1.28 (1.12–1.44)	1.02 (0.86–1.18)	3.92 (3.31–4.54)
Southeast coast traditional	1.51 (1.26–1.76)	1.25 (1.0–1.5)	4.81 (3.85–5.77)

9.1.3.4 LBSPR estimates for the traditional south-eastern assessment area

Results from the Length-Based Spawning Potential Ratio (LBSPR) model corroborated the mortality estimates above by indicating high long-term fishing pressure and severe reduction in female spawning potential in the traditionally surveyed south-eastern assessment area (Table 30; Figure 77). Under the default scenario, relative fishing mortality was estimated at F/M = 6.62 (95% CI: 5.48–7.76) and spawning potential at SPR/SPR_0 = 0.06 (95% CI: 0.05–0.07) (Table 30; Figure 77A; Figure 77B). These values are well below the commonly applied limit reference point of 0.2 and far below the more desirable target range of 0.4–0.5 of unfished spawning potential.

The fast growth and slow growth scenarios produced very similar qualitative outcomes. The fast growth scenario estimated slightly higher fishing mortality and slightly lower spawning potential, whereas the slow growth scenario gave almost identical results to the default scenario (Table 30). Thus, the finding of severe depletion in the traditional south-eastern area was robust to uncertainty in Flinders Island-based growth assumptions.

By contrast, the alternative SEC baseline scenario produced notably lower estimates of fishing mortality and less severe depletion, with F/M = 3.79 (95% CI: 3.09–4.49) and SPR/SPR_0 = 0.22 (95% CI: 0.20–0.25) (Table 30; Figure 78). Under this alternative scenario, the south-eastern stock remained subject to unsustainable fishing mortality, but estimated spawning potential was close to the standard limit reference point rather than notably below it. Although it is important to note that this model is most likely parameterised by a shifted baseline in the southeast when considering the larger sizes revealed through comparison of data collected in the 1990s reported in previous chapters.

Table 30. Estimates of the long-term relative fishing mortality (F/M) and spawning potential (SPR/SPR_0) of female Sand Flathead at traditional sampling areas in the south-east coast region using the Length-Based Spawning Potential Ratio (LBSPR) assessment approach. See text above and Table 28 for details on scenarios.

Scenario	***F/M* in 2025** (Limit = 1.0)	***SPR/SPR_0* in 2025** (Limit = 0.2)
Estimate	6.62 (5.48–7.76)	0.06 (0.05–0.07)
Fast growth	8.5 (7.08–9.92)	0.05 (0.04–0.05)
Slow growth	6.57 (5.43–7.71)	0.06 (0.05-0.07)
SEC baseline	3.79 (3.09–4.49)	0.22 (0.20–0.25)

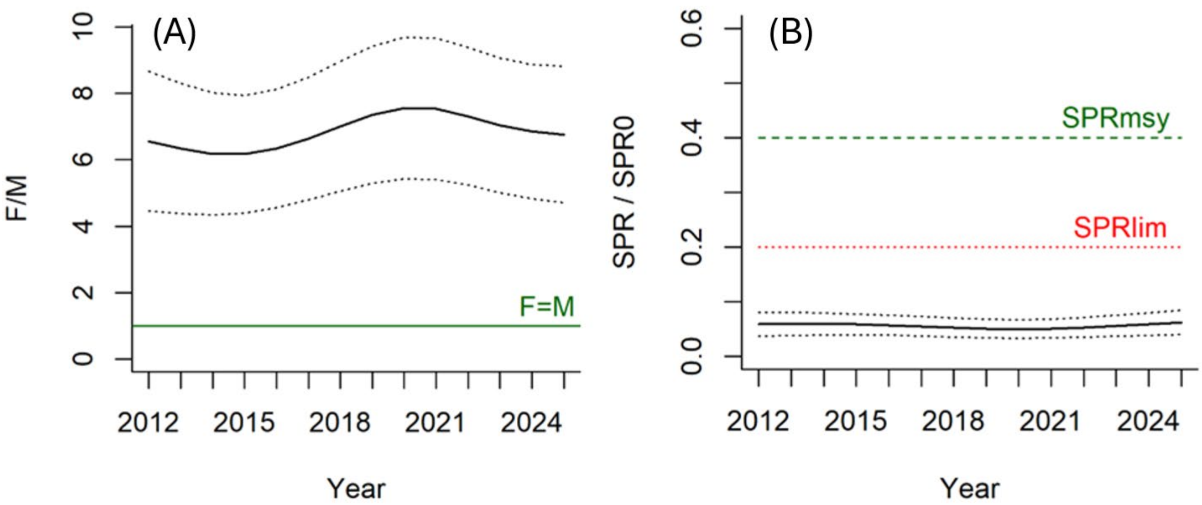


Figure 77. Smoothed trends in the long-term relative fishing mortality (A) and spawning potential (B) of female Sand Flathead in the south-east coast region using the Length-Based Spawning Potential (LBSPR) assessment approach. Fishing mortality relative to natural mortality (F/M) ratios > 1 are widely used to infer overfishing (solid line in A). Estimates of the current spawning potential ratio relative to unfished levels (SPR/SPR_0) is assessed against the standard limit reference point of 0.2 (20% of unfished levels) to infer depletion and against a desirable target reference point of 0.4 (40% of unfished levels) to assess productivity.

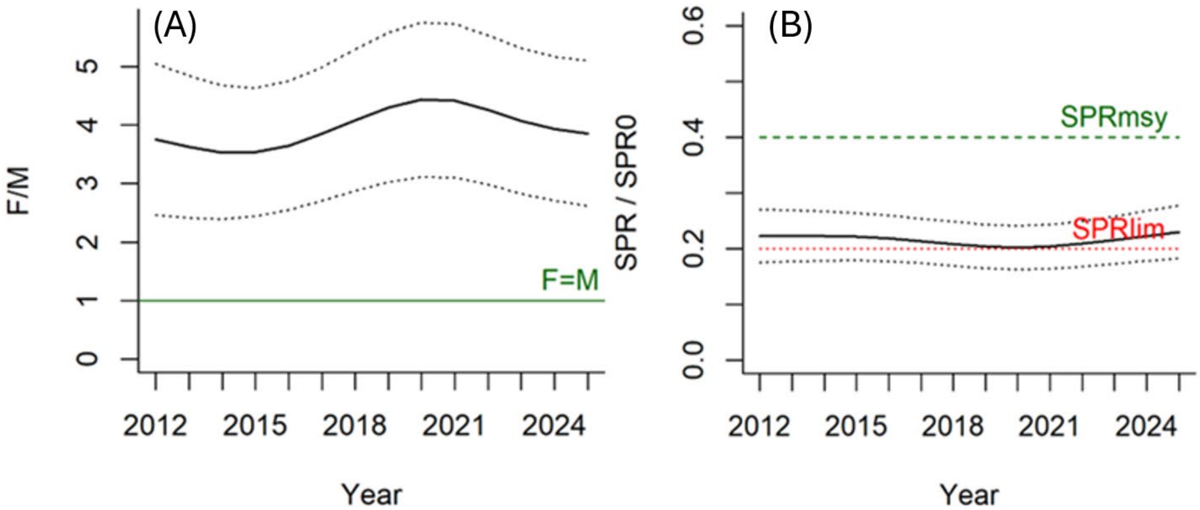


Figure 78. Smoothed trends in the long-term relative fishing mortality (A) and spawning potential (B) of female Sand Flathead in the south-east coast region using the Length-Based Spawning Potential (LBSPR) assessment approach. Results are as presented in Figure 9 but using pooled data from the south-east coast region ("SEC baseline") to estimate key input parameters.

9.1.3.5 Baseline contrast and interpretation of truncation

The contrast between the Flinders Island and SEC baseline assumptions was illustrated by comparing observed length frequencies against theoretical unfished distributions generated by LBSPR (Figure 79). Under the default Flinders Island baseline, observed female length frequencies at Flinders Island closely matched the theoretical unfished distribution (Figure 79A), explaining the low fishing mortality and high spawning potential estimated for that region. In contrast, observed length frequencies in the traditional south-eastern area were strongly truncated relative to the unfished expectation, with a strictly limited representation of fish greater than 40 cm and correspondingly reduced spawning potential (Figure 79B).

Under the SEC baseline scenario, the interpretation changed materially. The model effectively assumed that the much larger fish routinely observed at Flinders Island could not occur under south-eastern growth conditions, even in the absence of fishing (Figure 79C). This assumption reduced the degree of apparent truncation in the southeast (Figure 79D) and therefore reduced the estimated degree of depletion. The contrast between Figure 79A–B and Figure 79C–D demonstrates that the severity of depletion estimates depends strongly on whether Flinders Island is treated as the most defensible approximation of an unfished reference state, or whether south-eastern Tasmania is assumed to have intrinsically lower asymptotic size and slower growth independent of historical fishing pressure.

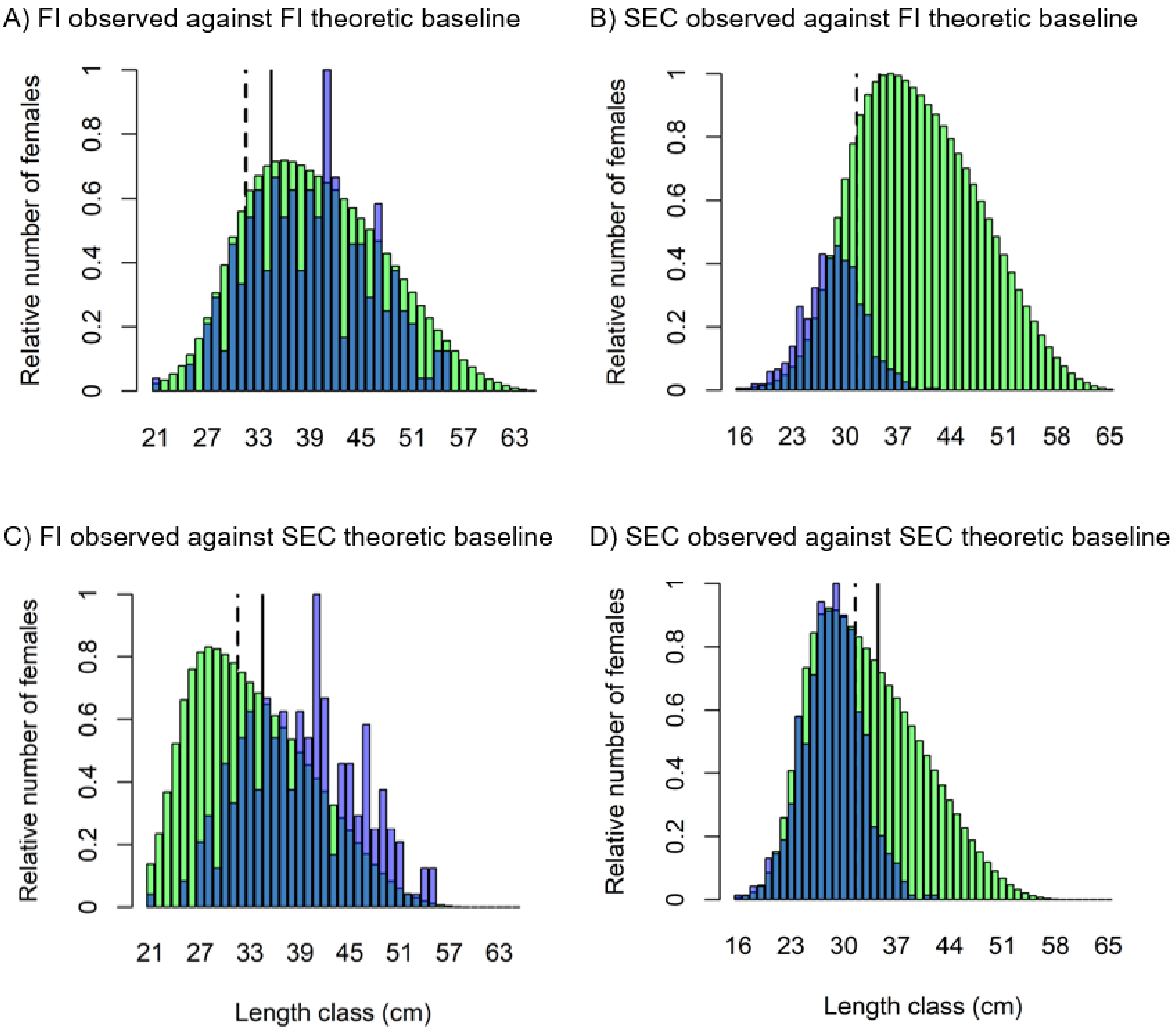


Figure 79. Contrasting baseline assumptions and size truncation illustrated by observed vs theoretical unfished length-frequency distributions. Observed length frequencies over the last three years (blue) are compared here to theoretical unfished length frequencies (green) using LBSPR. Upper panels represent the assumption that all fish could grow as observed at Flinders Island if fishing stopped, indicating that observed length frequencies A) at Flinders Island represent nearly unfished conditions, while B) in the south-east coast region are heavily size truncated. Lower panels represent the assumption that growth conditions in the south-east coast region are different from those at

Flinders Island and that growth estimates based on regional data are unaffected by the high long-term fishing mortality estimated for this region. This alternative baseline assumption resulted in observed length frequencies C) at Flinders Island that are higher than expected even if there was no fishing (i.e., either the SEC baseline assumption is invalid due past overfishing or growth patterns at Flinders Island are notably different), and B) size truncation in the south-east coast region that is less severe than estimated in panel B. Note that frequencies in these plots are based on numbers produced by the LBSPR function in R, but that estimates of depletion in spawning potential are based on weight (which is higher for large fishes due to allometric growth). Vertical black lines represent the medium-term (dashed line: 32 cm) and most recent minimum size limit (solid line: 35 cm, introduced from end of 2023).

9.1.3.6 Regional stock status estimates across Tasmania

Regional LBSPR analyses based on samples collected between 2023 and 2025 confirmed that depletion was a statewide concern, although not spatially uniform (Table 31). Under the default Flinders Island-based baseline, all regions other than Flinders Island were estimated to be overfished, with *F/M* > 2, and all were assessed as having female spawning potential below the standard limit reference point of 0.2 of unfished levels. The most extreme estimates occurred in the D'Entrecasteaux Channel, Frederick Henry–Norfolk Bays, and Tamar, where the estimated long-term relative fishing mortality exceeded *F/M* > 7 and spawning potential fell below 0.1 of unfished levels. Great Oyster Bay also returned high fishing mortality (*F/M* > 6.0) and spawning potential below 0.1, while Mercury Passage, St Helens, Bridport and Stanley all remained below the limit reference point despite somewhat lower fishing mortality estimates. Flinders Island was the only region not assessed as overfished (*F/M* < 1.0), and the only region estimated to retain spawning potential above the target reference point (SPR/SPR_0 > 0.4) (Table 31).

When the alternative SEC baseline was used, depletion estimates for eastern Tasmania were less severe (Table 32). Under this scenario, Great Oyster Bay and Mercury Passage were estimated to remain below the target reference point but above the standard limit reference point, whereas both the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays remained below the limit reference point. However, all four assessed regions still showed unsustainable long-term fishing mortality (*F/M* > 2), indicating that even under this more optimistic baseline assumption, south-eastern and eastern populations remained under substantial fishing pressure.

Table 31. Regional estimates of the long-term relative fishing mortality (F/M) and the spawning potential ratio (SPR/SPR_0) for female Sand Flathead sampled between 2023 and 2025. Results are based on the "best estimate" of growth using Flinders Island data as the baseline. Sustainable *F/M* < 1. Limit reference point >0.2 and target reference point >0.4.

Region	**Fishing mortality *(F/M)***	**Spawning Potential *(SPR/SPR_0)***
Bridport (NEC)	Overfished (>3)	Below limit (<0.2)
D'Entrecasteaux Channel (SEC)	Overfished (>8)	Below limit (<0.1)
Flinders Island (FI)	Not overfished (<1)	Above target (>0.4)
Frederick Henry & Norfolk Bays (SEC)	Overfished (>7)	Below limit (<0.1)
Great Oyster Bay (EC)	Overfished (>6)	Below limit (<0.1)
Mercury Passage (EC)	Overfished (>4)	Below limit (<0.2)
Stanley (NWC)	Overfished (>2)	Below limit (<0.2)
St Helens (EC)	Overfished (>5)	Below limit (<0.2)
Tamar (NEC)	Overfished (>7)	Below limit (<0.1)

Table 32. Estimates of the long-term relative fishing mortality (F/M) and the spawning potential ratio (SPR/SPR0) for female Sand Flathead sampled between 2023 and 2025. Results are based on the alternative growth estimate using the traditionally surveyed south-east coast data as the baseline ("SEC baseline"). Classification thresholds are the same as above.

Region	**Fishing mortality *(F/M)***	**Spawning Potential *(SPR/SPR$_0$)***
D'Entrecasteaux Channel	Overfished (>5)	Below limit (<0.2)
Frederick Henry & Norfolk Bays	Overfished (>4)	Below limit (<0.2)
Great Oyster Bay	Overfished (>3)	Below target (<0.3)
Mercury Passage	Overfished (>2)	Below target (<0.3)

9.1.3.7 Temporal interpretation and evidence of rebuilding

Smoothed trends in the estimated long-term *SPR* and *F/M* for the traditional south-eastern assessment area showed no clear evidence of substantial recovery over recent years under either the default or SEC baseline scenarios (Figure 77; Figure 78). However, these trends require cautious interpretation because LBSPR is an equilibrium-based method and therefore estimates the long-term fishing pressure that generated the observed contemporary length composition, rather than current annual fishing mortality. In addition, earlier survey chapters showed only limited directional change in age and size composition since 2012, suggesting that most depletion likely pre-dated the survey era and that present-day populations may have remained at broadly comparable depletion levels through much of the monitoring period.

The higher mortality and depletion estimates obtained in the current assessment relative to the previous two years did not reflect a worsening of recent stock trends in the observed data but instead were attributable primarily to re-estimation of key input parameters, including M, SL_{50}, and SL_{95}. These updated inputs altered modelled expectations of unfished size structure and vulnerability, thereby changing the inferred stock status even in the absence of major change in the contemporary length-frequency data.

Overall, the quantitative assessment results were strongly consistent with the broader evidence developed in previous chapters. Regions estimated to have the highest fishing mortality and lowest spawning potential were the same regions previously shown to contain the smallest fish, the strongest age truncation, the lowest representation of large females, and the clearest historical evidence of long-term decline. Regions estimated to be in stronger condition corresponded with broader contemporary size structure and higher proportions of larger fish. Collectively, these outputs indicate that Sand Flathead in Tasmania is mostly but not uniformly depleted, comprising regions in markedly different condition, with south-eastern Tasmania remaining the principal rebuilding priority and Flinders Island the clearest contemporary reference area.

9.1.4 Discussion

9.1.4.1 Spatially explicit stock status

This chapter describes the most comprehensive quantitative stock assessments of Sand Flathead yet undertaken in Tasmania and integrates multiple independent lines of evidence developed throughout this report, including historical reconstruction, fishery-independent surveys, regional life-history analyses, movement studies, and contemporary length-based modelling. Considered collectively, these data indicate that the stock condition of Sand Flathead is spatially heterogeneous and cannot be adequately described by a single statewide signal. Rather, Tasmania supports regional populations in notably different demographic states, with south-eastern Tasmania remaining the principal area of concern and northern regions, primarily Flinders Island, retaining the strongest stock condition.

9.1.4.2 Fishing mortality relative to sustainability proxies

A particularly important finding of this assessment is that long-term fishing mortality has been highly unstainable and that current fishing mortality must be reduced to low levels if depleted Sand Flathead populations are to rebuild within realistic management timeframes. Across most model configurations, long-term fishing mortality relative to natural mortality (F/M) was elevated in nearly all assessed regions and was highest in south-eastern Tasmania, where values substantially exceeded commonly applied sustainability proxies. Even under more optimistic biological assumptions, several regions were estimated to have remained under potentially excessive long-term fishing pressure. This consistency across alternative scenarios suggests that uncertainty in absolute stock size does not alter the central management conclusion: rebuilding will require a material and sustained reduction in effective fishing mortality, with the greatest urgency in south-eastern Tasmania.

9.1.4.3 Regional demographic contrasts

The clearest result across chapters presented in this report was the persistent contrast between south-eastern Tasmania and the remainder of the state. The D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays consistently exhibited smaller mean lengths, truncated upper size structure, reduced age diversity, and the lowest modelled spawning potential. These patterns are characteristic of prolonged size-selective exploitation, where larger and to a lesser degree older fish are progressively removed from the population, reducing reproductive biomass and age structure while catches of mostly smaller fish may still remain available to fishers because catch rates can remain disproportionately stable relative to true abundance declines, particularly in recreational fisheries (Beverton and Holt, 1957, Hixon et al., 2014, Charbonneau et al., 2025). In practical terms, Sand Flathead remain present in south-eastern Tasmania, but there is strong evidence that the stock structure has been materially altered from historical conditions.

9.1.4.4 Recruitment and biological capacity

Importantly, these results cannot be interpreted as evidence of imminent stock collapse. Recruitment remains evident across surveyed regions, and younger fish continue to enter sampled populations. However, under the Status of Australian Fish Stocks (SAFS) framework, the key management concern is not whether recruitment has already failed, but whether stock biomass or associated biological capacity has been reduced toward levels where current or future recruitment impairment is likely. For Sand Flathead, multiple indicators presented throughout this report, including a low estimated spawning potential, truncated size and age structure, and depletion of larger females, suggest that some populations are at or below globally adopted limit reference points[3].

9.1.4.5 Spawning capacity and resilience

The central issue is therefore one of reduced spawning capacity, diminished resilience, and lower probability of sustaining desirable catch quality, abundance, and long-term productivity. In many fisheries, erosion of age structure and reproductive capacity can precede measurable recruitment failure, particularly where exploitation is chronic but not extreme (Hilborn and Walters, 1992, Walters and Martell, 2004). This distinction is important for management because it supports timely rebuilding action before more serious biological outcomes emerge and while recovery pathways remain more achievable.

9.1.4.6 Spawning potential ratio and sexual dimorphism

The low spawning potential ratio (SPR) estimated for south-eastern Tasmania is therefore a particularly informative result. It indicates that the female component of the stock may now contribute only a small proportion of historical reproductive output. This is amplified by the pronounced sexual dimorphism demonstrated elsewhere in this report. Females attain larger sizes and dominate upper size classes, thereby contributing disproportionately to egg production. In many teleost species, larger older females also produce eggs and larvae of higher average quality, enhancing recruitment stability under variable environmental conditions (Berkeley et al., 2004b, Hixon et al., 2014). The female-only assessment framework adopted here was therefore biologically justified and precautionary, focusing inference on the component of the stock most influential to long-term productivity.

9.1.4.7 Regional reference conditions

Regional contrasts in stock condition presented throughout this report have direct implications for management design. Flinders Island consistently exhibited broader size structure, lower fishing mortality, and substantially higher spawning potential than any other assessed region. While not assumed to represent an unfished state, it provides the most defensible contemporary approximation of a lightly exploited reference condition currently available in Tasmania. Conversely, south-eastern Tasmania represents the opposite end of the spectrum, where prolonged fishing pressure and accessibility to population centres have likely combined to drive stronger depletion signals.

9.1.4.8 Effects of statewide aggregation

A major management implication of this chapter is that statewide aggregation masks localised depletion. When data were pooled across Tasmania, stronger northern regions diluted the severe truncation evident in south-eastern areas, producing average estimates that were not representative of either the healthiest or most

[3] *Status of Australian Fish Stocks* (SAFS). How are the Status of Australian Fish Stocks reports done? Available at: https://fish.gov.au/about/how-are-the-status-of-australian-fish-stock-reports-done (Accessed: 22 April 2026).

depleted components of the fishery. This phenomenon is well recognised in spatially structured fisheries, where regional declines can remain obscured beneath stable aggregate indicators (Hilborn et al., 2005, Ying et al., 2011). For Sand Flathead, the evidence strongly supports regionally explicit monitoring, assessment and management.

9.1.4.9 Connectivity and rebuilding processes

The present findings are also consistent with earlier chapters examining movement and connectivity. Conventional tagging suggested limited adult displacement, while otolith chemistry indicated the potential for broader connectivity earlier in life. Together, these results suggest a system in which larval or juvenile dispersal may link regions to some extent, but adults become relatively resident. If so, rebuilding of depleted south-eastern populations is unlikely to occur rapidly through immigration of large adults from healthier northern areas. Recovery is therefore likely to depend primarily on local survival, recruitment, and sustained spawning output.

9.1.4.10 Interpretation of equilibrium-based assessment methods

The assessment approaches applied here also require appropriate interpretation. LBSPR and related equilibrium-based methods infer the long-term fishing mortality and depletion that generated the currently observed size composition. They do not directly estimate present-day annual fishing mortality and are relatively insensitive to short-term shifts in catch following recent regulation changes. Accordingly, if bag limits, size limits, slot limits and closure of the commercial fishery have materially reduced recent harvest, current fishing mortality may now be considerably lower than the long-term rates inferred by the equilibrium model. This does not invalidate the assessment; rather, it clarifies that these methods are strongest for diagnosing status and rebuilding need, not for evaluating immediate year-to-year policy effects (Haddon, 2011, Hordyk et al., 2015a).

9.1.4.11 Temporal lag in recovery indicators

However, the distinction between long-term and current fishing mortality is highly relevant given recent management reforms. In a relatively long-lived species, such as Sand Flathead, rebuilding of upper size classes can lag reductions in fishing pressure because cohorts require several years of survival to recruit into larger and older age groups. Where older females have already been depleted, this lag may be more pronounced. Consequently, limited short-term evidence of recovery should not be interpreted as failure of management, nor should strong recent regulation changes be expected to generate immediate changes in size structure.

9.1.4.12 Uncertainty and sensitivity analyses

As with all data-limited assessments, uncertainty remains regarding growth, natural mortality, selectivity, compliance, and the extent of biological separation among regions. These uncertainties were explicitly examined through multiple scenarios and sensitivity analyses. While absolute numerical estimates varied, the principal spatial diagnosis remained stable: south-eastern Tasmania repeatedly emerged as the most depleted component, northern regions remained stronger overall, and Flinders Island consistently represented the highest contemporary stock status. This robustness across plausible assumptions materially strengthens confidence in the core management conclusions.

9.1.4.13 Monitoring and data integration

Monitoring design is another important consideration. Length composition and age structure provide valuable indicators of fishing mortality and stock condition, but future management would be strengthened by continued development of abundance indicators, routine recreational harvest estimation, and integrated use of multiple datasets. The existing fishery-independent survey program already provides one of the more informative long-term monitoring datasets available for an Australian recreationally dominated inshore fishery. Building from that foundation is likely to yield greater benefit than replacing it.

9.1.4.14 Environmental variability

Environmental variability also deserves consideration. Sand Flathead populations occur within south-eastern Australia, including eastern Tasmania, a recognised climate-change hotspot where ocean warming has been rapid relative to global averages (Oliver et al., 2018). Climatic influences may affect growth, recruitment, distribution, and catchability, thereby interacting with fishing pressure and influencing rebuilding trajectories. Although environmental change does not explain the strong regional exploitation signals identified here, future assessment frameworks should seek to incorporate these drivers where feasible.

9.1.4.15 Future assessment frameworks

The logical next step for management science is progression toward integrated dynamic assessment models and management strategy evaluation (MSE). Frameworks such as OpenMSE and the Stock Assessment Continuum Tool (SACT) can combine multiple data sources, simulate uncertainty, and compare alternative rebuilding pathways under different regulatory settings. These approaches are especially valuable in socially important recreational fisheries because they allow managers to evaluate likely trade-offs among rebuilding speed, access, risk, and compliance before measures are implemented (Punt et al., 2016).

9.1.4.16 Synthesis

Overall, the evidence indicates that Sand Flathead remains a recoverable fishery, but not a uniformly healthy one. The greatest biological risk remains concentrated in south-eastern Tasmania, where rebuilding should remain the central management priority. At the same time, stronger northern regions demonstrate the productivity and fishery quality that can be retained where exploitation remains lower or more effectively constrained. Tasmania now has an unusually strong scientific foundation from which to move beyond reactive management toward transparent, regionally explicit and evidence-led recovery.

9.1.5 Conclusion

This chapter provides the first regionally resolved quantitative stock assessment of Sand Flathead in Tasmania and demonstrates that stock condition differs markedly among regions. South-eastern Tasmania, particularly the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays, exhibited the highest long-term fishing mortality, lowest spawning potential, and strongest evidence of demographic truncation. In contrast, northern regions, especially Flinders Island, retained broader size structure, lower exploitation rates, and substantially stronger reproductive capacity.

The findings strongly support the broader conclusion of this report that Sand Flathead should not be managed as a single homogeneous statewide stock. Statewide averages obscure potentially severe local depletion and risk underestimating rebuilding needs in historically important fishing grounds. Regionally explicit monitoring, assessment, and management are therefore essential.

Assessments focused on females was biologically appropriate given pronounced sexual dimorphism and the disproportionate contribution of larger females to stock productivity. The depletion of large females in heavily fished regions indicates that rebuilding success should be measured not only by numbers of fish, but by restoration of size structure, age diversity, and spawning biomass.

The equilibrium-based methods applied here provide robust estimates of the long-term fishing pressure that produced the current stock structure, but they are not designed to forecast recovery under recent regulatory changes. Development of integrated dynamic assessment models and management strategy evaluation now represents the logical next phase of evidence-based management for this fishery.

Sand Flathead remains one of Tasmania's most socially and culturally important recreational fisheries. The stock is not beyond recovery, but successful rebuilding will require decisive management, continued monitoring, realistic recovery timeframes, and transparent evaluation of alternative management pathways. The scientific foundation now exists to support that process. The priority ahead is to translate improved understanding into measurable rebuilding outcomes, particularly in south-eastern Tasmania.

10 Management scenarios for consideration

The management scenarios presented below are informed by the integrated findings of this study, including the quantitative stock assessment, analyses of life history and spatial population structure, historical reconstruction of exploitation, and a targeted survey of Tasmanian recreational fishers examining perceptions of stock condition, management preferences, and acceptable pathways to recovery (Tracey et al., 2023).

Collectively, the evidence indicates that the principal management challenge is not uncertainty over whether action is required, but how best to reduce fishing mortality in a socially acceptable and biologically effective manner. Across most stock assessment scenarios, fishing mortality relative to natural mortality remained elevated in nearly all assessed regions and was highest in south-eastern Tasmania, where spawning potential was lowest and demographic truncation most acute. Even under more optimistic biological parameterisations, several regions continued to exhibit stock status consistent with long-term over-exploitation. Accordingly, the primary management implication is that measurable rebuilding is likely to require a substantial and sustained reduction in effective fishing mortality, with the most immediate priority in south-eastern Tasmania where depletion indicators were strongest.

The human dimensions component reported by Tracey et al. (2023) also provides important context. Sand Flathead remains Tasmania's most socially important recreational fishery, accounting for a large proportion of participation and retained catch. Fishers are diverse in motivations and values, but there is broad recognition that stock condition has declined, particularly in the south-east, and considerable support for management intervention where it is clearly linked to recovery. Importantly, many respondents considered ongoing stock decline to be more detrimental than management change itself. Support was strongest where measures were transparent, evidence-based, regionally targeted, and accompanied by clear objectives and review points.

Accordingly, the scenarios below integrate biological rebuilding requirements with the social and behavioural realities within which management must operate. They are presented in order from those most strongly supported by the evidence to those more exploratory, complementary, or contingent in nature. They are intended to provide a structured basis for formal testing through a Management Strategy Evaluation (MSE) framework.

10.1 Tier 1 Priority Scenario: Regionally explicit rebuilding in south-eastern Tasmania

The strongest evidence-based management scenario is a regionally differentiated rebuilding strategy with immediate priority given to south-eastern Tasmania, particularly the D'Entrecasteaux Channel and Frederick Henry–Norfolk Bays.

These regions consistently exhibited the poorest stock condition in the present study. They had the highest fishing mortality, lowest spawning potential, smallest mean fish lengths (approximately 267 mm and 277 mm respectively), the most truncated upper size structure, and very limited representation of larger and older fish. Assessment outputs indicate that these populations are likely at or more likely below precautionary proxy limit reference points, with rebuilding constrained if current effective mortality remains high.

Under this scenario, south-eastern Tasmania would operate under formal rebuilding settings specifically designed to reduce fishing mortality and restore spawning biomass. Options may include temporary closure, substantially reduced possession limits, effort caps, or staged rebuilding harvest rules linked to biological indicators, or a combination of these.

The rationale is clear: directing the strongest intervention toward the most depleted areas is likely to generate the greatest biological gain per unit of management cost while preserving more access in stronger regions.

This approach is also broadly consistent with fisher perceptions identified in the human dimensions analysis. While closures are significant interventions, support increased where measures were region-specific, temporary, evidence-based, and linked to measurable recovery outcomes. Successful implementation would depend heavily on compliance, visible enforcement, and clear communication of recovery goals.

In parallel, an MSE model should be developed to specify the estimated timeline to recovery and optimal management scenarios, should the fishery remain open, or assess the timeline to reopening and subsequent optimal management scenarios if there is a closure imposed.

10.2 Tier 1 Priority Scenario: Statewide reduction in effective fishing mortality

Because overfishing was identified across most regions, a complementary high-priority scenario is a broader statewide reduction in effective fishing mortality, calibrated most strongly toward depleted areas. This scenario recognises that stock rebuilding cannot occur unless total removals decline. Management tools may include lower bag limits, reduced boat or trip possession limits, cumulative seasonal caps, effort constraints, and regional closures in the most depleted areas or combinations of these measures.

The advantage of this scenario is simplicity and direct alignment with the principal stock assessment finding. It also reduces the risk that effort displaced from constrained south-eastern regions simply shifts mortality pressure into stronger northern or eastern stocks. A regionally weighted version, where stronger reductions apply in the south-east and lighter settings elsewhere, may offer the best balance of biological gain and social acceptability.

10.3 Tier 1 Priority Scenario: Integrated effort reduction and optimised size-based controls

A strongly supported management scenario is an integrated package combining substantial reductions in overall fishing mortality with size-based harvest controls designed to protect spawning biomass and progressively restore demographic structure. The evidence from this assessment indicates that neither effort controls nor size limits alone are likely to deliver rapid rebuilding in the most depleted regions. Rather, the greatest benefit is expected from combining lower harvest pressure with regulations that better protect reproductively valuable fish.

The current statewide 350–400 mm harvest slot provides a practical and defensible baseline, particularly because Sand Flathead mature well below the lower bound of the slot and larger individuals are disproportionately female. Protection of larger females is biologically important given their likely elevated contribution to egg production and stock productivity. Accordingly, retaining an upper size threshold remains a sound principle within any rebuilding strategy.

However, results from this study suggest that the present slot may not yet be optimally configured. In heavily depleted south-eastern Tasmania, few fish currently survive into the protected upper size range, limiting the immediate rebuilding benefit of the maximum size limit. At the same time, the minimum legal size remains well above the size at maturity. Where minimum size limits are set too high in sexually dimorphic species such as Sand Flathead, harvest can become increasingly biased toward females because proportionally fewer males grow into the harvestable slot. This may unintentionally exacerbate skewed sex and size structure while reducing spawning potential.

These considerations indicate that future review of slot-limit design should be a priority. A biologically optimised slot may involve reconsideration of both lower and upper bounds to better balance protection of mature fish, access to harvest, sex-specific selectivity, and rebuilding outcomes. Such optimisation is likely to be especially important in south-eastern Tasmania, where restoration of larger and older age classes is a central management objective.

Nevertheless, regionally tailored slot limits should be approached cautiously. Although regional optimisation could yield biological gains by reflecting differences in growth, maturity schedules, exploitation history, and stock status, these benefits must be weighed against increased regulatory complexity, fisher movement between regions, and potential reductions in compliance if rules become overly complicated. For this reason, a simple statewide framework with periodic evidence-based refinement may provide the most effective near-term pathway.

Crucially, slot limits should not be viewed as a substitute for mortality reduction. Where fishing pressure remains high, rebuilding is likely to be slow regardless of size settings. Slot limits are therefore best implemented alongside lower bag limits, constrained cumulative harvest opportunity, and strong compliance. If appropriately calibrated, they are likely to be a critical tool not only for increasing biomass, but also for reversing the truncation of size and age structure observed across Tasmania, particularly in the southeast.

10.4 Tier 1 Supporting Scenario: Compliance and stewardship uplift

Management settings will not rebuild a stock if effective fishing mortality is not reduced in practice. For this reason, compliance and stewardship should be treated as a core rebuilding measure rather than a secondary operational issue. Survey responses indicated that fishers themselves recognise non-compliance occurs within the fishery. This suggests management credibility, simplicity of rules, enforcement visibility, and fisher buy-in are likely to materially influence outcomes.

Actions under this scenario could include:

- targeted compliance operations in high-risk regions
- simplified regulations where possible
- education on slot limits and handling practices
- public reporting of enforcement outcomes
- co-designed stewardship messaging with recreational stakeholders.

This scenario is particularly important because it increases the effectiveness an intent of all other management options.

10.5 Tier 2 Supporting Scenario: Seasonal Spawning Protection

Reproductive analyses indicated that Sand Flathead are prolonged spawners, with peak spawning generally occurring between October and December across most regions. A seasonal closure during this peak reproductive period could reduce fishing mortality on spawning fish and protect annual reproductive output. A simple statewide closure from October to December would provide administrative simplicity, while regional tailoring may increase biological benefit at the cost of greater complexity.

Seasonal closures alone are unlikely to resolve chronic historical overfishing in depleted areas, but they may provide useful complementary protection within a broader rebuilding package. Fishers may view predictable, time-limited seasonal closures more favourably than indefinite closures, particularly where benefits are clearly explained.

10.6 Tier 2 Supporting Scenario: Effort Diversification and Alternative Species Opportunities

In moderately depleted regions such as Great Oyster Bay and Mercury Passage, there may be value in reducing directed Sand Flathead effort while maintaining recreational participation through diversification toward alternative species.

The human dimensions study indicated that diversification is possible, but constrained by access, fisher preferences, and perceived quality of substitute species. Accordingly, diversification should not be assumed to occur automatically.

Supporting measures may include:

- education on alternative local species
- promotion of multi-species fishing opportunities
- responsible harvest messaging across substitute fisheries.

This scenario may reduce pressure on Sand Flathead while retaining social and economic benefits of recreational fishing.

10.7 Tier 2 Supporting Scenario: Conservation-Focused Management for Stronger Northern Stocks

Flinders Island and some northern regions currently represent the strongest remaining Sand Flathead stock components in Tasmania. These areas exhibited larger fish, broader size structure, and substantially higher spawning potential than depleted south-eastern regions. Decisive management in these regions now can help prevent serial depletion of remaining high-quality stocks. Measures may include long-term conservative bag and size limits, monitoring fishing pressure, and preventing effort displacement from more restricted southern areas. Protecting stronger regions is strategically important because it safeguards productivity, preserves fishery quality, and avoids repeating historical decline patterns observed elsewhere.

11 Conclusion

This project has provided a comprehensive reassessment of the population dynamics, status, and monitoring requirements for Sand Flathead in Tasmania. By integrating historical data, fishery-independent surveys, biological analyses, movement studies, quantitative stock assessment and considering recent complementary human dimensions research, it has directly addressed the key objectives of improving data collection, resolving spatial and temporal variability, updating life-history understanding, and developing an assessment framework to inform management. Collectively, these components provide the most complete evidence base yet assembled for Tasmania's most important recreational fishery.

The results demonstrate that Sand Flathead populations across Tasmania exhibit clear and persistent signs of size and age truncation consistent with prolonged size-selective fishing. While recruitment remains evident and local populations are unlikely to face imminent collapse, most populations are characterised by reduced productivity, with diminished capacity to generate biomass, spawning output, and high-quality fishing opportunities, resulting in the most recent assessment defining the stock as 'Depleted' due to estimated biomass being below limit reference points in some areas. These effects are most pronounced in south-eastern Tasmania, where fishing mortality was consistently highest, spawning potential lowest, and demographic structure most truncated, indicating prolonged depletion and limited capacity for rapid local replenishment.

In contrast, northern and north-eastern regions, particularly Flinders Island, retain broader size structures, older age classes, and higher reproductive potential, highlighting considerable spatial variation in stock condition across Tasmania. Although all except for Flinders Island are defined as currently Depleted. These contrasts demonstrate that Sand Flathead should not be viewed as a single homogeneous statewide stock for management purposes. Movement and connectivity analyses further indicate that while some exchange occurs among regions, it is likely insufficient to offset localised depletion, reinforcing the need for regionally differentiated management and caution against the assumption that healthier areas can replenish more heavily exploited regions.

A key outcome of this study is the demonstration that a cost-effective fishery-independent monitoring framework, combined with a regionally structured assessment approach, can resolve these dynamics and provide a robust basis for management. The project also showed that survey precision is driven strongly by the number of independent sites sampled rather than simply the number of fish measured within sites, confirming the importance of spatially representative sampling design. This finding represents a significant advancement in capability, enabling stock status to be assessed using biologically meaningful indicators such as size structure, mortality, biomass depletion, spawning potential, and rebuilding trajectory, even in a fishery where conventional long-term CPUE data are limited.

Importantly, evaluation of management pathways indicates that effective rebuilding will require a substantial and sustained reduction in effective fishing mortality, particularly in south-eastern Tasmania where depletion is most acute. Recovery is unlikely to be achieved through effort reduction alone. Restoration of size and age structure, especially protection and the recovery of larger females, is also likely to be critical. In this context, well-designed slot limits are likely to remain an important management tool, although future optimisation of lower and upper size thresholds may improve biological outcomes and reduce unintended sex-selective harvest. Regional rebuilding strategies, including more restrictive controls in depleted south-eastern waters and maintenance of stronger stock condition elsewhere, are strongly supported by the evidence.

The integration of human dimensions research further indicates a broad recognition of stock decline within the recreational fishing community, alongside concerns regarding historical non-compliance and strong interest in transparent, evidence-based management. Support exists for interventions when clearly linked to measurable recovery outcomes, fair application, and improved future fishing quality. This provides a strong social foundation for implementing targeted and regionally appropriate measures with a reasonable expectation of legitimacy, compliance, and effectiveness.

Overall, Sand Flathead in Tasmania now exist within a spatially structured and historically altered system shaped by long-term exploitation and size-selective fishing. Rebuilding will require management approaches that explicitly account for these dynamics, reduce fishing mortality, restore demographic structure, and remain supported by ongoing monitoring and adaptive decision-making. The framework developed through this project provides the necessary scientific foundation to support that transition and to restore the long-term sustainability, resilience, and social value of Tasmania's favourite recreational fishery.

12 Implications

The outcomes of this project have important implications for fisheries management, industry, the recreational sector, and the broader Tasmanian community. These arise from both an improved understanding of stock dynamics and the development of a cost-effective monitoring and assessment framework capable of supporting adaptive, evidence-based management.

For fisheries management, the project represents a transition from reliance on limited or potentially biased fishery- and age-based indicators toward a system grounded in fishery-independent monitoring and regionally structured assessment. This transition enables stock status to be interpreted using biologically meaningful indicators, including size structure, biomass, and spawning potential, rather than abundance alone. The clear spatial differences in stock condition, with relatively higher productivity in the north-east and pronounced depletion in south-eastern Tasmania, demonstrate that effective management will require regionally appropriate approaches rather than uniform statewide settings.

The evaluation of management scenarios further highlights that rebuilding will depend on reducing fishing mortality and restoring size structure, particularly in the most depleted regions. Importantly, the integration of human dimensions indicates that there is broad recognition among recreational fishers that the stock is in poor condition, particularly in the south-east, and general support for management action where it is clearly linked to recovery outcomes. Management effectiveness will thus depend not only on biological design, but also on transparent communication, credibility of evidence, and alignment with fisher values to support compliance and long-term behavioural change.

The monitoring regime developed through this project represents a significant advancement in capability. The combination of standardised fishery-independent surveys, biological sampling, and site-aware analytical approaches provides a repeatable and cost-effective system for tracking stock condition through time. This framework is sufficient to support adaptive management, including the evaluation of rebuilding trajectories and the implementation of management strategy evaluation to test alternative harvest strategies under uncertainty.

For the recreational sector, which dominates the fishery, the findings reinforce a shift from maximising catch quantity toward improving fishery quality. Reduced catch rates or access in the short term represent a cost, particularly in more heavily impacted regions. However, the longer-term fishery benefits of rebuilding include larger fish, more stable catch rates, and improved fishing experiences. Survey results indicate that fishers value both the experience of fishing and the quality of fish caught, and that stock recovery is likely to improve overall satisfaction.

For industry and the broader Tasmanian community, similar trade-offs apply. Short-term reductions in harvest opportunity may affect participation and associated expenditure in some regions, but these costs are likely to be outweighed by the longer-term benefits of a sustainable, resilient, and attractive recreational fishery. As Sand Flathead is one of Tasmania's most culturally recognised and widely accessed recreational species, its recovery carries broader social, tourism, and community value beyond direct harvest. It is also important to recognise that according to the last statewide assessment, Sand Flathead supported harvest levels an order of magnitude greater than any other recreationally retained species in Tasmania. As a result, rebuilding may be strengthened by encouraging diversification of recreational effort toward alternative species that are currently sustainable and capable of supporting quality fishing experiences. Supporting fishers to broaden skills, techniques, and target options can help maintain recreational amenity during the rebuilding period while reducing concentrated pressure on Sand Flathead. The recreational tackle and boating sectors are well placed to contribute to this transition through provision of information, gear, lures, and equipment that enable participation across a wider range of fisheries.

Overall, the project demonstrates that rebuilding Sand Flathead stocks is achievable, but only through a coordinated implementation of regionally appropriate management, lasting reductions in overall fishing mortality, restoration of demographic structure, strong compliance, sustained community engagement, and broader diversification of recreational opportunity. The scientific and monitoring framework developed here provides the foundation to support that transition.

13 Recommendations

The results of this project provide a clear and practical foundation for implementing an effective monitoring regime, stock assessment framework, and rebuilding strategy for Sand Flathead in Tasmania. Collectively, the evidence indicates that future management should be regionally structured, biologically informed, adaptive, and focused on reducing fishing mortality while restoring population structure and stock productivity.

A central recommendation is the ongoing implementation of the fishery-independent monitoring program as the primary basis for stock assessment. This should consist of standardised, regionally stratified surveys, with a core set of fixed indicator sites sampled consistently through time, complemented by a rotating set of additional sites to maintain broader spatial coverage and operational efficiency. Survey design should continue to prioritise the number of independent sites sampled, given the demonstrated importance of site replication for statistical precision. Sampling frequency should be sufficient to detect changes in size structure, abundance, and rebuilding trajectory, with annual or near-annual monitoring strongly recommended for south-eastern Tasmania where depletion is greatest and management sensitivity highest. Biological sampling should continue to collect length, sex, maturity, and age data to support refinement of model inputs and tracking of demographic recovery.

Fishery-dependent information should be retained as a complementary data source, particularly for biological sampling, fisher observations, and trends in catch experience, but should be interpreted cautiously and calibrated where possible against fishery-independent observations. In a recreationally dominated fishery, fishery-dependent data can provide valuable supplementary insight, but should not be relied upon as a primary basis for stock status inference.

The region-, sex-, and size-structured assessment framework developed through this project should serve as the basis for ongoing annual stock assessments. Continued refinement should include updated life-history parameters, selectivity assumptions, regional movement understanding, and sensitivity testing as new evidence becomes available. An important next step will be to advance the existing framework into a formal management strategy evaluation platform capable of testing alternative harvest strategies under uncertainty. Emphasis should be placed on representing spatial structure, size-selective fishing, fisher behaviour, compliance, and recruitment variability to ensure robust evaluation of rebuilding options.

Management should prioritise a substantial and sustained reduction in effective fishing mortality. This is the most important recommendation arising from the stock assessment. Given status estimates, all assessed regions other than Flinders Island remain depleted, with the most acute impacts in south-eastern Tasmania. Accordingly, rebuilding measures should be strongest in depleted south-eastern waters, while precautionary settings should remain in all other regions to support recovery and avoid further decline.

Restoration of size and age structure should be pursued alongside mortality reduction. Management should therefore maintain size-based regulations that protect both immature and mature fish, specifically large and highly fecund individuals, recognising that slot-limit design is likely to be critical to long-term rebuilding success. The current statewide slot limit provides a practical starting point, but future review of both lower and upper size thresholds is recommended. Consideration should be given to whether the current minimum size is unnecessarily high relative to maturity, whether too few fish presently reach the protected upper slot in depleted regions, and whether sexual dimorphism may create unintended female-biased harvest. Regionally optimised slot limits may ultimately improve outcomes, but simplicity, fisher understanding, and compliance must remain central considerations.

Management might also consider supporting the diversification of recreational fishing opportunity toward alternative species that are currently sustainable if this can measurably reduce impacts on Sand Flathead. Sand Flathead are harvested at rates substantially greater than any other species in Tasmania and reducing concentrated pressure on this stock is likely to be aided by encouraging broader participation across other fisheries. This may include education, promotion of alternative target species, and collaboration with tackle retailers, charter operators, and peak recreational bodies to support fishers in developing new skills, gear choices, and fishing opportunities while rebuilding progresses.

Importantly, management should be implemented within a regionally structured and adaptive framework that explicitly recognises the strong spatial variation in stock condition identified in this study. This includes prioritising rebuilding in the most depleted regions, maintaining stronger areas such as Flinders Island, and periodically reviewing settings as monitoring data indicate change.

Finally, successful implementation will require clear communication of stock status, management objectives, and expected outcomes. Complementary recent human dimensions research indicates that recreational fishers are more likely to support and comply with management measures when they are transparent, evidence-based, fairly applied, and clearly linked to improved fishery outcomes. Regular public reporting of stock status and rebuilding progress, combined with visible compliance effort and adaptive review, will be critical to maintaining trust and ensuring long-term effectiveness.

14 Further Development

While this project represents a substantial advancement in understanding and managing Sand Flathead, several areas require further development to fully support adaptive management and long-term recovery. Addressing these priorities will be critical to transitioning from a well-resolved diagnosis of stock status to a system capable of predicting, evaluating, and optimising recovery outcomes for the benefit of the Tasmanian community.

A key next step is development of integrated, time-dynamic stock assessment and management strategy evaluation frameworks that can incorporate multiple data sources and explicitly resolve changes in stock status through time. The approaches applied in this study provide strong inference on long-term fishing mortality, depletion, and spawning potential, but are inherently less sensitive to short-term dynamics and very recent management change. Future integrated models should combine fishery-independent survey data, updated biological parameters, and calibrated fishery-dependent information to estimate recruitment variability, temporal changes in fishing mortality, and rebuilding trajectories under alternative management scenarios. There is value in progressing from equilibrium-based assessment approaches toward bespoke temporally explicit models capable of simulating sex-specific size distributions, spatial structure, and responses to changing combinations of bag, boat, and size limits through time. Robust management strategy evaluation will be central to testing harvest control rules capable of recovering depleted stocks while maintaining long-term social and economic value.

Further refinement of the monitoring framework is also warranted. While the current survey design is effective, there is scope to improve efficiency and resolution through continued optimisation of indicator sites, reduction of redundant sampling, and refinement of regional stratification. Increased sampling intensity in south-eastern Tasmania should remain a priority given that these waters are the most depleted and most management sensitive. Continued biological sampling for length, age, sex, maturity, and reproductive condition remains essential for tracking demographic rebuilding and refining future assessments. There is also merit in expanding lightly exploited reference areas, including Flinders Island and other low-pressure regions, to strengthen understanding of unfished or lightly fished benchmarks.

Improved understanding of regional population dynamics also remains important. Strong regional differences in growth, maturity, size structure, and stock condition suggest that productivity is shaped by a combination of fishing pressure, environmental variation, and potentially density-dependent processes. Resolving the relative contribution of these drivers will require targeted analyses integrating biological datasets with environmental covariates and spatially explicit models. Additional movement and connectivity studies, including expanded passive tagging and citizen-science tagging partnerships, would further clarify the extent to which depleted areas can benefit from external recruitment subsidies versus requiring local rebuilding of spawning biomass. Population genetic analyses using contemporary genomic tools would also help resolve stock structure, demographic connectivity, and appropriate spatial scales for management. Further, genomic techniques may provide insight into adapted traits verifying size-selective restructuring of populations that may lead or have led to fisheries induced evolution in some regions.

Additional work is required to better quantify the relationship between size structure and reproductive output, and how this translates into recruitment and biomass production. This study demonstrates strong evidence of productivity impairment associated with size truncation, particularly through loss of larger females and older age classes. Future research should quantify size- and age-specific fecundity, spawning frequency, egg quality, larval success, and recruitment contribution across regions. This would improve reference point development and allow management to assess whether rebuilding is restoring true reproductive function rather than simply increasing abundance.

An important emerging area for future investigation is whether prolonged size-selective fishing has driven persistent biological change through phenotypic plasticity, fisheries-induced evolution, or both. The observed shifts in growth, maturation, and size structure are consistent with several possible mechanisms. Distinguishing among them is important because recovery expectations differ substantially. If responses are largely plastic, rebuilding of life-history traits may occur relatively quickly once fishing mortality is reduced. If heritable change has occurred, recovery may take longer and require more precautionary management settings. Comparative studies of fast- and slow-growing regional populations, including physiology, metabolism, thermal tolerance, swimming performance, behaviour, and capture vulnerability, would materially improve understanding of resilience and recovery potential.

These tools may also inform any future consideration of stock enhancement or translocation. For example, there may be interest in whether lightly exploited regions such as Flinders Island could contribute broodstock or demographic support to more depleted areas. However, such options should only be considered cautiously and after robust evaluation of stock structure, local adaptation, ecological risk, and long-term effectiveness. Without this information, translocation or selective enhancement could compromise locally adapted traits or create unsustainable short-term gains.

Climate change should also be incorporated more explicitly into future research and management. Tasmanian coastal waters are experiencing ocean warming that may influence growth, metabolism, reproductive timing, larval development, habitat use, and recovery potential. These pressures may be especially important in already depleted populations where reduced size and age diversity may have eroded resilience. Experimental and field-based studies examining thermal tolerance, condition, reproductive performance, and acclimation capacity under warming scenarios would materially strengthen future rebuilding planning.

There is also a continuing need to strengthen understanding of the human dimensions of the fishery. Complementary recent research has shown that fisher behaviour, compliance, effort redistribution, perceptions of fairness, and communication effectiveness are likely to strongly influence realised fishing mortality and rebuilding success. Future work should therefore include structured behavioural research, including experimental testing of stewardship messages, communication framing, and incentives that encourage voluntary reductions in fishing mortality and stronger compliance. Integrating these behavioural dynamics into future assessment and management frameworks will enhance the ability to design regulations that are both effective and socially durable.

Finally, diversification of recreational fishing opportunity should form part of the long-term rebuilding pathway. Sand Flathead are harvested at rates far exceeding any other species in Tasmania, and reducing concentrated pressure on this stock is likely to be aided by encouraging participation across other sustainable fisheries. Supporting fishers through education, tackle innovation, skills development, and promotion of alternative target species can help maintain recreational amenity while rebuilding proceeds. Industry, tackle retailers, charter operators, and recreational fishing organisations are well placed to assist this transition.

In summary, continued investment in monitoring, modelling, targeted biological research, stewardship, and adaptive management will be required to build on the strong foundation established by this project. Sand Flathead rebuilding is achievable, but will require sustained reductions in fishing mortality, restoration of demographic structure, regionally differentiated management, and long-term commitment to evidence-based decision-making. Advancing these priorities will maximise the ecological, social, and economic value of Tasmania's most iconic recreational fishery, with particular urgency in the most depleted south-eastern regions.

15 Extension and Adoption

This project was undertaken with a strong focus on ensuring that the outputs are not only scientifically robust, but also directly usable by managers, stakeholders, and the broader community. As such, extension and adoption have been built into the project throughout, rather than treated as an end point.

Engagement with fisheries managers at the Department of Natural Resources and Environment Tasmania (NRE Tas), has occurred consistently across the life of the project. This has included regular discussions around survey design, analytical approaches, and interpretation of results, as well as alignment of outputs with management needs. The project has also contributed to ongoing discussions through the Flathead for the Future program facilitated by NRE Tas, which has provided an important forum for sharing results and maintaining dialogue with both management and the recreational sector. This has included engagement with TARFish through this process, as well as a dedicated webinar presentation to recreational fishers and ongoing opportunities to share emerging findings. In addition, quarterly updates have been provided to management and peak bodies to ensure a high level of transparency as the project has progressed. Collectively, this has helped ensure that the research remains accessible and that there is a clear line of sight between the science, management considerations, and the fishing community.

There has also been a strong focus on engaging with the recreational fishing community, which is central to this fishery. Community-facing communication has been supported through platforms such as the Tasmanian Fish Frame Collection Facebook page, providing an accessible mechanism for sharing updates, improving awareness of stock status, and reinforcing key messages around fish size and sustainability. The intent has been to maintain openness in how results are communicated and to ensure that fishers are able to see how their fishery is changing over time.

The integration of human dimensions work alongside the biological and assessment components has importantly been reflected on in this this project. It has provided insight into fisher perspectives, including recognition of stock decline and views on potential management responses. This has helped ensure that the management scenarios developed are not only biologically sound but also grounded in an understanding of how they are likely to be received and adopted. In a predominantly recreational fishery, this alignment is critical to achieving effective outcomes. This is especially important when considering the risk of low compliance levels. Compliance is likely to be increased when the management decisions are based on readily understandable and effectively communicated decision-making, with minimised complexity.

In terms of adoption, the project is already influencing how Sand Flathead is being considered in a management context. The recognition of strong regional differences, the extent of depletion in the south-east, and the importance of size structure are now clearly informing discussions and management decisions around rebuilding. The monitoring and assessment framework developed here provides a practical pathway for embedding these insights into an ongoing, adaptive management cycle, including future use in management strategy evaluation and harvest strategy development.

Looking ahead, the main priority is to ensure that the monitoring program is maintained and that the assessment framework continues to be developed and applied. Continued engagement with managers and stakeholders will be important to support this, particularly as management responses evolve.

Overall, the project has delivered more than just improved understanding. It has provided a set of tools and approaches that can be applied directly to support the recovery and long-term sustainability of the Sand Flathead fishery in Tasmania.

16 Project coverage

Note: Links might not be attached or broken due to IMAS updating website and/or external links expiring.

16.1 Media Coverage

16.1.1 Media coverage 2025

- Coverage October: Sand flathead recreational fisher tagging program – rec fisher tagging trip (reel by Vertigo Visuals)
- Coverage September: Sand flathead tagging workshop for rec fishers to boost tagged fish numbers in our waters
- Coverage July: Sand Flathead Tag Lottery winners announced; Tagged fish program: Fresh season on the line | Carl Hyland | Mercury
- Coverage May: IMAS students catch and tag Sand flathead as part of their Marine Resources (Fisheries) major

16.1.2 Media coverage 2024

- Coverage December: Scalefish sustainability remains high but popular species are in decline (UTAS news); Scalefish assessment: Ruth Sharples in Tasmania's fish stocks under threat from overfishing | The Examiner TAS
- Coverage November: Sand flathead – IMAS mentions: TARFish CEO Jane Gallichan on ABC Mornings; Tasmanian writer in The only fish – by Ben Walter | Australian Literary Arts Magazine | ISLAND
- Coverage September and October: IMAS scientists cast line to capture recreational fishing trends (UTAS News); Recreational fishing survey, sand flathead and hatchery study funding: Sean Tracey on ABC News, Seven News, WIN News and ABC Radio Hobart; Young Tassie fishers participating at almost 20-year high, report finds | The Examiner; Tasmanian rec fishing survey finds increased participation - Fishing World Australia; National Tribune; ABC News Tonight; SEA FM Breakfast Radio news; Flathead's still on the menu: when a ban is not a ban | Tasmanian Country Newspaper; Investment into increasing sand flathead stocks in Tasmania - ABC News; Sand flathead feasibility study looks to boost declining population numbers in Tasmanian waters - ABC News; TARFish interview on ABC Radio Hobart (++) and Hatching a plan for flathead | Mercury; Workshop news – Alyssa Marshall and Nils Krueck: Researchers join capacity building workshop on Fisheries Science and Marine Protected Areas - Island Times
- Coverage June: Student Nic Shelverton was curious to know more about flathead tagged during a field trip – he recaptured 3 on a weekend fishing trip. This is what he discovered.
- Coverage May: Peter Coulson demonstrates flathead dissection & tagging at Agfest; IMAS fisheries students help researchers measure & tag over 250 Sand flathead in the Derwent to better understand their population dynamics

- Coverage April: Report your tagged sand flathead – and win; Sean Tracey on sand flathead recreational fisher research: ABC Country Hour
- Coverage March: Fisher insights to help shape Sand flathead stock recovery – IMAS News & pitched; Capturing the economic value of Tasmania's fisheries and aquaculture sectors – IMAS News; Flathead research – Sean Tracey: ABC Drive 28/3 (starts 35:15); Tasmanian recreational anglers key to sand flathead's future | The Chronicle (Mercury & syndicates) A Strong Plan to bring our Flatties back and support our wild fisheries | Tasmanian Liberals & Sunday Tasmanian story – 'A feed of MEDIA, COMMS & ENGAGEMENT MARCH 2024 Page | 3 flatties' no problem for anglers, vows Rockliff; Mirage News; IMAS Study: Sand flathead stock concerns among Tasmanian fishers | The Examiner | Launceston, TAS (+ Advocate)
- Coverage January: IMAS fisheries researchers worked with and learnt from pakana Sea Country Rangers in Tayaritja Milaythina Muka (Sea Country around the Bass Strait Islands)' Sean Tracey on sand flathead: Fishing limits hurt Tasmanian commercial fishers - ABC listen (national coverage); and with Swee-Hoon Chuah (COBE) on ABC Radio Hobart (national coverage); Peter Coulson demonstrates sand flathead dissection and tagging at Agfest; Sand flathead rec fisher research: Sean Tracey on ABC Country Hour, ABC Drive 28/3 (starts 35:15), Tasmanian recreational anglers key to sand flathead's future | The Chronicle, Fishing limits hurt Tasmanian commercial fishers - ABC listen

16.1.3 Media coverage 2023

- Coverage November: Joining forces for Sand Flathead recovery in Tasmania; Sean Tracey: Sand flathead Tasmania: IMAS receives $4.2m to save species as police pounce on anglers | Mercury ++; Tasmanian fish: Sand flathead subject to bag cuts to protect species | The Mercury; IMAS receives $3.29 Million grant for sand flathead research | The Examiner | Launceston, TAS – Sean Tracey and Swee-Hoon Chuah (COBE) on new flathead project: ABC Country Hour; ABC Rural (15:32–22:29); – IMAS mentions: Sand flathead: Flattie furore far from over | Opinion | The Mercury; Former Recreational Fishing Tasmania president, Don Paton, asks Tas govt to perform seal cull | The Mercury; New Rules For Recreational Fishers To Protect At Risk Populations Of Sand Flathead - Australian Business Journal (theabj.com.au)
- Coverage October: Sean Tracey on Govt new sand flathead rules announcement: ABC Mornings (30/10); New rules for recreational fishers to protect at risk populations of sand flathead - ABC News; Tasmanian fish: Sand flathead subject to bag cuts to protect species | The Mercury
- Coverage June: How IMAS researchers determine fish age (otoliths)—Sand flathead explainer series
- Coverage May: Sand flathead reels with James Hardy IMAS – biomass and growth stunting (reels by Tas Fisheries);
- Coverage April: Protecting fish stocks in TAS (IMAS; S Tracey); fisheries assessment (IMAS); Sean Tracey on science informing proposed new fishing conditions (see 'events' below): Tasmania's flathead are in decline and fishers told to take no more than ten | The Examiner | Launceston, TAS; ABC MEDIA & COMMUNICATION UPDATE APRIL 2023 Page | 2 Drive Northern Tas (starts 1:12:48). IMAS mentions and general media: Minister on ABC Drive Hobart (starts

44:14); Tasmanian Country; The Examiner; Burnie Advocate; Fisheries assessments: Tide of Public Opinion Backs the Science - The Australia Institute; Australia Institute releases results from fin-fish survey of Tasmanians | The Advocate | Burnie, TAS (and in the Mercury)

- Coverage March: Flathead: Have your say on flatties – Carl Hyland column in Mercury
- Coverage January: Sand flathead (K Fraser); sand flathead (N Krueck), Letter to Editor on flathead (IMAS); NRE flathead discovery days (IMAS); Nils Krueck / IMAS on scalefish assessment: Advocate & Examiner – Institute of Marine and Antarctic Studies releases latest scalefish assessment in Tasmania; Sand Flathead under threat (Mercury, Carl Hyland column 30/12/22); Fishing battle looms (Mercury + outlets); Fishing Tasmania hosts Flathead Discovery Day in Launceston | The Examiner

16.1.4 Media coverage 2022

- Taking stock of Tasmania's scalefish fishery (IMAS News)
- Coverage December: Scalefish assessment/sand flathead (N Krueck), Nils Krueck on scalefish assessment: ABC News and online; ABC Drive; FarmTable; MSN; VNexplorer; NewonNews and more
- Coverage August: Scientists assess southward-bound scalefish arriving in Tasmanian waters (IMAS News)
- Coverage July: ABC Rural: provided a full story list; southward-bound scalefish (A Graba-Landry)

16.2 Events and Engagement

16.2.1 2025

- From May 1–3, Jeff Ross, John Keane and Peter Coulson headed up to Agfest to join NRE Tas on their Fisheries site, with Inland Fisheries Service, FRDC, Tasmania Police and Biosecurity Tasmania. There were 13,701 visitors to the Fishing Hub site, and 55,560 visitors in total to Agfest this year.

- From February 7–10, our scientists and students were in outreach action at the Australian Wooden Boat Festival. We were at the Seafood Industry Tasmania and FRDC marquee talking giant crabs, scallops, oyster food safety, Long-spined Sea urchins, giant kelp restoration, and the technology we use to survey fish habitats – and our Tas Marine Atlas was available for visitors to dive into as well. Thanks to all involved, including John Keane, Scott Ling, Alyssa Marshell, Scott Hadley, Ryan Day, Alison Turnbull, Andrew Trotter, Peter Coulson, Ben Quigley, Rafael Leon Leiva, Myriam Lacharite, Cecilia Villaneuva, Olivia Johnson, Claire Hedges, Ernest Chuku and Matthew Cieslak for sharing their expertise with visitors.

16.2.2 2024

- In November and December, Alyssa Marshell presented at Fisheries Tasmania's Fishing Forums in Hobart (27 Nov) and Launceston (4 Dec) talking about the size distribution of sand flathead around the state. At the expo part of the evening, Sarah Ugalde was at both events to chat with fishers – with Samantha Twiname and Peter Coulson joining in at the Hobart session (see Fisheries Tas Facebook post)

- In late October, Alyssa also presented on sand flathead at the TAS Police Academy's annual forum.

- From May 2-5, IMAS Fisheries was 'in the field' at Agfest, joining NRE Tas at their site in the Marine Precinct. IMAS Senior Technical Officer Dr Peter Coulson & Field Technical Officer Lachlan George were on hand to talk to visitors about Tasmania's depleted and depleting fish stocks, especially Sand flathead, and how the community and fishers can help in stock recovery efforts. Our display included sand flathead sampling equipment, survey methods and fish specimens for identification, dissections and biological sampling.

16.2.3 2023

- On 27 November, our third Fisheries and Aquaculture forum was held at IMAS. These forums allow IMAS and NRE Tas to share knowledge on research and marine resource management. The theme for this forum was depleted fisheries, focusing on scalefish fishery research, management and engagement, and the State Government's new Scalefish Rules announced this month. IMAS presenters included Alyssa Marshell and Nils Krueck.

- On 4–5 August, scientists & students were talking all things marine science at BEAKER STREET'S ROVING SCIENTIST BAR at TMAG - Alyssa Marshell (scalefish & cephalopods).

- From May 4-6, our IMAS Fisheries and Aquaculture team were back in the paddock at AGFEST with NRE's Fisheries Tasmania Fishing Hub. Dr James Haddy showcased the science behind managing depleted fisheries, including Sand Flathead, while visitors also discovered how we age fish using their ear bones (otoliths) and watched flathead otolith extraction demos.

- On April 19, Sean Tracey attended an NRE Ministerial press conference in Launceston on launch of govt consultation for proposed new conditions for the recreational and commercial fishing of scalefish—Govt media release. Sean took questions on the science and IMAS fisheries assessments. See media above.

- On 14 March, Sean Tracey and James Haddy joined a live TARFish Q&A about the science around sand flathead's current status.

17 Project materials developed

Figure 80. The evolution of the Tassie Fish Frame Collection Program poster from 2021 to 2025 (left to right).

18 Appendices

Estimates of von Bertalanffy growth parameters varied systematically among regions and between model formulations (Table 33; Table 34). Constrained models ($t_0 = 0$) consistently produced lower asymptotic lengths (L_∞) and substantially higher growth coefficients (k) relative to unconstrained models, reflecting the influence of fixing the early growth trajectory in the absence of younger age classes. In contrast, unconstrained models yielded higher $L_\infty$and lower k, but frequently estimated strongly negative $t_0$values, often approaching model bounds, indicating limited information on early-life growth and instability in parameter estimation.

Table 33. Sex-specific von Bertalanffy growth parameters for sand flathead (*Platycephalus bassensis*) across surveyed Tasmanian regions, estimated using constrained models with $t_0 = 0$. Values shown are asymptotic length (L_∞, mm), growth coefficient (k), and sample size (n) for each region.

t_0 = 0 (constrained)	**Females**			**Males**		
Region	**n**	**L∞ (mm)**	**k**	**n**	**L∞ (mm)**	**k**
Channel	1036	305.8	0.537	399	273.2	0.608
Frederick Henry–Norfolk	884	331.3	0.485	578	292.4	0.584
Mercury Passage	305	339.7	0.619	103	308.7	0.709
Great Oyster Bay	1227	328.2	0.647	302	290.7	0.816
St Helens (Outside)	120	355.8	0.775	63	325.6	0.692
Flinders Island	273	486.2	0.320	145	390.2	0.379
Bridport	222	341.7	0.797	170	311.9	0.894
Tamar (Outside)	155	321.0	0.751	184	299.7	0.775
Stanley	253	373.9	0.422	147	316.7	0.511

Table 34. Sex-specific von Bertalanffy growth parameters for sand flathead (*Platycephalus bassensis*) across surveyed Tasmanian regions, estimated using unconstrained models with $t_0$fitted. Values shown are asymptotic length (L_∞, mm), growth coefficient (k), theoretical age at zero length (t_0), and sample size (n) for each region.

t0 = unconstrained	**Females**				**Males**			
Region	**n**	**L∞ (mm)**	**k**	**t_0**	**n**	**L∞ (mm)**	**k**	**t_0**
Channel	1036	340.3	0.236	-2.43	399	299.7	0.228	-3.50
Frederick Henry–Norfolk	884	388.9	0.200	-2.28	578	346.0	0.152	-5.00
Mercury Passage	305	431.0	0.135	-5.00	103	330.7	0.257	-3.71
Great Oyster Bay	1227	391.4	0.157	-5.00	302	310.3	0.233	-5.00
St Helens (Outside)	120	464.9	0.151	-4.32	63	353.2	0.285	-2.49
Flinders Island	273	621.1	0.102	-4.14	145	452.3	0.124	-5.00
Bridport	222	483.8	0.122	-5.00	170	357.3	0.197	-5.00
Tamar (Outside)	155	404.0	0.149	-5.00	184	336.2	0.197	-5.00
Stanley	253	617.0	0.072	-5.00	147	364.1	0.156	-4.51

Table 35. Results of Kruskal–Wallis tests assessing interannual variability in Sand Flathead age composition within Tasmanian survey regions, analysed separately for females (F) and males (M). Age (years) was treated as the response variable and survey year as the grouping factor. Significant results indicate that the distribution of age classes differed among years within a region–sex combination, reflecting temporal variation in cohort strength, mortality, recruitment, and/or sampling composition. Degrees of freedom (*df*), test statistic (χ^2), and associated *p*-values are shown.

Region	**Sex**	**Test**	***df***	**Statistic**	***p*-value**	**ΔAIC**	**Interpretation**
Channel	F	Age (KW)	4	χ^2 = 21.3	**<0.001**	–	Age differs among years
		Age × Year	4, 245	F = 3.92	**<0.01**	+18.6	Growth slopes differ
Channel	M	Age (KW)	4	χ^2 = 18.7	**<0.001**	–	Age differs among years
		Age × Year	4, 198	F = 3.45	**0.01**	+15.2	Growth slopes differ
Frederick Henry–Norfolk	F	Age (KW)	4	χ^2 = 19.8	**<0.001**	–	Age differs among years
		Age × Year	4, 210	F = 3.76	**<0.01**	+17.4	Growth slopes differ
Frederick Henry–Norfolk	M	Age (KW)	4	χ^2 = 17.2	**<0.01**	–	Age differs among years
		Age × Year	4, 185	F = 3.21	**0.02**	+13.8	Growth slopes differ
Mercury Passage	F	Age (KW)	4	χ^2 = 14.9	**<0.01**	–	Age differs among years
		Age × Year	4, 132	F = 1.21	0.30	+2.1	Slopes similar
		Year effect	4, 136	F = 4.12	**<0.01**	+11.5	Mean size differs
Mercury Passage	M	Age (KW)	4	χ^2 = 7.1	0.13	–	No age difference
		Age × Year	4, 120	F = 3.05	**0.02**	+12.2	Growth slopes differ
Great Oyster Bay	F	Age (KW)	4	χ^2 = 22.6	**<0.001**	–	Age differs among years
		Age × Year	4, 260	F = 4.10	**<0.001**	+21.3	Growth slopes differ
Great Oyster Bay	M	Age (KW)	4	χ^2 = 20.4	**<0.001**	–	Age differs among years
		Age × Year	4, 240	F = 3.88	**<0.01**	+18.9	Growth slopes differ
St Helens (Outside)	F	Age (KW)	3	χ^2 = 12.3	**<0.01**	–	Age differs among years
		Age × Year	3, 110	F = 3.02	**0.03**	+10.1	Growth slopes differ
St Helens (Outside)	M	Age (KW)	3	χ^2 = 10.5	**<0.05**	–	Age differs among years
		Age × Year	3, 95	F = 1.12	0.34	+1.5	Slopes similar
		Year effect	3, 98	F = 0.89	0.45	+0.8	No growth difference
Flinders Island	F	Age (KW)	4	χ^2 = 5.2	0.27	–	No age difference
		Age × Year	4, 170	F = 0.94	0.44	+0.6	Slopes similar
		Year effect	4, 174	F = 0.88	0.48	+0.4	No growth difference
Flinders Island	M	Age (KW)	4	χ^2 = 4.7	0.32	–	No age difference
		Age × Year	4, 150	F = 0.91	0.46	+0.5	Slopes similar

		Year effect	4, 154	F = 0.85	0.50	+0.3	No growth difference
Bridport	F	Age (KW)	4	χ^2 = 16.8	**<0.01**	–	Age differs among years
		Age × Year	4, 180	F = 1.35	0.25	+3.2	Slopes similar
		Year effect	4, 184	F = 3.98	**<0.01**	+12.6	Mean size differs
Bridport	M	Age (KW)	4	χ^2 = 15.9	**<0.01**	–	Age differs among years
		Age × Year	4, 165	F = 1.22	0.30	+2.5	Slopes similar
		Year effect	4, 169	F = 3.54	**0.01**	+10.9	Mean size differs
Tamar (Outside)	F	Age (KW)	4	χ^2 = 17.5	**<0.01**	–	Age differs among years
		Age × Year	4, 155	F = 1.41	0.23	+3.8	Slopes similar
		Year effect	4, 159	F = 3.77	**<0.01**	+11.8	Mean size differs
Tamar (Outside)	M	Age (KW)	4	χ^2 = 16.2	**<0.01**	–	Age differs among years
		Age × Year	4, 140	F = 1.30	0.27	+2.9	Slopes similar
		Year effect	4, 144	F = 3.61	**<0.01**	+10.7	Mean size differs
Stanley	F	Age (KW)	4	χ^2 = 14.3	**<0.01**	–	Age differs among years
		Age × Year	4, 130	F = 1.28	0.28	+2.6	Slopes similar
		Year effect	4, 134	F = 3.44	**0.01**	+9.8	Mean size differs
Stanley	M	Age (KW)	4	χ^2 = 6.5	0.16	–	No age difference
		Age × Year	4, 120	F = 3.08	**0.02**	+11.9	Growth slopes differ

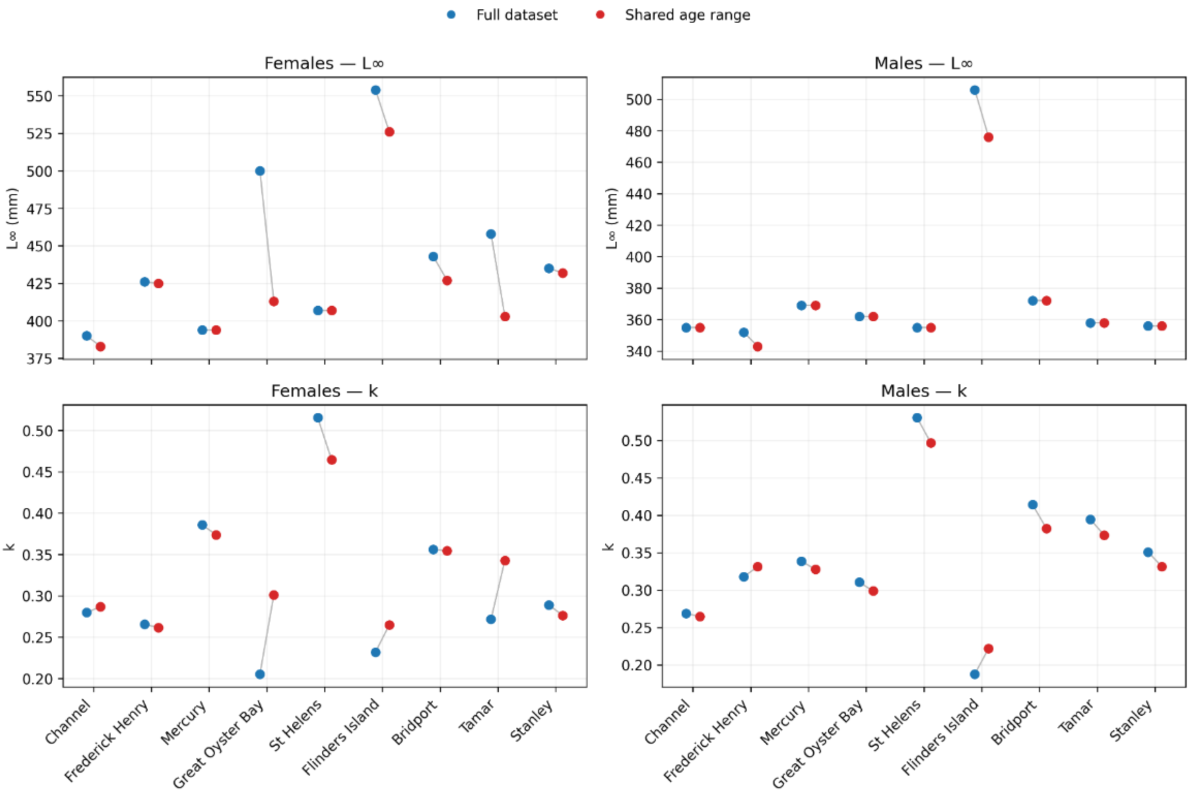


Figure 81. Comparison of constrained t_0 = 0 von Bertalanffy growth parameters estimated from full datasets and from data restricted to the age range shared across all regions for Sand Flathead. Panels show asymptotic length (L_∞) and growth coefficient (k) for females and males across nine regions around Tasmania. Points represent parameter estimates for each region, with paired values connected by lines to illustrate changes between full and shared age-range models. Shared age ranges were 2.15–8.55 years for females and 2.35–10.46 years for males.

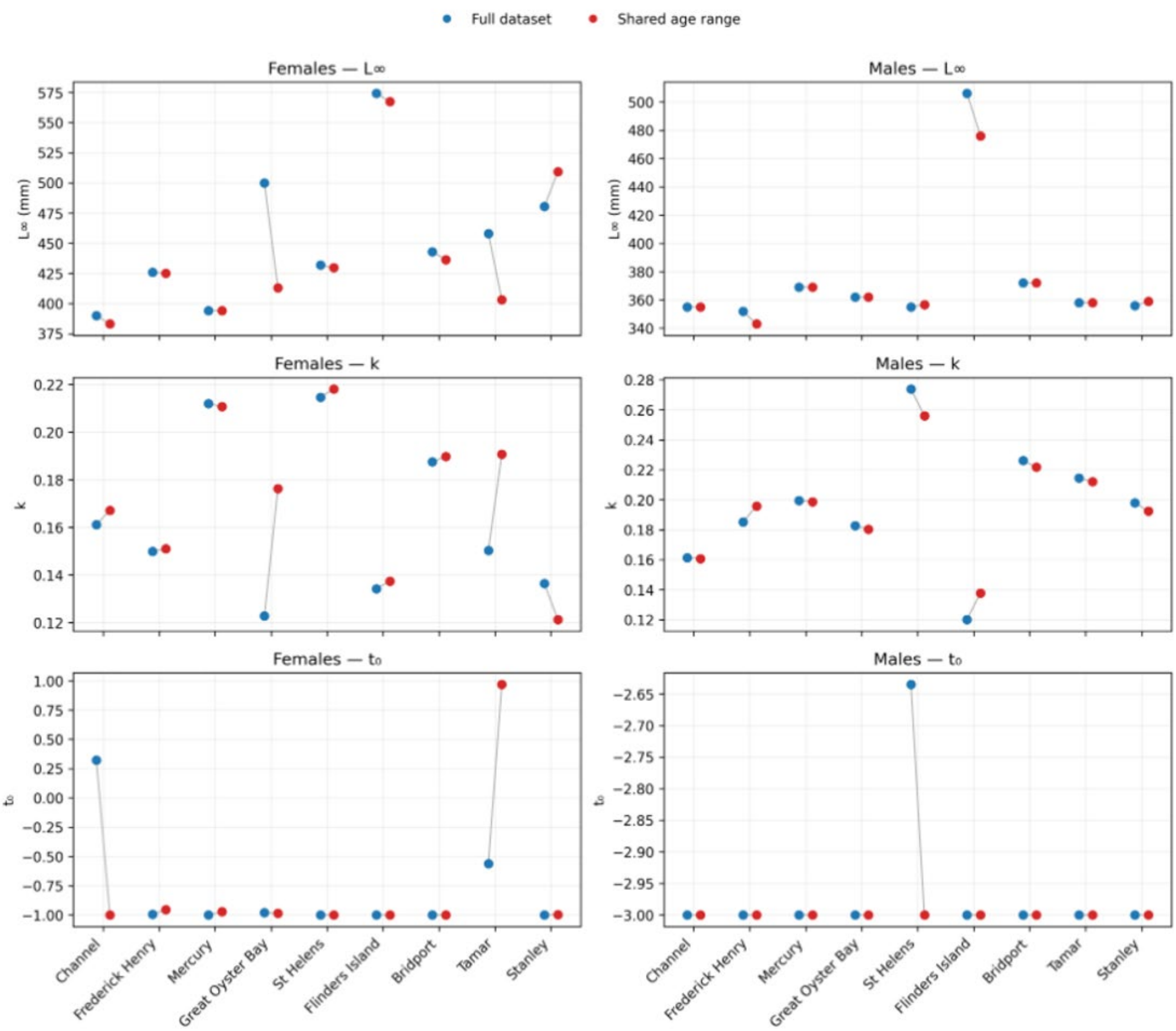


Figure 82. Comparison of von Bertalanffy growth parameters estimated from full datasets and from data restricted to the age range shared across all regions for Sand Flathead, using unconstrained growth models (t_0 estimated). Panels show asymptotic length (L_∞), growth coefficient (k), and theoretical age at zero length (t_0) for females and males across nine regions. Points represent parameter estimates for each region, with paired values connected by lines to illustrate differences between full and shared age-range models. Shared age ranges were 2.15–8.55 years for females and 2.35–10.46 years for males.

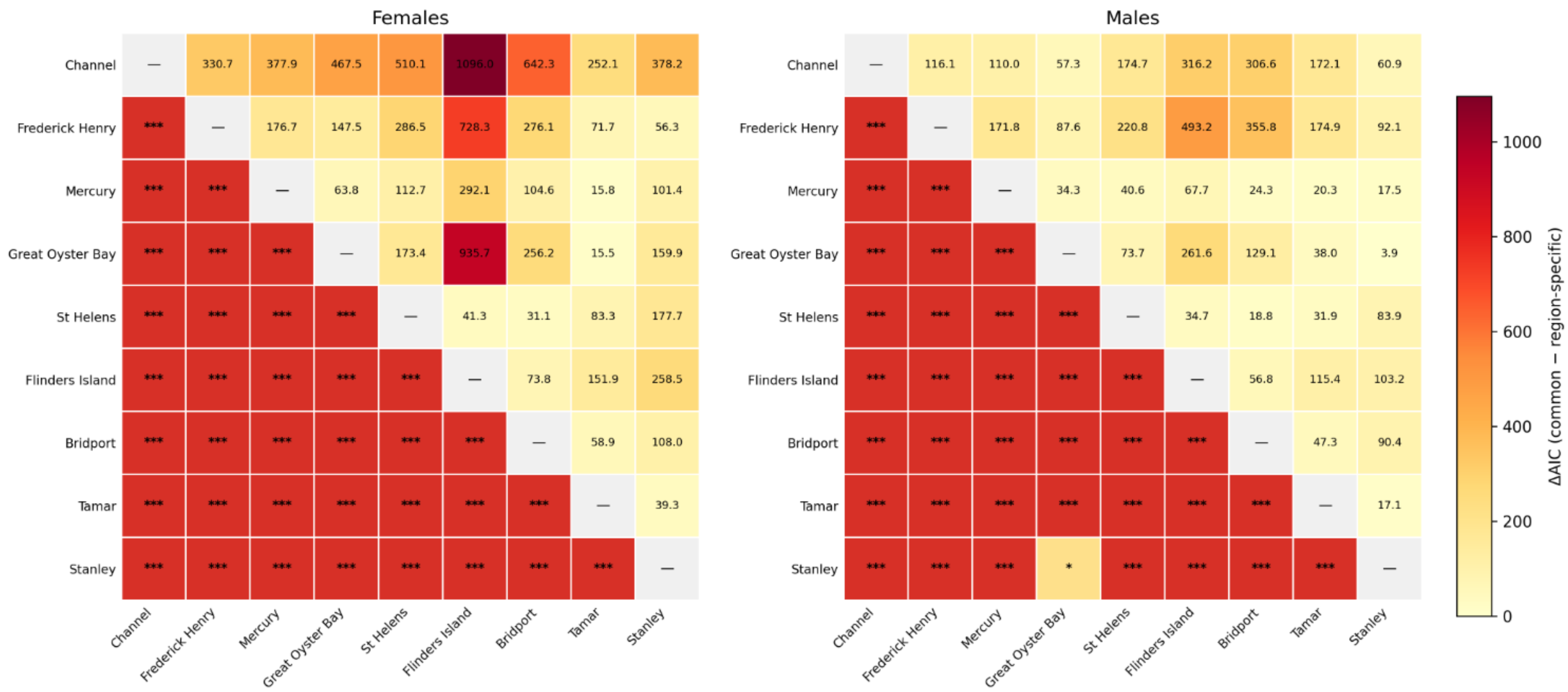


Figure 83. Pairwise comparisons of constrained von Bertalanffy growth curves among regions for sand flathead, shown separately for females and males, using only fish within the age range shared across all regions. The lower triangle displays the significance of likelihood ratio tests (LRTs) comparing a common growth model versus a region-specific model, with significance levels indicated as *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$), and ns (not significant). The upper triangle shows differences in Akaike Information Criterion (ΔAIC; common − region-specific), where positive values indicate stronger support for region-specific growth.

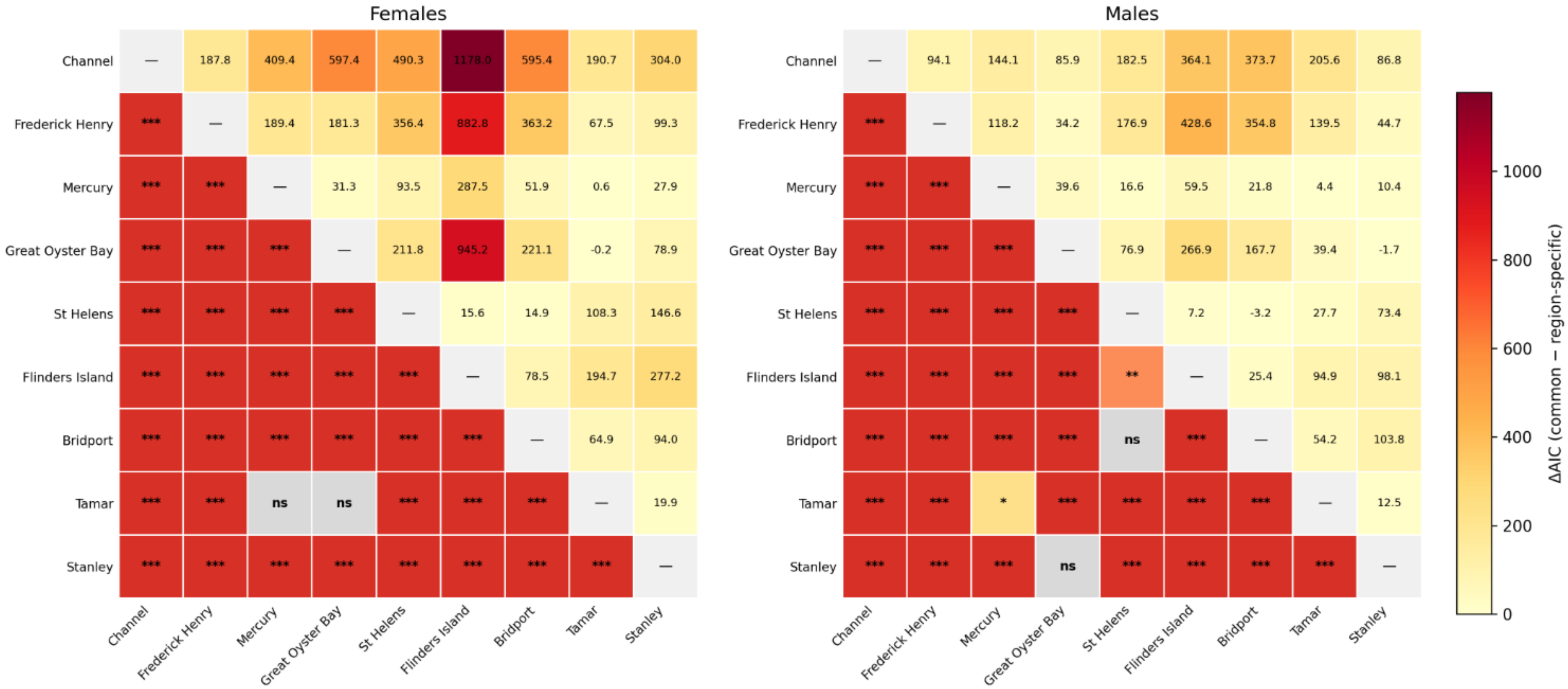


Figure 84. Pairwise comparisons of unconstrained von Bertalanffy growth curves among regions for sand flathead, shown separately for females and males, using only fish within the age range shared across all regions. The lower triangle displays the significance of likelihood ratio tests (LRTs) comparing a common growth model versus a region-specific model, with significance levels indicated as *** (p < 0.001), ** (p < 0.01), * (p < 0.05), and ns (not significant). The upper triangle shows differences in Akaike Information Criterion (ΔAIC; common − region-specific), where positive values indicate stronger support for region-specific growth.

Comparison growth of individuals within estuary and adjacent regions

Across both regions, fish from estuarine sites generally exhibited lower asymptotic lengths (L_∞) than those from adjacent coastal sites, indicating reduced maximum size in estuarine environments (Appendix Figure 85; Appendix Figure 86). In some cases, estuarine fish also displayed relatively higher growth coefficients (k), consistent with faster early growth but earlier asymptotic attainment.

Unconstrained models occasionally produced biologically unrealistic parameter estimates (e.g., extreme L_∞ or strongly negative t_0), particularly for the Tamar region, suggesting reduced stability of these models when early age classes were under-represented. Consequently, the constrained formulation (t_0 = 0) was considered the more robust basis for inference.

These results demonstrate that growth patterns of sand flathead differ between estuarine and coastal environments. Accordingly, estuarine sites within the Tamar River and St Helens (Georges Bay) regions were excluded from subsequent regional analyses, and only coastal sites were retained. Hereafter, the retained coastal regions are referred to as "Tamar" and "St Helens", respectively.

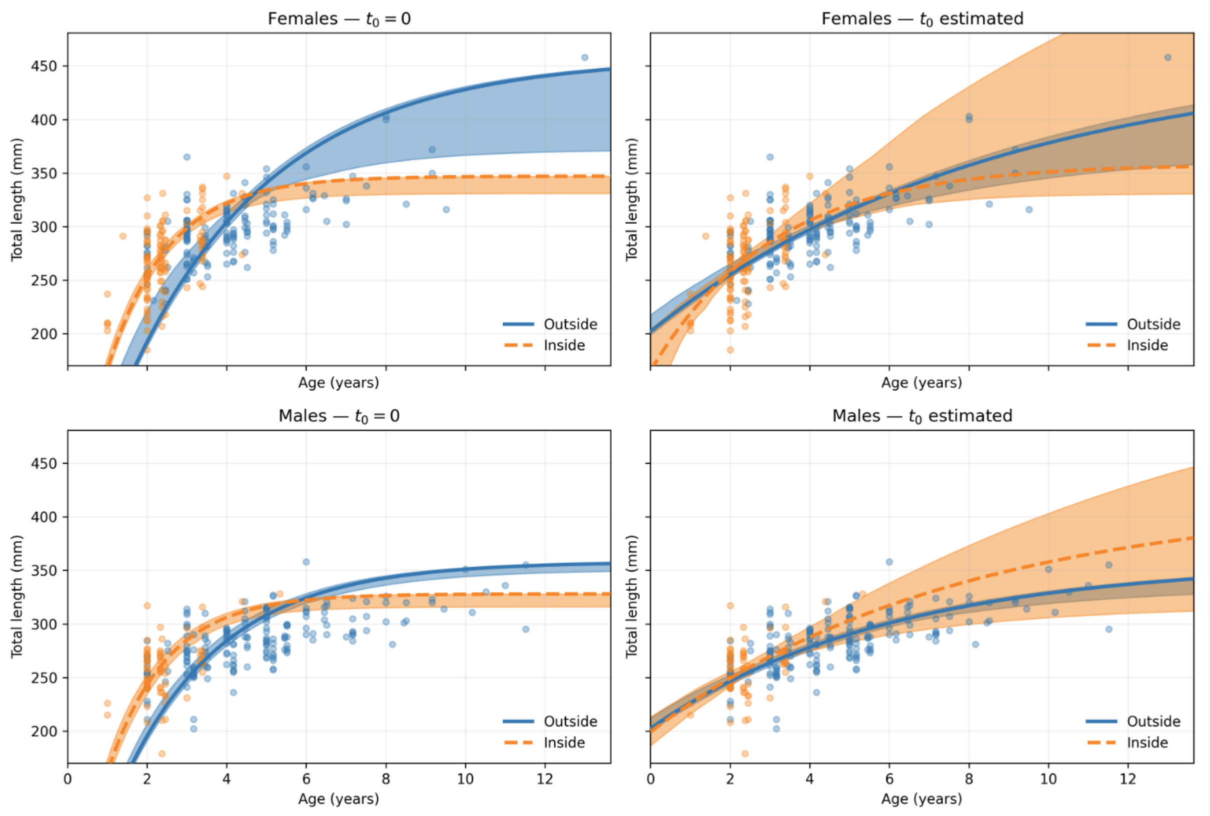


Figure 85. Sex-specific von Bertalanffy growth curves for Sand Flathead from inside (estuarine) and outside (coastal) sites in the Tamar region. Panels show females and males under constrained (t_0 = 0) and unconstrained (t_0 estimated) model formulations. Points represent observed length-at-age data, solid lines represent fitted growth curves for coastal (outside) sites, and dashed lines represent estuarine (inside) sites. Shaded ribbons indicate 95% confidence intervals around fitted growth curves.

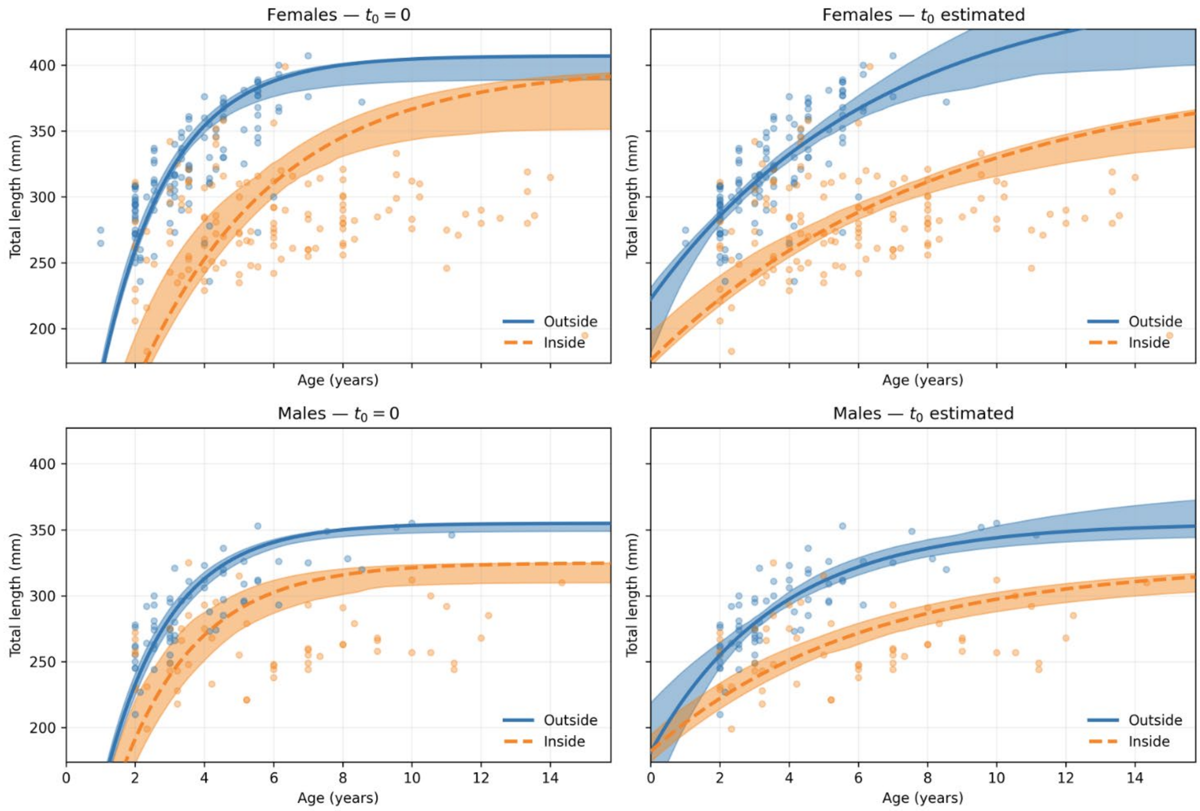


Figure 86. Sex-specific von Bertalanffy growth curves for Sand Flathead from inside (Georges Bay) and outside (coastal) sites in the St Helens region. Panels show females and males under constrained (t_0 = 0) and unconstrained (t_0 estimated) model formulations. Points represent observed length-at-age data, solid lines represent fitted growth curves for coastal (outside) sites, and dashed lines represent Georges Bay (inside) sites. Shaded ribbons indicate 95% confidence intervals around fitted growth curves.

18.1 Survey Design Diagnostics, Statistical Methods and Supporting Analyses for Fishery-Independent Monitoring of Sand Flathead

18.1.1 Methods

Fishery-independent gillnet surveys undertaken between 2012 and 2025 across Tasmanian coastal regions generated the length-frequency dataset used to evaluate survey design performance and alternative spatial monitoring structures. Individual Sand Flathead lengths (total length, mm) were recorded from standardised net sets and collated across years, sites and regions. For these analyses, data were recognised as hierarchically structured, with individual fish sampled within sites, sites nested within regions, and regions sampled within survey years. This nested structure was explicitly considered throughout all subsequent analyses because fish captured from the same site are not statistically independent.

Prior to analysis, datasets were screened for transcription errors, implausible values and duplicate records. Length data formed the primary response variable because they represented the most complete and consistent long-term biological dataset available across the monitoring program.

18.1.1.1 Intraclass Correlation Coefficients and Design Effects

To inform subsequent analyses, we assessed the fisheries independent survey's design effect. Because the independent survey is hierarchically structured with fixed sites sampled within each region, the proportion of variance in Sand Flathead lengths attributable to the site level influences the amount of unique information obtained from the survey. Higher site-level correlation reduces the effective sample size. This is known as the design effect, which must be accounted for when analysing region-level trends in Sand Flathead lengths.

We used two complimentary metrics. The first is intra-class correlation (ICC; ρ), which measures the proportion of total variance attributable to differences among sites within a region. Typical cut-offs for where ICC is substantial enough to require consideration in analysis are suggested at ρ = 0.05–0.20 and should be considered at ρ > 0.2.

The second is Design Effect (DEFF), which quantifies the inflation of sampling variance due to clustering (i.e., of length samples collected at discrete sites within each survey region). DEFF represents how much smaller the *effective* sample size is relative to the nominal sample size. For example, a DEFF of 2 implies that 1,000 length measurements within a region provide the same information as 500 independent samples, due to the hierarchical survey design.

Letting $\bar{m}$ be the average number of observations per cluster (e.g. mean number of fish per site), the general relationship between ICC (ρ) and DEFF is:

$$\mathrm{DEFF} = 1 + (\bar{m} - 1)\,\rho,$$

We undertook three analyses to estimate these metrics, each corresponding to a different aspect of survey length analysis investigating in this chapter: i) Site-level ICCs estimated from intercept-only mixed effect models of mean length; ii) Quantile-specific ICCs of Sand Flathead length frequencies; and iii) Implied DEFF from site-bootstrapped Wasserstein distance pairwise comparisons.

Site-level ICCs from mixed-effects models of Sand Flathead length (per-region, per-FY): Intraclass correlation coefficients (ICCs) were estimated separately for each region using intercept-only linear mixed-effects models fitted to individual Sand Flathead lengths. Models took the form

$$\text{length}_{is} \sim 1 + (1 \mid \text{site}_s),$$

and were fitted using the *lme4* package.

Let σ^2_{site} denote the between-site variance component and σ^2_{ϵ} the within-site (residual) variance component estimated from the model. The ICC was calculated as the proportion of total variance attributable to differences among sites:

$$\rho = \frac{\sigma^2_{\text{site}}}{\sigma^2_{\text{site}} + \sigma^2_{\epsilon}}$$

Quantile-based ICC of Sand Flathead length distributions (per-region, per-FY): As the degree of correlation between sites may vary across important quantiles of regional length frequencies (e.g., the median size $Q_{0.50}$ or $Q_{0.90}$ i.e., presence of large fish), we also estimated ICC across length distributions. We estimated a quantile-specific ICC curve $\rho(p)$ as follows: for each of 50 positions p across the curve $(0,1)$, site-level quantiles $Q_s(p)$ were estimated.

To account for differences in the number of length samples at each site s, site weights $w_s$were calculated as the relative proportion of observations at each site. Let n_s denote the number of observations at site s; then

$$w_s = \frac{n_s}{\sum_s n_s}.$$

The regionally weighted mean quantile at each probability level $p$was calculated as

$$\mu_p = \sum_s w_s \, Q_s(p),$$

and the between-site variance at each p as

$$\text{Var}_{\text{between}}(p) = \sum_s w_s \left(Q_s(p) - \mu_p\right)^2.$$

Within-site variance was estimated by bootstrap resampling. For each of $B = 1{,}000$ bootstrap iterations b, lengths within each site were resampled with replacement and site-specific quantiles $Q_s^{(b)}(p)$ were calculated. Site-specific within-site variance was then estimated as

$$v_s(p) = \text{Var}\left\{Q_s^{(b)}(p)\right\}_{b=1}^{B}.$$

These site-specific variances were combined using the original weights to obtain the overall within-site variance at each p:

$$\text{Var}_{\text{within}}(p) = \sum_s w_s \; v_s(p).$$

Finally, the quantile-specific intraclass correlation coefficient (ICC) was calculated as

$$\rho(p) = \frac{\text{Var}_{\text{between}}(p)}{\text{Var}_{\text{between}}(p) + \text{Var}_{\text{within}}(p)}.$$

For each region, $\rho(p)$ across the full distribution curve was summarised over fishing years and plotted. Values of $\rho(p)$ near 0 indicate little site-level clustering at quantile p, whereas values near 1 indicate strong clustering. Differences in $\rho(p)$ across p reveal where in the length distribution (e.g., lower, median, upper tails) site effects are most pronounced.

Implied DEFF from site-bootstrapped Wasserstein distance pairwise comparisons (per-region pair, per-FY): This approach exploits differences in uncertainty associated with Wasserstein distance (W_1) comparisons between regions when site structure is either accounted for or ignored. For each pair of regions compared within a fishing year, W_1 distances and their 95% confidence intervals (CIs) were estimated using (i) site-aware permutations ($W_{1,\text{clus}}$) and (ii) individual-level permutations that ignored site effects ($W_{1,\text{ind}}$).

Standard errors for each estimate were approximated by treating the 95% CIs as arising from a two-sided normal distribution, such that

$$\text{SE} = \frac{CI\ width}{2z_{\alpha/2}}$$

where $\alpha = 0.05$ and $z_{\alpha/2}$ is the corresponding standard normal quantile. The implied design effect was then calculated as the ratio of variances of the standard errors obtained with and without accounting for site effects:

$$\text{DEFF} = \left(\frac{\text{SE}_{\text{ind}}}{\text{SE}_{\text{clus}}}\right)^2$$

Implied DEFF estimates were subsequently collated across fishing years and region pairs.

18.1.1.2 Wasserstein Distance Comparisons

Regional and temporal differences in Sand Flathead length-frequency distributions were quantified using the first Wasserstein distance (W_1), also known as the earth mover's distance. Conceptually, W_1 represents the average distance (in mm) that individuals in one length distribution would need to be shifted to match another, providing a metric that is directly interpretable in length units.

Formally, for two empirical cumulative distribution functions (ECDFs), $F(x)$ and $G(x)$,

$$W_1(F, G) = \int_{-\infty}^{\infty} |\, F(x) - G(x) \,|\ dx.$$

Unlike rank-based metrics such as the Kolmogorov–Smirnov statistic, W_1 integrates differences across the full length range and therefore captures changes in overall size structure rather than being dominated by central tendencies.

Pairwise W_1 distances were calculated using the wass_stat() function from the R package *twosamples* for all region pairs of interest within each fishing year (FY). Sampling variability was quantified using a site-level bootstrap that respected the nested survey design. Specifically, individuals within each sampled site were resampled with replacement for 2000 bootstrap resamples and 95% confidence intervals were estimated from the 2.5th and 97.5th percentiles of the bootstrapped W_1 distribution.

Statistical significance of regional differences was assessed using a site-level permutation test. For each region-pair comparison, sites were randomly reassigned between regions without replacement while preserving the original number of sites per region. This procedure generates a null distribution of W_1 values under the hypothesis that observed differences arise solely from random allocation of sites rather than true differences in length structure. Two-sided p-values were calculated as the proportion of permuted W_1 values that were as extreme or more extreme than the observed W_1. P-values were adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate procedure (Benjamini and Hochberg, 1995) within each family of tests (e.g. among region pairs within a FY or among FY pairs within a region).

Pairwise W_1 estimates and associated 95% confidence intervals were examined across a series of spatial and temporal contrasts, including comparisons among regions within fishing years and among fishing years within regions, with results summarised graphically to highlight both the magnitude and stability of length-frequency differences over time.

18.1.1.3 Principal Components Analysis

As a complementary approach to comparing W_1 distance between regional length distributions, which provides a single value that incorporates the entire length frequency, we applied a multivariate ordination base on lengths from each region each FY to characterise how Sand Flathead length frequency shapes vary between regions and financial years.

For each FY, individual fish lengths were grouped into 10-mm bins to form regional length-frequency tables. Length-frequencies were first Hellinger-transformed, which is equivalent to the square root of the proportion of lengths in each bin, which scales each length frequency to unit Euclidean norm (i.e., a total of 1) for suitability for ordination. This down-weights very large bins while preserving relative differences in length frequency shape.

A principal components analysis (PCA) was then carried out on the Hellinger-transformed length-frequency matrix (region-FY x length bin). The amount of variance explained by each principal component (PC) was calculated, and region-FY length frequencies were plotted on a biplot of the first two PCs. This allows separation in length frequency composition among regions and FYs to be discerned: points that are close together represent regions with similar binned length structures, whereas distant points indicate stronger differences.

For length frequency data, this technique often captures changes in median of length frequencies on the first principal component (PC1; biplot x axis) and changes in width/variance on PC2 (biplot y axis). To aid interpretation, the length frequency shapes associated with PC1 and PC2 were reconstructed by projecting the PCA loadings back-transformed into the 10-mm length frequency space at -1 and +1 standard deviation along both PC1 and PC2. These reconstructed “eigen” length frequencies represent the characteristic length-frequency patterns that best explain differences among regions and provide a guide to interpretation of changes in length frequency shape across the ordination biplot.

18.1.1.4 Linear Mixed-Effects Models

Temporal trends in fish length were examined using linear mixed-effects models fitted to annual survey data. While the previous W_1 distance tests provide pairwise tests of differences between regions incorporating the entire length frequency, here we use parametric tests with a focus on central tendency to test for continuous trends over time. All models were fit with the R package *lme4* (Bates et al., 2015) using the Nelder–Mead optimiser and restricted maximum likelihood (REML).

The general form of the model was:

$$Length_{ij} = \beta_0 + \beta_1 Year_{ij} + b_{0j} + b_{1j} Year_{ij} + \epsilon_{ij}$$

where:

- β_0, β_1 are fixed intercept and slope terms
- b_{0j}, b_{1j} are region-specific random intercepts and slopes
- ϵ_{ij} is residual error

Competing random-effects structures included:

1. random intercept only
2. random intercept + slope
3. correlated random intercept + slope

Models were compared using Akaike Information Criterion (AIC), likelihood ratio tests (after refitting with maximum likelihood) with r package *lmerTest* (Kuznetsova et al., 2017). The most strongly supported structure was retained for inference.

Type III ANOVA with Satterthwaite-approximated degrees of freedom was used to test for the significance of each fixed effect of the best model. The emtrends() function from r package *emmeans* (Lenth, 2023) was used to estimate regional slopes (i.e., changes in mean length over time) with Kenwood-Roger approximated degrees of freedom, and test for overall significance (i.e., omnibus hypothesis that slopes are not equal to 0). If an effect was present, Tukey-adjusted pairwise differences in slopes were estimated. Regional estimated marginal means and 95% CIs were plotted to visually represent regional mean differences and linear trends in length (or their absence) over time.

18.1.1.5 Quantile Generalised Additive Models

To examine changes in multiple positions of the length-frequency distribution and assess whether regional trends in length were nonlinear through time, we fitted multi-quantile generalized additive mixed models (MQGAMs). This complementary approach provides insight into whether changes in mean length are driven by shifts in central tendency, truncation of larger individuals, or changes in the lower tail of the size distribution.

Models were fitted using the *qgam* package in R (Fasiolo et al., 2021). Rather than modelling the conditional mean, MQGAMs estimate specified conditional quantiles of the response. We modelled the τ = 0.1, 0.5, and 0.9 quantiles of individual Sand Flathead lengths, corresponding to the 10th percentile, median, and 90th percentile of the annual length-frequency distribution.

For quantile level τ, the general model form was:

$$Q_\tau(\text{Length}_{isry}) = \alpha_{\tau,r} + f_{\tau,r}(\text{Year}_y) + b_{\tau,s},$$

where:

- $Q_\tau(\cdot)$ is the conditional quantile at level τ,
- $\alpha_{\tau,r}$ is a fixed intercept for region r,
- $f_{\tau,r}$(Year) is a smooth function of year, potentially varying by region,
- $b_{\tau,s}$ is a random intercept for site s.

For the long-term regional subset, region-specific smooths of year were fitted using adaptive smoothing splines, allowing the degree of smoothness to vary through time and enabling the model to capture nonlinear or abrupt changes in length structure. In this subset, the learning parameter was allowed to vary with year to accommodate temporal heterogeneity in variance.

For the shorter, expanded regional subset, year was modelled using a thin-plate regression spline with a common smoothing structure across regions. In all models, site was included as a random intercept to account for within-site dependence in individual lengths.

Models were fitted using restricted maximum likelihood (REML). Basis dimension (kkk), representing the maximum allowable wiggliness of the year smooths, was selected by comparing REML scores across candidate models with varying kkk. Values of k=10k = 10k=10 were selected for the long-term regional subset, and k=5k = 5k=5 for the expanded subset.

Regional estimated marginal means predicted from QGAMs were plotted for each subset at each quantile along with their 95% credible intervals to allow for inference into trends across quantiles within regions and among regions, with the site terms excluded to provide standardised region-level predictions for inference.

18.1.1.6 Evaluation of Regional Pooling Scenarios

Alternative regional pooling scenarios were evaluated to determine whether adjacent survey regions could be combined into broader monitoring sectors without substantial loss of biological information. Candidate structures were guided by region-level analysis results and included three-sector and four-sector formulations.

Pooling scenarios were assessed using multiple criteria, described above for the region-level analyses:

1. within-group Wasserstein similarity
2. coherence of temporal trends
3. mixed-model fit statistics (AIC and likelihood ratio tests)
4. biological interpretability relative to known regional stock structure

The preferred grouping was that which retained meaningful spatial contrasts while reducing unnecessary fragmentation of neighbouring regions with similar dynamics or obscuring meaningful trends by pooling dissimilar neighbouring regions.

These supplementary analyses were intended to support optimisation of the fishery-independent monitoring program and interpretation of regional trends, rather than replace formal stock assessment modelling.

18.1.2 Results

This section includes results that were not presented in the main chapter (Section 6.2.3).

18.1.2.1 Clustered sampling diagnostics

Quantile-specific ICC estimates showed that within-site clustering was typically weakest around the median of the length distribution and strongest at the lower and upper quantiles (Appendix Figure 87). This indicates that localised sites often contained concentrations of similarly sized small or large fish, whereas mid-sized fish were more evenly distributed among sites.

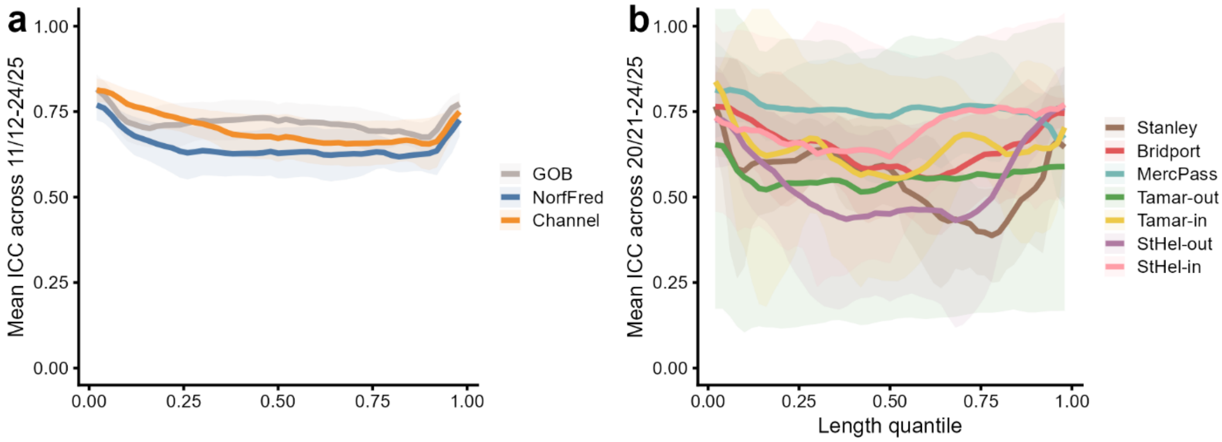


Figure 87. Quantile-specific intraclass correlation (ICC) summarised across financial year by region for long-term (a) and expanded (b) survey regions. Bands represent bootstrapped confidence intervals.

Across pairwise regional annual comparisons, DEFF values were commonly between 2 and 4, with occasional values exceeding 5 in lower-sample years or where site-level clustering was pronounced (Appendix Figure 88). These higher values were generally associated with fewer sampled sites and greater variability in samples per site.

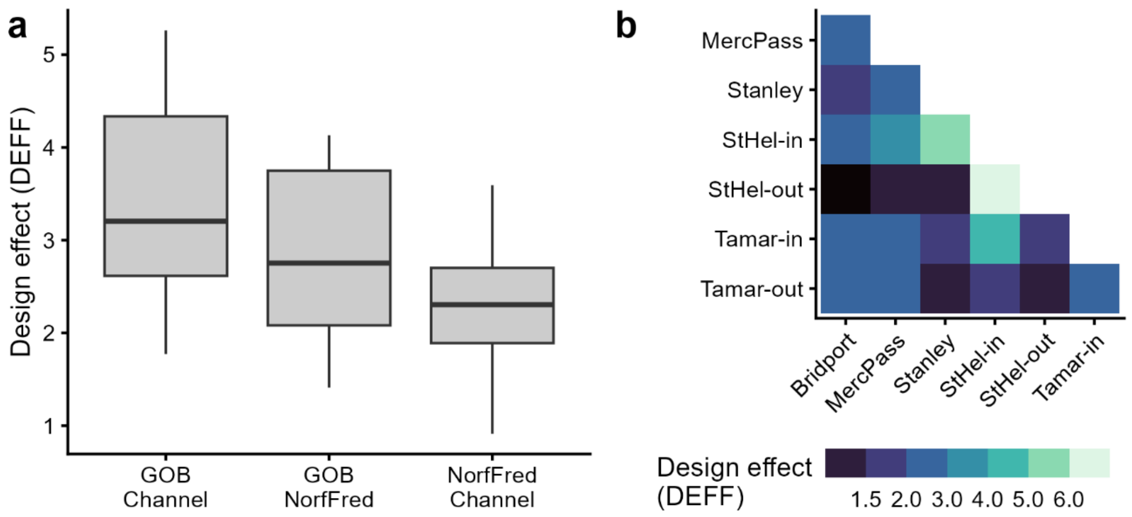


Figure 88. Implied design effect (DEFF) derived from pairwise Wasserstein distance confidence intervals calculated with and without site-structured bootstrapping for the long term (a) and expanded (b) survey sites. DEFF is equivalent to how much smaller the effective sample size of a comparison is than the total sample size due to correlation of Sand Flathead lengths among sites within regions.

The relationship between ICC, mean cluster size and DEFF (see definition in Section 19.1.1.1) indicates that survey precision can be improved through increasing the number of independent sites in regional strata, while diminishing returns would be gained by increasing sampling at existing survey sites.

18.1.2.2 Supporting regional comparisons in length composition

Principal components analysis (PCA) provided a complementary, multivariate perspective on regional differences in LF structure. The first two principal components explained 42.4% and 12.1% of variance, respectively, with PC1 representing shifts in overall size and PC2 representing changes in distribution spread, followed by PC3-5 with 6.6%, 5.1% and 4.8%).

The reconstructed length frequencies at +/- 1 standard deviation of the first two principal components (Appendix Figure 89, *bottom*) reveal that PC1 captures a shift in overall lengths within regional LF samples (i.e., LFs are smaller to larger overall when moving from left to right on the x axis of the biplot, Appendix Figure 89, *top*). PC2 captures a shift from lesser to greater variance (i.e., LFs are narrower to broader overall when moving from bottom to top of the biplot).

Estuarine samples from Tamar Inside and St Helens Inside were positioned separately from adjacent coastal samples, consistent with their differences in both overall size and breadth of length frequencies (Appendix Figure 90a; Figure 90b). By contrast, the southeast regions Frederick Henry-Norfolk Bays and Channel, and the east coast regions Great Oyster Bay and Mercury Passage were both highly consistent in both overall size and length frequency shape (Appendix Figure 90b; Figure 90c).

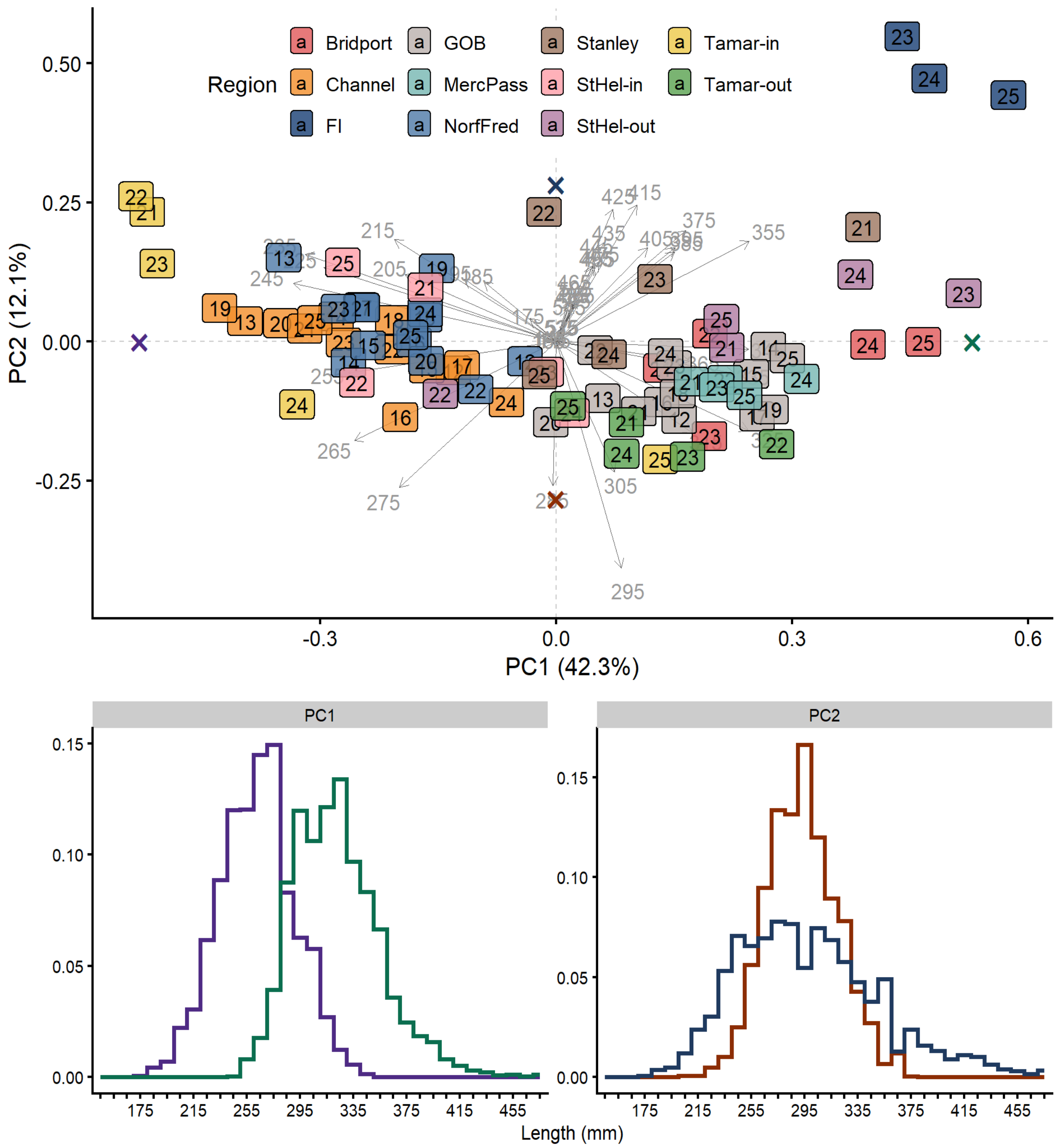


Figure 89. Principal components analysis (PCA) ordination biplot (*top*). The number of each marker indicates the second year of each financial year (e.g., '25' = 24/25) and regions are colour coded. The vectors show the loadings of each 10 mm length bin by midpoint. The 'x' markers indicate the position of the reconstructed length frequencies at position along PC1 (x axis) and PC2 (y axis) and the marker colours match the reconstructions shown (below). The same ordination space is represented in the panels of Appendix Figure 89 with regional subsets of survey LFs.

Supplementary annual density plots for the expanded statewide survey network are provided in Appendix Figure 91, further illustrating the temporal consistency of these regional contrasts from 2020/21 onward.

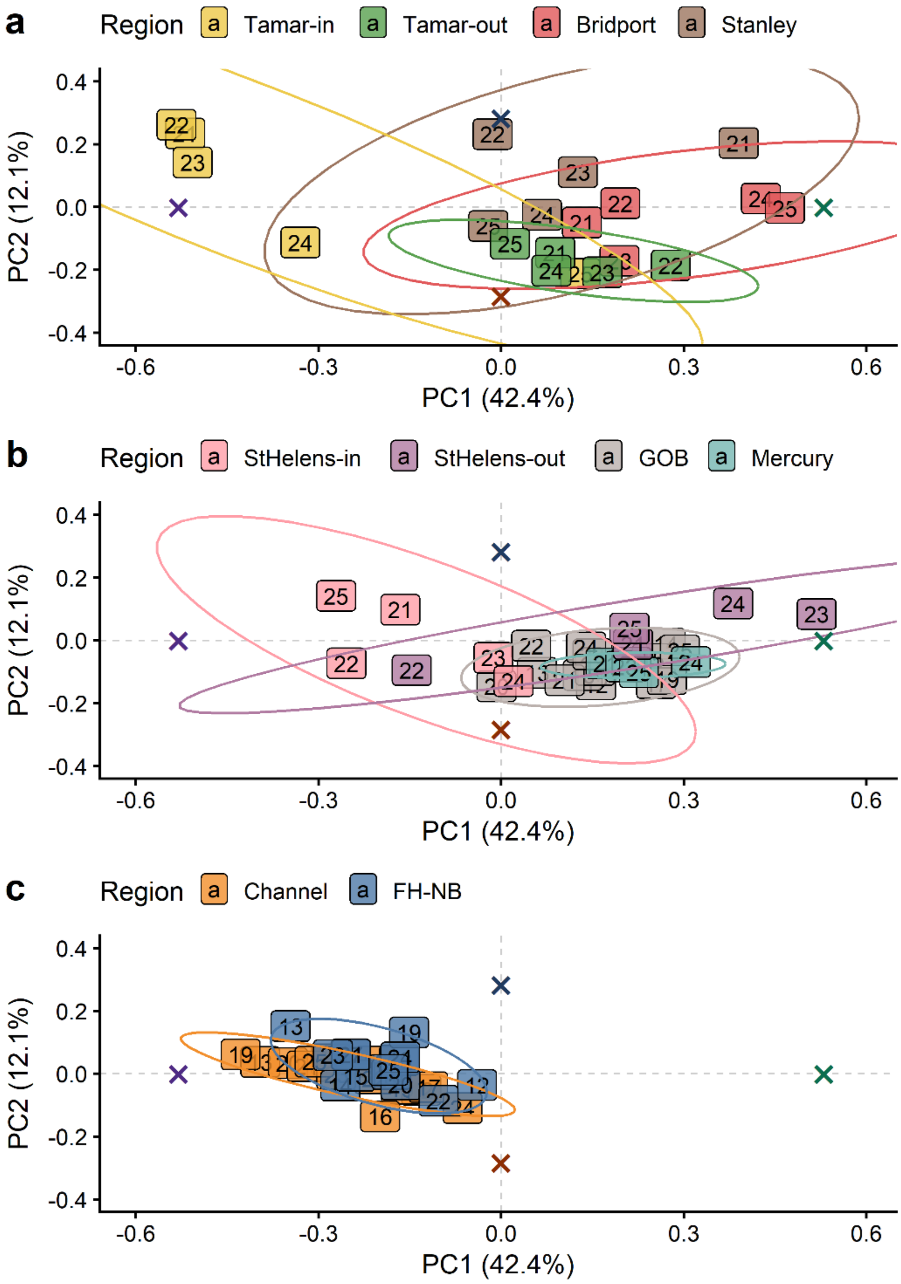


Figure 90. Principal components analysis (PCA) ordination biplots for north coast survey regions (a); east coast survey regions (b); and southeast survey regions (c). The number of each marker indicates the second year of each financial year (e.g., '25' = 24/25) and regions are colour coded. The 'x' markers indicate the position of the reconstructed length frequencies shown on the bottom of Appendix Figure 88. Ellipses indicate bivariate normal 95% probability contours for each region.

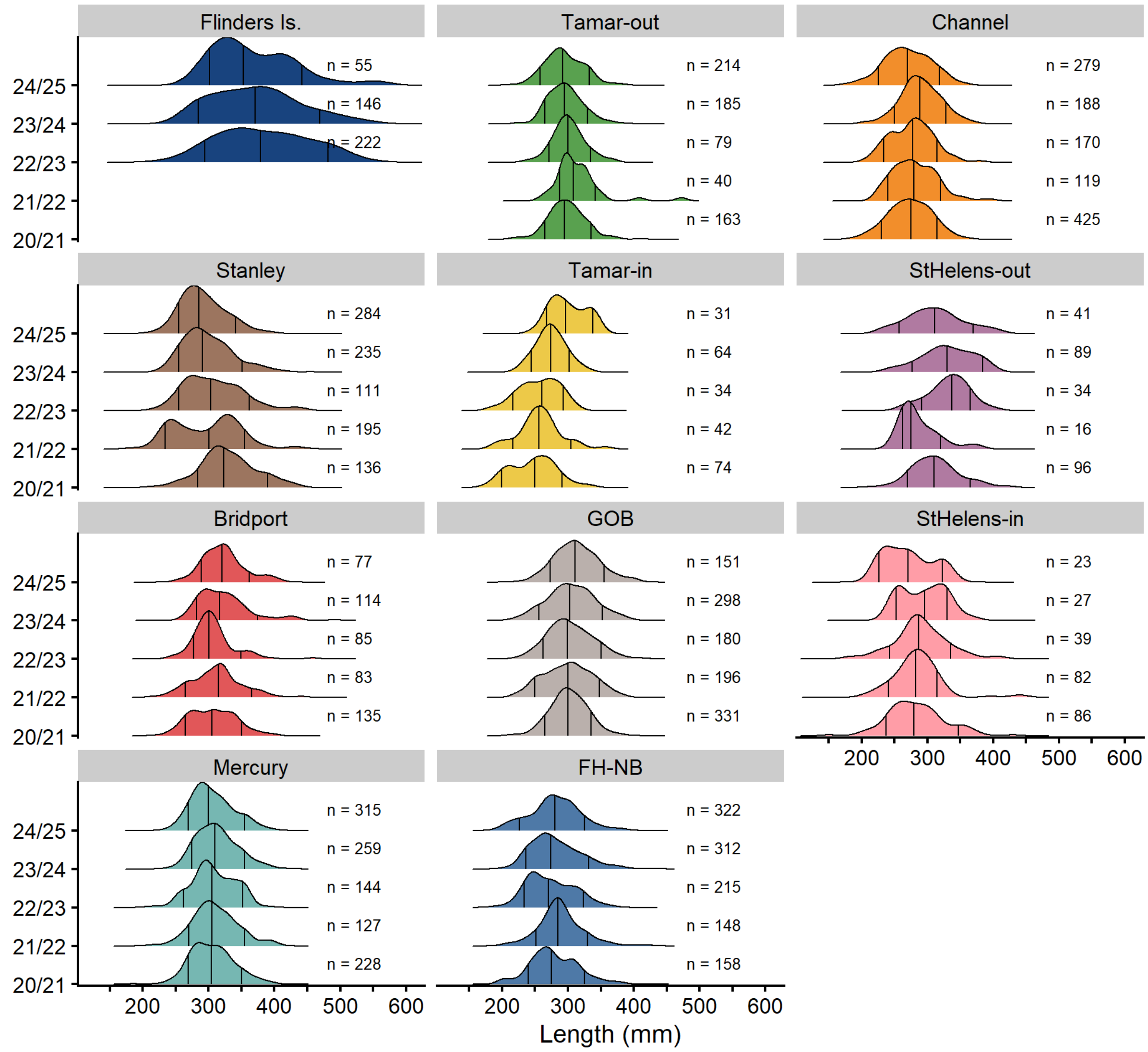


Figure 91. Regional length-frequency densities of Sand Flathead total lengths (mm) across all regions surveyed annually since financial year (Jul-Jun) 2020/21. Densities are scaled to equal area under the curve, and vertical lines denote the 10th percentile, median, and 90th percentile length quantiles for each Samples sizes for each are indicated by '*n*'. 'Tamar-in' and 'StHelens-in' refer to sites inside the Tamar estuary and Georges Bay, respectively.

East coast comparisons

Among east coast regions, the only significant annual difference detected was between Great Oyster Bay and St Helens Outside in 2022/23. Great Oyster Bay and Mercury Passage were particularly similar, with W_1 distances consistently <10 mm, indicating they captured near-identical size-structure information (Appendix Figure 92). St Helens Outside showed greater variability through time, although low site numbers and small samples in 2021/22 and 2022/23 likely reduced statistical power.

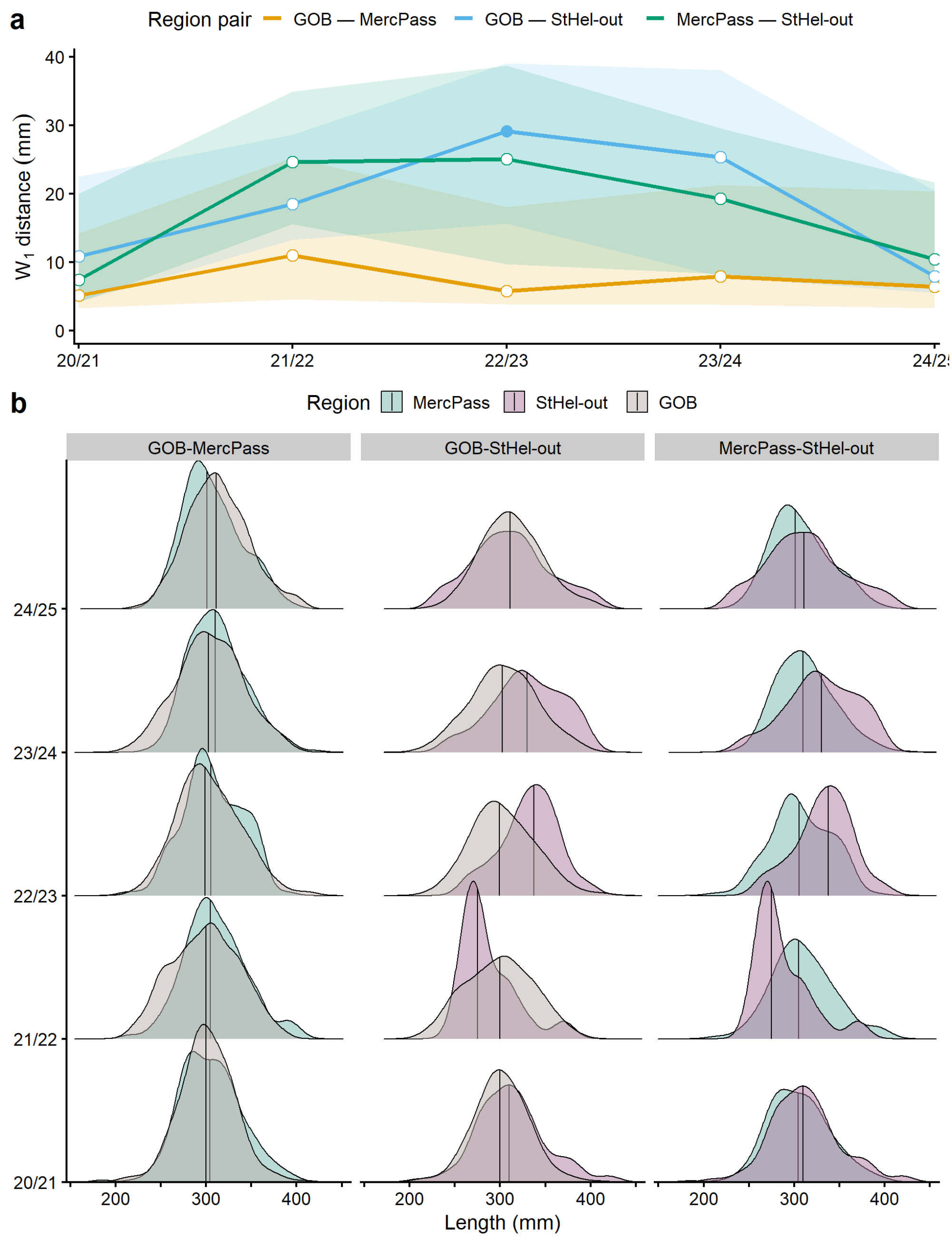


Figure 92. Wasserstein distance between length frequencies from surveys of East coast survey regions by financial year (a), excluding St Helens-inside. 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected: (b) density plots of the two regions in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each region.

North coast comparisons

Among north coast regions, patterns were more dynamic. Stanley and Tamar Outside converged through time, with W_1 declining from >30 mm to <10 mm, whereas Bridport diverged from Tamar Outside in later years ($W_1 \approx 24$–28 mm) due to larger median size and stronger representation of large fish. Differences between Bridport and Stanley were generally moderate and variable among years (Appendix Figure 93).

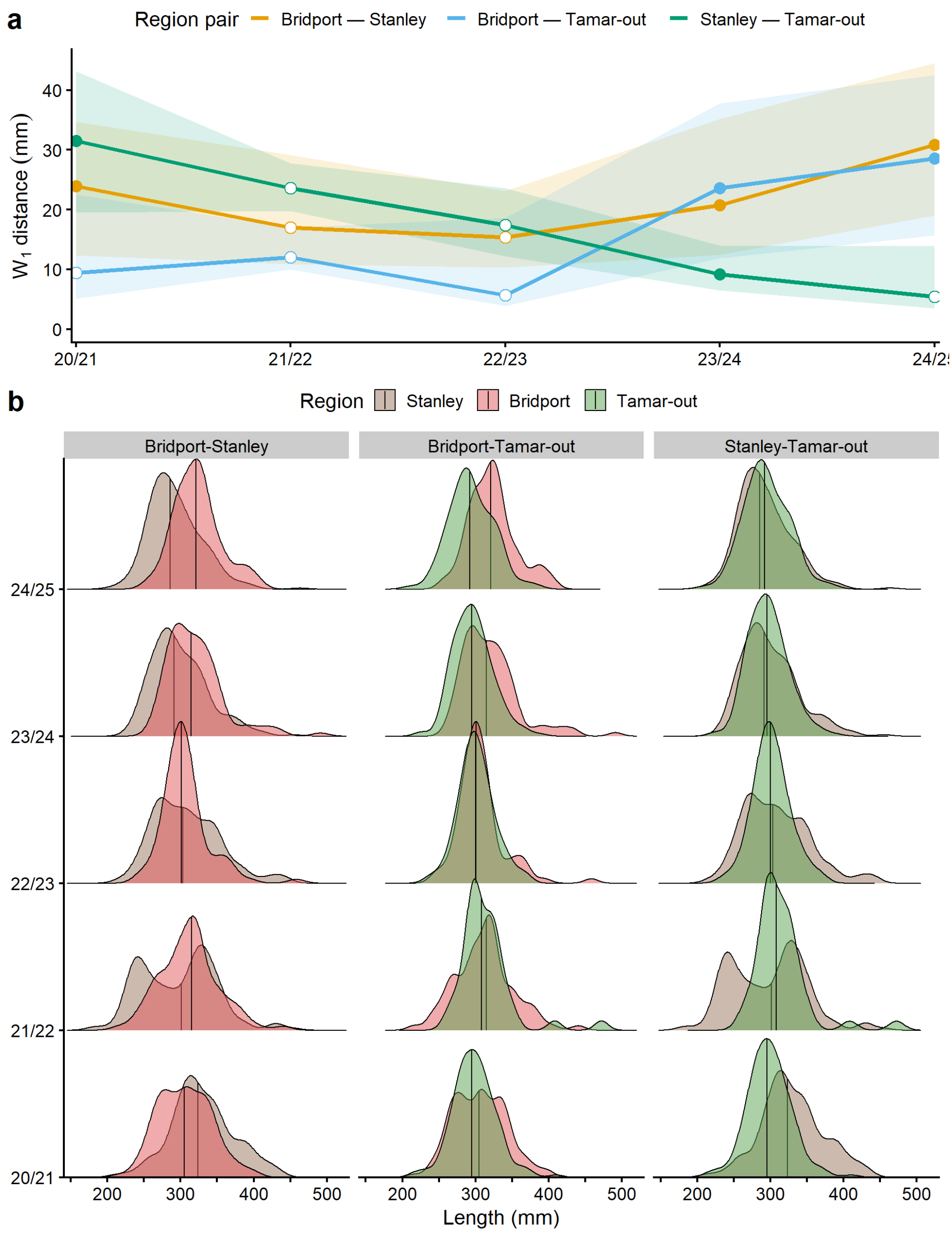


Figure 93. Wasserstein distance between length frequencies from surveys of North coast survey regions financial year (a). 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected: (b) density plots of the two regions in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each region.

Southeast and northeast comparisons

Among the long-term south-eastern regions, Frederick Henry–Norfolk Bays and the Channel were highly similar over the 14-year series (W_1 typically <10 mm), with significant differences only in 2018/19, 2019/20, and 2023/24 (Appendix Figure 94). By contrast, both south-eastern regions were significantly different from Great Oyster Bay in all years except 2021/22, reinforcing persistent east versus southeast separation.

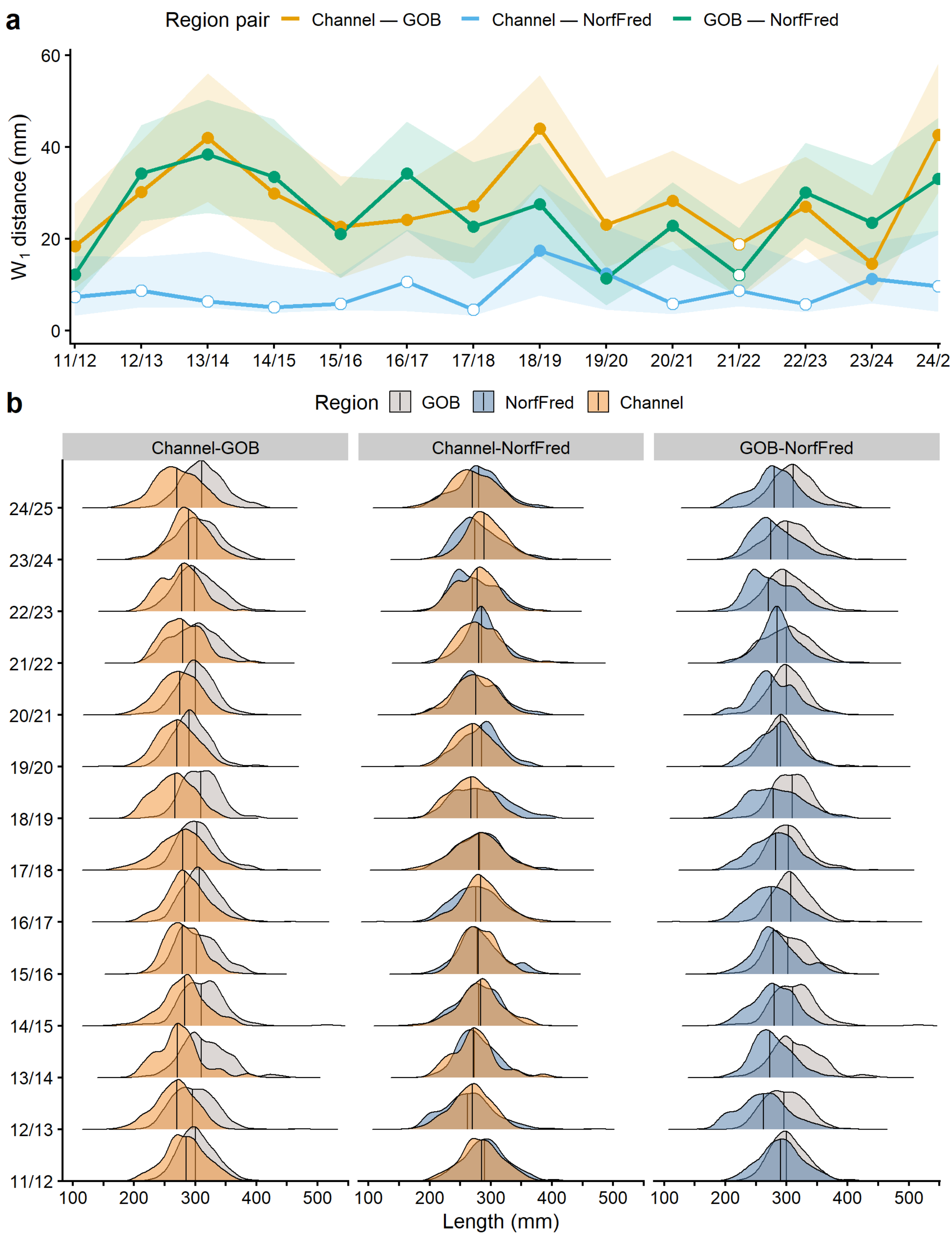


Figure 94. Wasserstein distance between length frequencies from surveys at the three long-term sites per financial year (the southeast sites Freder (a). 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected: (b) density plots of the two regions in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each region.

Comparisons between the two northeastern-most survey regions (St Helens Outside and Bridport) showed broadly similar length distributions in most years (Appendix Figure 95). Significant differences in 2021/22 and 2022/23 likely reflected small sample sizes at St Helens Outside (n = 16 and 34, respectively), supporting their consideration as a shared northeastern grouping for broader regional analyses.

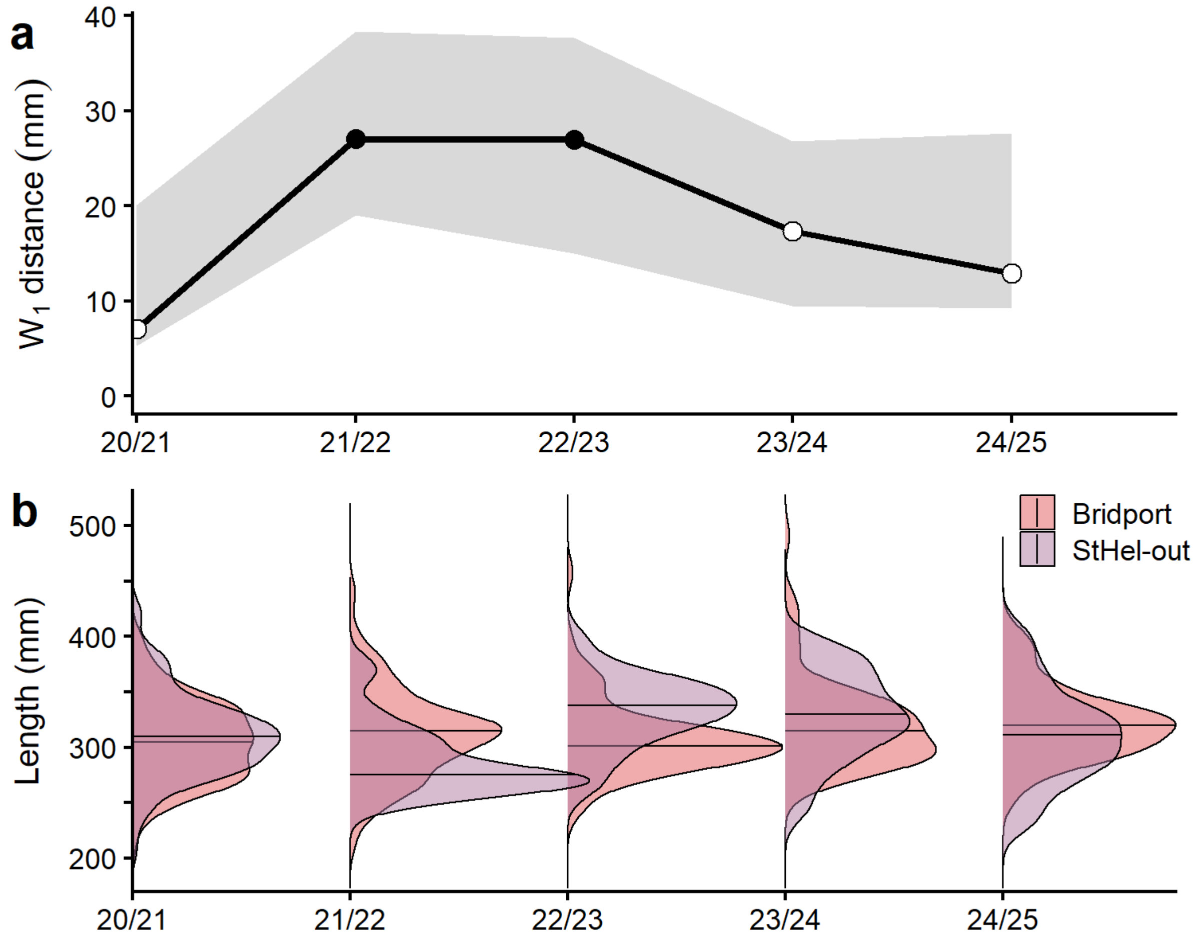


Figure 95. Wasserstein distance between length frequencies from surveys of St Helens-outside and Bridport survey regions by financial year (a). 95% confidence intervals are represented by grey band and solid points indicate significant differences in Wasserstein distance while open white points indicate no significant difference between regional length frequencies detected: (b) density plots of the two regions in each pairwise comparison by financial year for reference. Horizontal lines indicate the median Sand Flathead length of each region.

18.1.2.3 Supplementary temporal modelling outputs

Contrasts between regional slope estimates with confidence intervals are provided in Appendix Table 36.

Quantile GAM analyses suggested several regional trends that are disproportionately driven by change among one portion of the length frequency through time. Stanley exhibited contraction of upper quantile ($\tau = 0.9$) size through time (Appendix Figure 98), consistent with less large fish in surveys driving the mean length down. Bridport displayed a slightly faster increase of the lower ($\tau = 0.1$) quantile than at the median or upper quantile, as did Tamar-inside in the most recent survey years. St Helens-outside, which demonstrated a strong linear increase in mean size, exhibited a growing difference between upper and lower quantiles in recent years suggesting a broader length frequency. Overall, trends were largely coherent across quantiles within regions, suggesting that surveys captured biologically meaningful changes in size structure rather than artefacts driven by a sampling bias or sampling of a single segment of size structures.

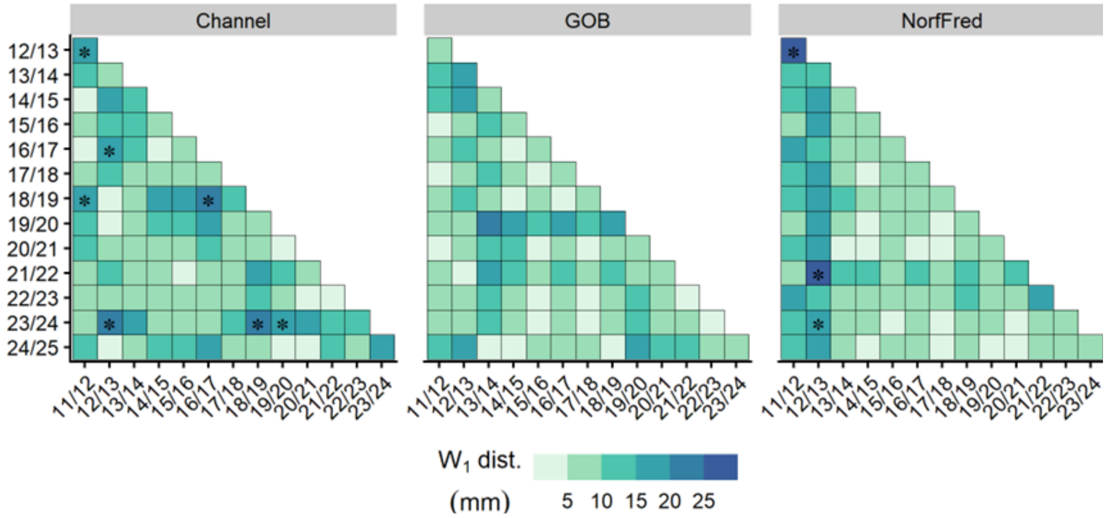


Figure 96. Pairwise Wasserstein distances (W_1) between financial years within each of the long-term survey regions. Significant differences are indicated with asterisks.

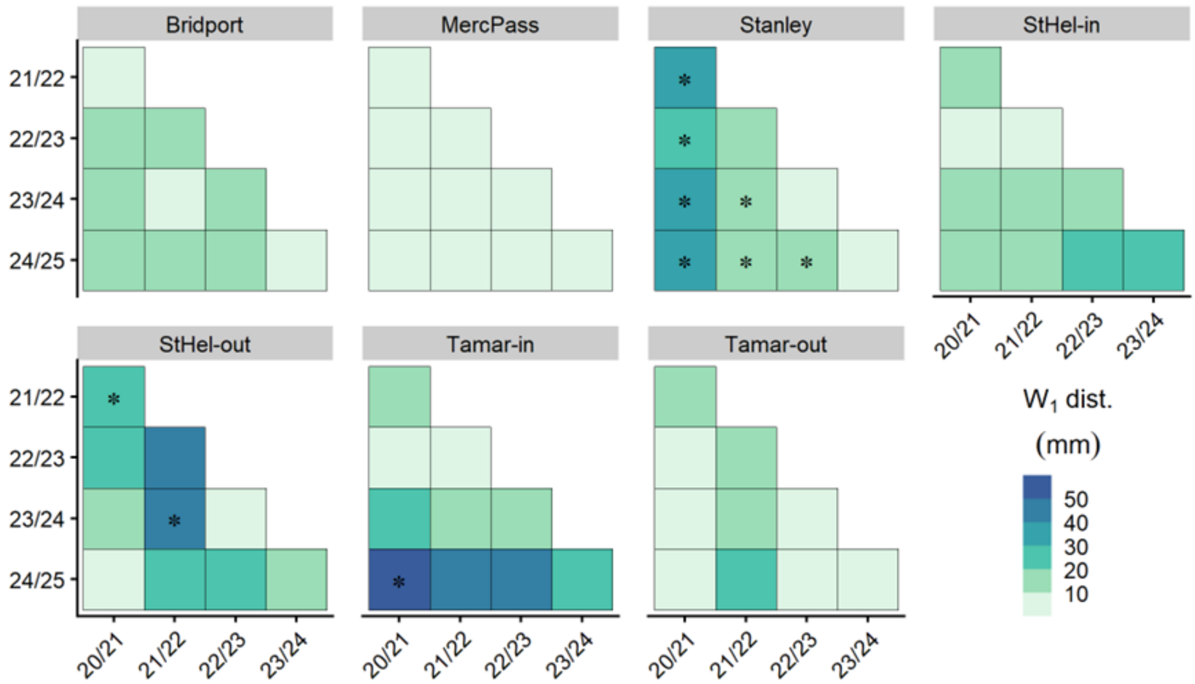


Figure 97. Pairwise Wasserstein distances (W_1) between financial years within each of the expanded survey regions. Significant differences are indicated with asterisks.

Table 36. Pairwise differences in region-specific estimated marginal mean slopes (Tukey-adjusted for multiple comparisons).

Contrast	Difference (mm/yr)	SE	df	*t stat.*	*p* value
Stanley - (Tamar-out)	-3.410	1.969	54.933	-1.732	0.598
Stanley - (Tamar-in)	-16.019	2.519	81.979	-6.359	**0.000**
Stanley - (StHelens-out)	-8.749	2.380	99.140	-3.676	**0.007**

Contrast	Difference (mm/yr)	SE	df	*t stat.*	*p* value
Stanley - (StHelens-in)	-5.221	2.747	95.865	-1.900	0.485
Bridport - Mercury	3.223	1.969	63.944	1.637	0.659
Bridport - (Tamar-out)	6.384	2.088	64.654	3.058	**0.048**
Bridport - (Tamar-in)	-6.224	2.613	89.696	-2.382	0.218
Bridport - (StHelens-out)	1.046	2.479	109.179	0.422	1.000
Bridport - (StHelens-in)	4.573	2.833	103.131	1.614	0.674
Mercury - (Tamar-out)	3.162	1.881	46.216	1.681	0.632
Mercury - (Tamar-in)	-9.447	2.451	73.972	-3.854	**0.004**
Mercury - (StHelens-out)	-2.177	2.308	88.574	-0.943	0.964
Mercury - (StHelens-in)	1.351	2.685	88.046	0.503	0.999
(Tamar-out) - (Tamar-in)	-12.609	2.547	73.639	-4.950	**0.000**
(Tamar-out) - (StHelens-out)	-5.339	2.410	86.734	-2.215	0.298
(Tamar-out) - (StHelens-in)	-1.811	2.773	86.674	-0.653	0.995
(Tamar-in) - (StHelens-out)	7.270	2.877	106.514	2.527	0.160
(Tamar-in) - (StHelens-in)	10.798	3.188	102.335	3.388	**0.017**
(StHelens-out) - (StHelens-in)	3.528	3.077	119.534	1.146	0.912
Stanley - (Tamar-out)	-3.410	1.969	54.933	-1.732	0.598

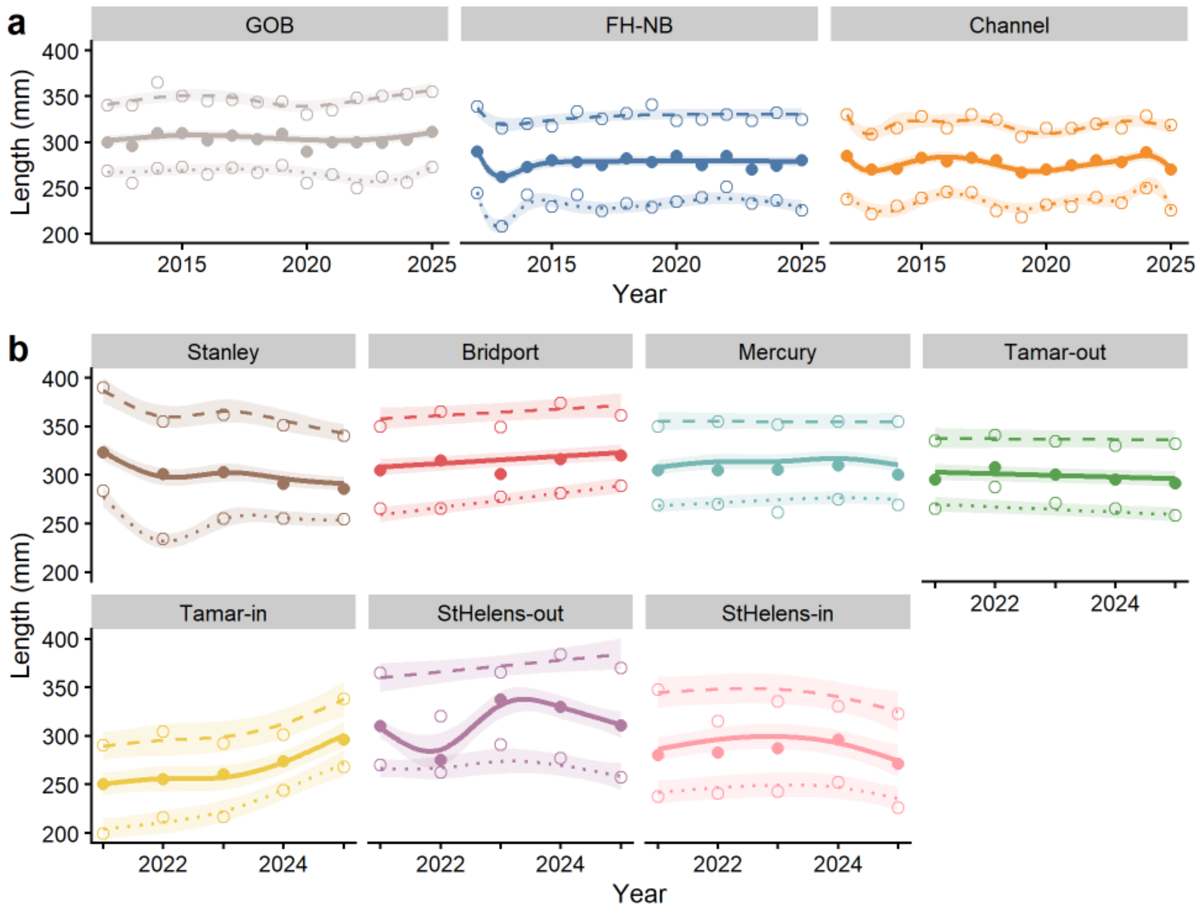


Figure 98. Estimated marginal length predictions from quantile general additive models at median (solid line) and 10th and 90th percentiles (dashed and dotted lines respectively) of annual regional length frequencies of each region in (a) the long-term subset and (b) the expanded region subset. Years indicate the second year of each survey financial year *(i.e., during which nearly all sampling was conducted)* e.g., 2022 = 2021/22. The points represent raw length frequency quantiles (0.1 and 0.9 open points, 0.5 closed points) calculated without controlling for site-level effects.

18.1.2.4 Supporting pooling comparisons

Within-sector year-to-year comparisons of length frequency W_1 differences indicated limited significant differences in the North sector, of only three significant contrasts among early and later years of the survey (Appendix Figure 99a). Under the four-sector scheme, with Bridport partitioned into a separate Northeast sector along with St Helens-outside, the remaining North/Northwest sector displayed clearer and more coherent temporal signal with five significant contrasts between early and late years in the data series with greater W_1 distances identified. This is consistent with the declining size signal at the remaining North/Northwest regions being obscured when pooled with Bridport's increasing size trend. Meanwhile, the separate East sector showed no significant year-to-year differences and the Northeast sector showed moderate but non-significant variation among recent years (Appendix Figure 99b). The Southeast sector, unchanged between schemes, remained broadly stable through recent years but differed from some of the earliest survey years (Appendix Figure 99c).

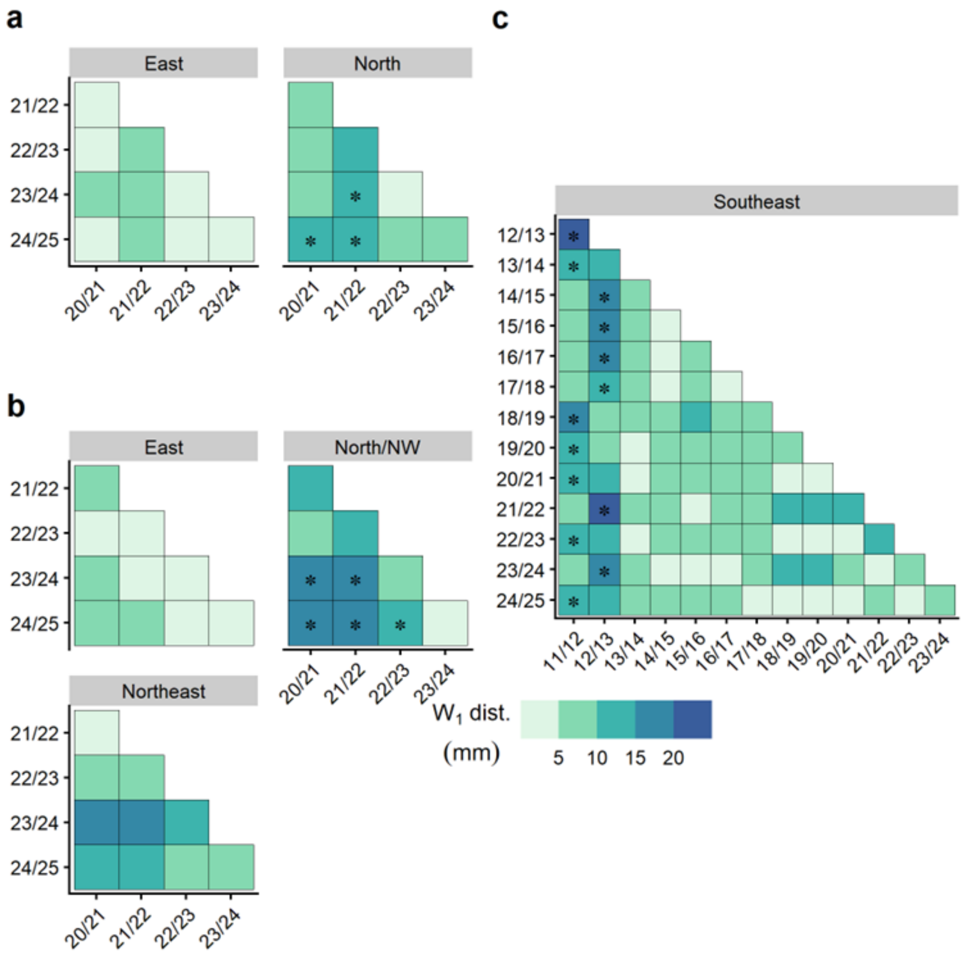


Figure 99. Pairwise Wasserstein distances between financial years within pooled-region coastal sectors under the three-sector scheme (a; East: St Helens-outside, Great Oyster Bay, Mercury Passage; North: Stanley, Tamar-outside, Bridport; Southeast: Frederick Henry Norfolk, Channel) and the four-sector scheme (b; same except Bridport and St Helens-outside pooled into their own Northeast coastal sector, with the other Northern regions assigned to 'North/NW'). The Southeast sector which consists of two of the three long-term survey regions is displayed in for the full time series available (c). Significant pairwise differences are indicated with asterisks.

Quantile GAM analyses indicated that temporal changes within pooled sectors were generally coherent across the size distribution, with 10th, 50th and 90th percentile trends tracking one another through time (Appendix Figure 100). This suggests that sectoral changes in mean length reflected broad shifts in pooled size composition rather than isolated changes in one component of the distribution. Exceptions included greater variability in the lower decile of the Southeast sector and an anomalously low lower decile in the North during 2021/22.

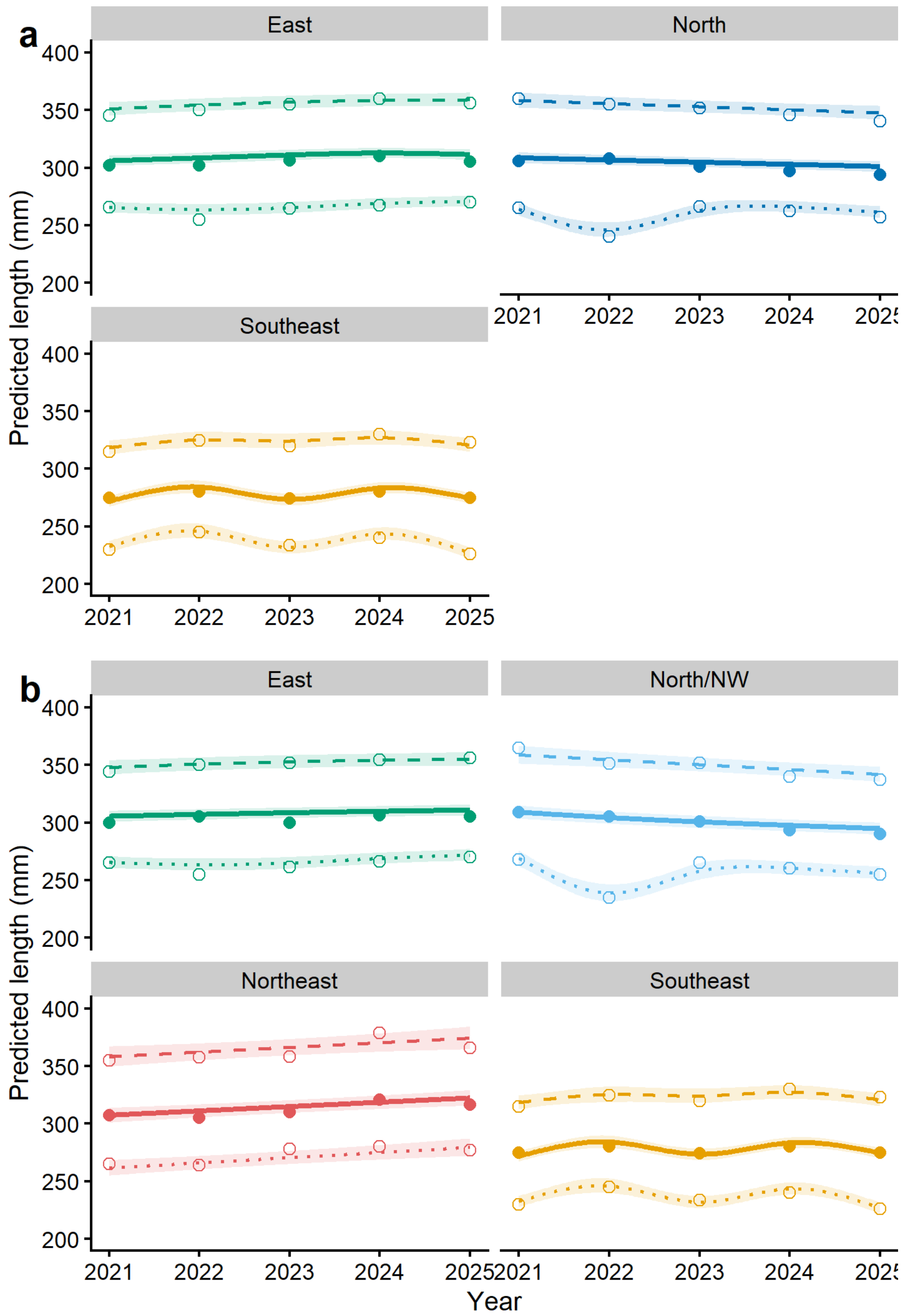


Figure 100. Estimated marginal length predictions from quantile general additive models at median (solid line) and 10th and 90th percentiles (dashed and dotted lines respectively) of fishery-independent survey regions pooled into (a) three coastal sectors and (b) four coastal sectors (Northeast consisting of Bridport and St Helens-outside, with the other assignments the same). The points represent annual quantiles (0.1/0.9 open, 0.5 closed points) calculated without controlling for region- or site-level effects. Years represent the second year in each financial year during which surveys were conducted (e.g., 2021 = 2020/21).

The proportion of fish above regulated size limits also supported the four-sector framework (Appendix Table 37). In the Southeast, only 12.5% of fish exceeded 320 mm and 2.9% exceeded 350 mm (n = 2,336). By contrast, the Northeast had 43.6% ≥320 mm and 18.1% ≥350 mm (n = 770), while Flinders Island was markedly stronger again (77.8% ≥320 mm, 61.7% ≥350 mm; n = 423). These contrasts were partially obscured under the broader three-sector pooling arrangement.

Table 37. Proportion of fish total fish sampled during fishery-independent surveys (2020/21–2024/25) that were greater length than the previous (320 mm) and current (350 mm) minimum regulated size limits, by coastal sector. Flinders Island is presented for reference.

			Proportion *n* above	
Pooling scheme	**Region**	***n***	**320 mm**	**350 mm**
both	Southeast	2,336	12.5%	2.9%
three-sector	North	2,136	31.3%	10.9%
three-sector	East	2,505	35.4%	12.5%
four-sector	East	2,229	33.6%	11.2%
four-sector	North/NW	1,642	28.5%	9.6%
four-sector	Northeast	770	43.6%	18.1%
n/a	Flinders Is.	423	77.8%	61.7%

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