DEVELOPING A LOW-COST MONITORING REGIME TO ASSESS RELATIVE ABUNDANCE AND POPULATION CHARACTERISTICS OF SAND FLATHEAD

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TRANSLATING**NATURE**INTO**KNOWLEDGE**

FINAL REPORT

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EXECUTIVE SUMMARY

Sand Flathead (*Platycephalus bassensis*) are the most commonly caught fish taken by recreational fishers in Tasmania, accounting for over half of all fish (by number) captured by recreational fishing in Tasmania. Sand Flathead are caught mainly by line fishing in estuarine and inshore waters off the east and south-east coast of Tasmania; catch estimates indicating that the recreational harvest is at least five times larger than that landed by the commercial sector.

Sand Flathead biology and population dynamics have been the focus of several previous studies, however, the status of the Tasmanian stocks is unknown. While there is no compelling evidence that stocks are being overfished, there have been many expressions of concern over many years that catch rates are declining.

Given the significance of Sand Flathead to the recreational fishery, the Recreational Fishery Research Advisory Group identified the need to develop an assessment of stock condition for Sand Flathead as a high priority. The present project was developed as a pilot study and involved research fishing between 2012-2014 in the regions of highest importance to the recreational fishery (D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay and Great Oyster Bay).

Sampling was conducted over three years using standardised protocols in terms of timing, fishing gear (hook and line) and sites fished. The size of all fish captured was recorded, random subsamples of which were retained for more comprehensive biological examination including determination of sex and age, the latter based on a validated ageing method using thin sectioned otoliths.

Catches were dominated by sub-legal sized fish; the size structure of Sand Flathead was characterised by a sharp reduction in numbers at sizes greater than 300 mm total length (the minimum size limit or MSL), similarly numbers at age fell sharply at around the age at which fish reached the MSL.

Females were found to grow more quickly and to greater maximum sizes than males and on average reached the MSL at younger ages than males. Differential growth rates have the consequence of catches of legal sized fish ($\geq$ 300 mm) being dominated by females, with age classes above the age at which females attain the legal size limit being increasingly dominated by males. Mortality rates estimated from catch curve analysis confirmed much higher rates of fishing mortality on females.

This study established that total mortality rates (natural plus fishing mortality) are high, with the D'Entrecasteaux Channel appearing to be the most heavily depleted of the three study regions. A strong year class (spawned in 2007) was evident in the Great Oyster Bay catches, but not in the other areas, and featured prominently in the catch of legal-sized fish from that area.

Yield per recruit analyses suggest that at current levels of fishing mortality, the present legal size limit is appropriate in terms of achieving maximum yield per recruit for females. The situation for males is, however, quite different, with maximum yield being achieved at a smaller size at first capture. As it is not possible to determine the sex externally in this species, differential minimum size limits would be impracticable.

Catch rates, as an index of relative abundance, were lowest in the D'Entrecasteaux Channel and highest in the Great Oyster Bay region, tending to support higher exploitation rates in the former area and, partly at least the influence of the strong 2007 year class in the latter area. In all regions catch rates were observed to have declined between 2012 and 2014, and while the significance for the stocks and the fishery are uncertain due to the limited time series and other potentially complicating factors, these data do suggest a need to reduce fishing pressure.

A management initiated proposal to increase the MSL for Sand Flathead to 320 mm is currently under consideration. Such an increase in size would result in a trade-off in terms of reduced theoretical yield per recruit but would be balanced by the combined effects of reducing the effective rate of fishing mortality for the same level of effort (i.e. more of the catch would be undersized and released) and additional protection conferred to the adult spawning stock, allowing females to spawn for an additional year or so before entering the fishery.

High exploitation rates, the significance of the species to the recreational fishery and uncertainty about population status emphasise the need for on-going monitoring of stock status. The fishery independent catch sampling regime implemented in this study has contributed important information about the stock status in the main regions of the fishery and represents a baseline against which future changes in abundance and management initiatives could be assessed.

In the absence of on-going catch and catch rate data from the fishery, fishery-independent catch sampling represents a viable option to monitor trends in stock status and population structure. The present study has demonstrated that research surveys based on about 10 days of field sampling per year have the potential to provide a low-cost (less than $10,000 per annum in operating costs) index of population and fishery status for Sand Flathead. It is recommended, therefore, that the monitoring regime developed in this study be implemented to support the on-going monitoring and assessment of Sand Flathead in Tasmania, with data to contribute to the annual assessment of the scalefish fishery.

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1. GENERAL INTRODUCTION

1.1. Literature review

1.1.1. General biology

Sand Flathead (*Platycephalus bassensis*) are found from Bremer Bay in Western Australia to Jervis Bay in New South Wales but are most common in New South Wales, Victoria and Tasmania (Edgar, 1997). They are found in estuarine and coastal waters to depths of 100 m but occur more commonly in shallow waters on sandy or muddy substrates (Jordan 2001) and grow to at least 550 mm fork length (FL) (Gomon *et al.* 1994).

Sand Flathead are asynchronous batch spawners, spawning every four to five days during a protracted spawning season that can extend from October to March with a peak in spawning during the day (Bani *et al.* 2009, Jordan 2001). Their spawning season may potentially be extended beyond this window to take advantage of favourable environmental conditions (Bani *et al.* 2009). Their protracted spawning season results in wide variation in growth of young of the year on the basis of their hatch date (Jordan 1998).

Jordan (1998) reported that Sand Flathead from Tasmanian waters mature at about 210 and 235 mm FL for males and females, respectively, but noted that the range of sizes at which individuals reached maturity was broad and associated with their broad spawning period. In a more recent study, Bani and Moltschaniwskyj (2008) reported sizes at maturity of 219 mm total length (TL)[1] for males and 235 mm TL for females and the number of years between age at first maturity (around 2.6 years for both sexes) and the age of females at the current minimum size limit (MSL) of 300 mm TL was as low as 3.6 years (i.e. effectively one spawning season). However, growth rates, size at maturity, and age at maturity vary regionally around Tasmania (Bani and Moltschaniwskyj 2008) and notwithstanding this variability, all evidence indicates that Sand Flathead mature at sizes below the current MSL.

Smaller Sand Flathead have been found to have shorter spawning seasons, a lower spawning frequency, and a lower energy investment in egg production (Bani *et al.* 2009). Sand Flathead eggs and larvae are pelagic prior to settlement onto unvegetated benthic habitats at around 2.1 mm FL (Jordan 2001, Jordan *et al.* 1998).

Jordan (1998) generated a robust ageing methodology for Sand Flathead using thin transverse sections of sagittal otoliths which show clear and distinctive increment

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[1] In Sand Flathead there is little difference between total and fork lengths since the caudal fin has a very shallow fork.

structure. The position of the first annual increment was determined by comparing the dimensions of the otoliths of known-age young-of-the-year with the inner structure of the otoliths of older fish. The periodicity of subsequent increment structure was confirmed to be annual using marginal increment analysis. Sand Flathead are moderately long-lived with maximum age estimates of 17 years in Tasmania (Jordan 1998) and 23 years in Port Phillip Bay, Victoria (Koopman 2005). Growth is rapid for the first 3 years, slowing at around 220 to 250 mm, coincident with the onset of maturity, and approaches an asymptote of around 360 and 400 mm for males and females, respectively. Females are larger than males in all age classes which may be an adaptation to increase reproductive potential through increased fecundity. Females also dominate sex ratios in inshore areas, and in larger size classes (>350mm) (Jordan 1998).

Jordan (1998) observed distinct seasonal variations in abundance of mature Sand Flathead, with lower abundances inshore during winter and higher abundances in summer, and offshore abundances lower in summer and higher in winter. He suggested that this reflected either movement to take advantage of summer peaks in inshore prey abundance (Edgar *et al*. 1994), or a change in catchability rather than abundance. Recent acoustic tracking research found that Sand Flathead moved out of the Pittwater estuary and into Fredrick Henry Bay towards end of May, with some individuals returning the following spring, suggesting movement into deeper water during the cooler months (Stehfest *et al*. 2014). The same study also observed changes in metabolic rate in response to environmental variables which influence feeding behaviour, potentially affecting the catchability of Sand Flathead to line fishing methods.

Research in Western Port Victoria reported that Sand Flathead are important ambush predators that consume primarily crustaceans, their diet shifting from predominantly peracarids (amphipods, isopods, etc.), to crabs and shrimps at around 100 g body weight (Edgar and Shaw 1995). They are also a dominant demersal fish predator in unvegetated habitats, particularly as they increase in size (Officer and Parry 2000).

1.1.2. Tasmanian recreational fishery

Flatheads (predominately Sand Flathead) comprised almost two-thirds (by number) of Tasmanian recreational catches in the 2007-08 fishing season, with an estimated 1.07 million Flathead (292 tonnes) captured and retained, and an additional 0.74 million individuals captured and released (Lyle *et al*. 2009). The Tasmanian recreational flathead harvest is at least five times greater than the commercial catch. Virtually all of the recreational catch is taken by line fishing methods, predominantly fishing from boats (95%) (Lyle *et al.* 2009). Recreational catches are regulated by a minimum size limit of 300 mm TL, a possession limit of 30 fish, and gear restrictions including a maximum of five hooks on rod and line (DPIPWE 2014).

Despite its current popularity among recreational fishers, Flathead were generally unpopular prior to the second half of the 20th century due to the species 'ugly' appearance, its ubiquity, its reputation as a scavenger, and the availability of more highly esteemed fish (Frijlink and Lyle 2013). Consequently, until the last 60 years Sand Flathead stocks in Tasmania were probably largely unfished, unlike a number of other inshore species (e.g. Bastard Trumpeter and Flounder) which have been heavily fished since European settlement (Frijlink and Lyle 2013).

The Flathead fishery in Tasmania is highly seasonal with a strong peak in catch and effort between January and February, a distinct trough between June and September. The main fishing period occurs from December to March and accounts for almost three quarters of annual catch (Lyle *et al*. 2009). This seasonal pattern matches variations in inshore abundance observed by Jordan (1998) and seasonal movement and activity patterns reported by Stehfest *et al.* (2014). Consequently, seasonality in the fishery probably reflects fisher's responses to a reduction in inshore abundance (availability) as well as catchability due to changes in feeding behaviour during the cooler months.

The recreational fishery for Flathead is concentrated on the east and south east coasts of the state, these areas accounting for over 85% of total state-wide catch (Lyle et al. 2009). Within this area, three regions dominate total catches; the D'Entrecasteaux Channel (24% of state-wide catches), Frederick Henry-Norfolk Bay (23%), and central east coast (20%). Despite a high awareness of the size and gear restrictions that apply to Sand Flathead (Frijlink and Lyle 2010), creel surveys undertaken during 1997 and 2001 revealed that retained catches were comprised of between 30 and 40% undersized fish (by number) indicating that the may be a substantial sub-legal component in the landed catch.

On the basis of interviews with long-term recreational fishers, Frijlink and Lyle (2013) reported a strong perception that both the abundance and average size of legal-sized Sand Flathead has declined considerably over the past 40-50 years. These long-term recreational fishers reported that catch rates may have declined by around 80% since the 1940s, from about 30 fish.h^{-1} during the 1940s to a current average of 6.6 fish.h^{-1} (Frijlink and Lyle 2013).

1.2. Objectives

A number of studies have investigated various aspects of Sand Flathead biology and population dynamics, however, despite the significance of the species to the Tasmanian recreational fishery, the status of stocks is unknown. While there is no quantitative fishery-independent evidence that stocks are being overfished, there have been many expressions of concern over the years from recreational fishers that catch rates are declining. Consequently, there is a need to develop an assessment of Sand Flathead stock status in Tasmania to support the sustainable management of this important fishery.

The main objectives of this project were to develop and trial a cost-effective monitoring program to assess the status of Sand Flathead stocks in the main fishing areas through:

1. the application of standardised catch rate indices as a proxy for trends in abundance/availability;
2. determination of population age structure as an indicator of stock condition; and
3. estimation of instantaneous total mortality rates.

Secondary objectives included:

1. the collation and synthesis of available information on Sand Flathead; and
2. examination of movement patterns based on conventional tagging to inform on factors such as seasonal variability in availability and mixing between areas.

1.3. General methods

This study collected Sand Flathead through fishery-independent sampling using fishing gear and targeting practices typical of recreational fishers. As population dynamics have been observed to vary spatially and in response to fishing pressure (Bani 2005), it was considered necessary to assess stocks in areas of significant fishing effort, and separately in sub-regions of the fishery. Further, as catchability and availability have been observed to vary seasonally, it was considered necessary to conduct sampling at a consistent time of the year using standardised fishing protocols. Consequently, the fishing methods, survey timing, and survey locations were determined with reference to Tasmanian recreational fishing surveys (Lyle and Campbell 1999, Lyle *et al*. 2009) and have been applied consistently across years.

Sand Flathead were sampled from three regions; D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay and Great Oyster Bay (Fig. 1). These regions yield the majority of the recreational Sand Flathead catch. Fishing was generally conducted over a minimum of three (not necessarily consecutive) days per region, with between 19-21 sites fished in each region. Sampling sites were selected to represent a range of suitable habitats (including depths) and provide wide spatial coverage within the given region (Fig. 1).

Sampling was conducted during February and March in each of 2012, 2013 and 2014. This timing was chosen to coincide with the peak period for recreational fishers and high catchability of Sand Flathead.

Structured fishing trials were conducted using a medium action rod and a standard spinning reel. Fishing line was 4.5 kg breaking strain rigged with a standard paternoster rig (27 kg line) with dual dropper loops, each with a suicide style hook (size 4/0) and a single lead weight. Each rig was baited with a piece of squid on one hook and a soft plastic lure on the second hook. The allocation of bait or lure to upper and lower hooks was haphazard.

Each site was fished concurrently by 2 to 4 fishers for 30 minutes, with the vessel allowed to drift. All fish caught were measured (Flathead were measured for total length, other species were measured for fork length) and the name of the fisher recorded. The first 100 or so Sand Flathead landed within each region, regardless of size, were retained for biological assessment including size, weight, sex, gonad stage (Mendonca *et al.* 2006), gonad weight, and age estimation. Catches in excess of those retained for biological examination were released, with individuals larger than 290 mm TL tagged with a standard T-bar style tags; smaller individuals were not tagged to increase their likelihood of survival (Lyle *et al.* 2007).
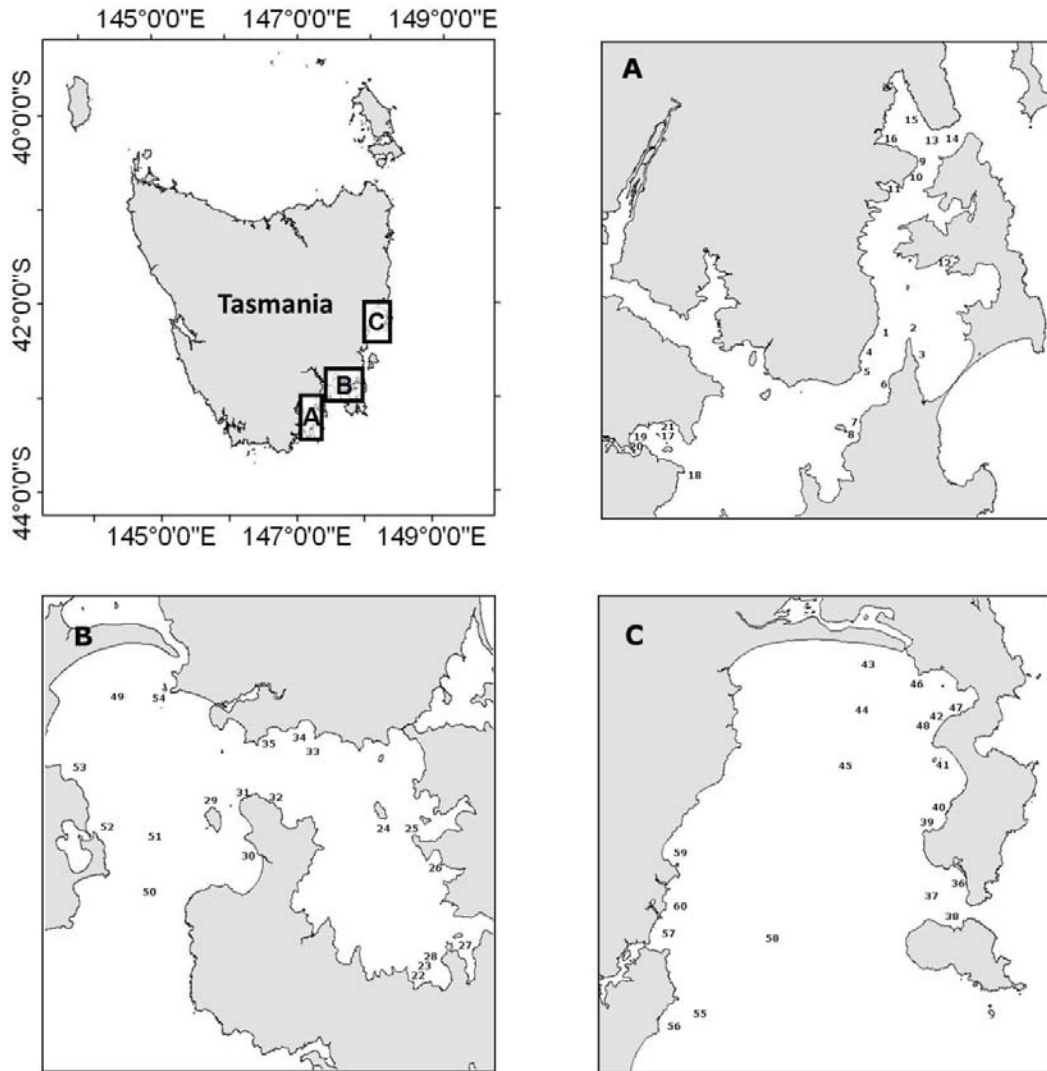
Fig. 1. Map showing sampling regions; D'Entrecasteaux Channel (A), Frederick Henry-Norfolk Bay (B), and Great Oyster Bay (C). Sample sites within regions are numbered in detail maps.

2. SIZE AND AGE STRUCTURE

2.1. Introduction

Interpretation of catch rates as an indicator of trends in abundance benefits from consideration of other biological parameters such as size and age structure. This is because factors such as recruitment variability and changes in the relative proportion of size classes in catches may help to explain catch rate variability and hence inform the need for management responses.

Estimating age from fish otoliths entails enumeration of an age-related increment structure, and conversion of that to an age with consideration of the actual age at the first enumerated increment, and the time elapsed between the last enumerated increment and date of capture (Ewing *et al.* 2007). Preparation of thin transverse sections of otoliths has been shown to provide more accurate age estimates than those prepared from whole otoliths which tend to result in under-aging of older fish (Beamish 1979). A necessary prerequisite for a robust ageing methodology is the validation of both the precision of age estimates and a measure of their accuracy (Beamish and McFarlane 1983, Campana 2001).

Jordan (1998) established a robust ageing protocol for Sand Flathead which includes confirmation of the annual periodicity of increment structure using marginal increment analysis, confirmation of the age at the first enumerated increment through analysis of the dimensions of the otoliths of known-age 0+ and 1+ cohorts, and confirmation of the timing of increment formation on the margin of the otolith.

2.2. Methods

Up to the first 100 Sand Flathead caught in each region (regardless of size) were retained for biological assessment including length, weight, sex, gonad stage (Mendonca *et al.* 2006), gonad weight, and age estimation. Unusually small or large flathead were also retained for this purpose but these were flagged as being non-randomly sampled.

2.2.1. Otolith preparation and interpretation

Otoliths were retained from 310, 249, and 278 Sand Flathead in 2012, 2013, and 2014, respectively. Otoliths were mounted in polyester resin and transverse sectioned (250 to 300 μm) using a diamond saw. Opaque zones in the otolith sections were counted by experienced readers using a dissection microscope under transmitted light.

2.2.2. Age validation

Age estimates were generated following the ageing protocol established by Jordan (1998). A library of 100 randomly selected otoliths was established and agreed reference age estimates were assigned by experienced otolith readers from two research agencies (IMAS and Fish Ageing Services, Victoria). The otolith reference library was used for training readers in the interpretation of Sand Flathead otoliths, and for routine checks of the precision of otoliths reads to address potential issues

associated with 'reader drift'. The index of average percentage error (IAPE) was used to measure the precision of re-reads; an IAPE >5% indicated the need to re-train.

2.2.3. Data analysis

Size distributions were compared between regions and years using Kolmogorov-Smirnov (KS) analyses. As these distributions are potentially non-continuous the bootstrap version of the KS test was used with 1000 iterations. Size selectivity of the fishing gear was assumed to have been constant across regions and between years. A Bonferroni adjustment to *p*-values was applied to correct for multiple comparisons.

The age structure of the sub-samples retained for biological examination were compared by sex, between regions and years using KS analyses. Non-randomly sampled fish were excluded from these comparisons. As these distributions are potentially non-continuous the bootstrap version of the KS test was used with 1000 iterations. Mean length at age was calculated for males, females, and sexes combined, by region and year sampled. A Bonferroni adjustment was applied to *p*-values to correct for multiple comparisons.

2.3. Results

2.3.1. Size structure

A summary of the size structure of the Sand Flathead captured is presented in Table 1 and length frequency histograms are presented in Figs 2, 3 and 4. The smallest individual encountered was 147 mm TL and was captured in the Frederick Henry-Norfolk Bay Bay region in 2012. The largest fish encountered was 470 mm TL and was captured in the D'Entrecasteaux Channel in 2013.

Size frequency distributions in the D'Entrecasteaux Channel and Frederick Henry-Norfolk Bay were characterised by the majority of fish being smaller than 300 mm TL whereas in Great Oyster Bay approximately half of the fish were larger than 300 mm. KS tests indicated several significant differences in the size composition of the samples between years (within regions) and between regions (within years) (Table 2). Frederick Henry-Norfolk Bay catches differed significantly between years for each pairwise comparison within the region, influenced by a general shift to the left (to small size classes) in 2013 and a contraction in the overall size range in 2014. The size composition for the D'Entrecasteaux Channel also differed significantly between 2012 and 2013, impacted by the reduction in the representation of legal-sized fish in 2013. By contrast, in Great Oyster Bay, the only significant pairwise comparison was between 2013 and 2014, the modal size moving to the right in the latter year. Regionally, there were significant differences between the size composition of catches from Great Oyster Bay and the D'Entrecasteaux Channel in each of the sampled years, and between Great Oyster Bay and Frederick Henry-Norfolk Bay in 2013 and 2014, these differences reflecting the greater representation of the larger size classes in Great Oyster Bay.
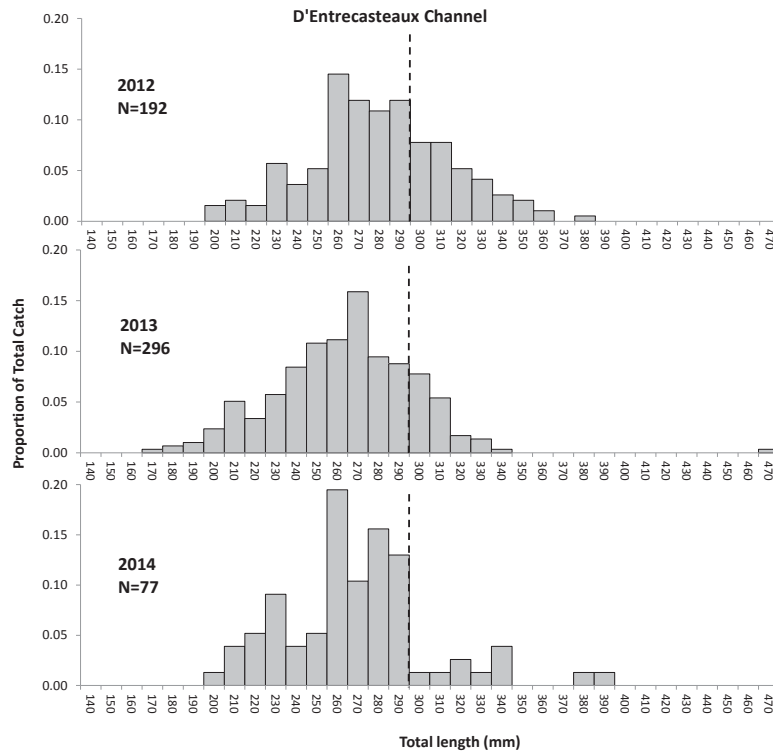
Fig. 2. Length frequency histograms for Sand Flathead captured in the D'Entrecasteaux Channel region. Dotted line is the minimum legal size limit.
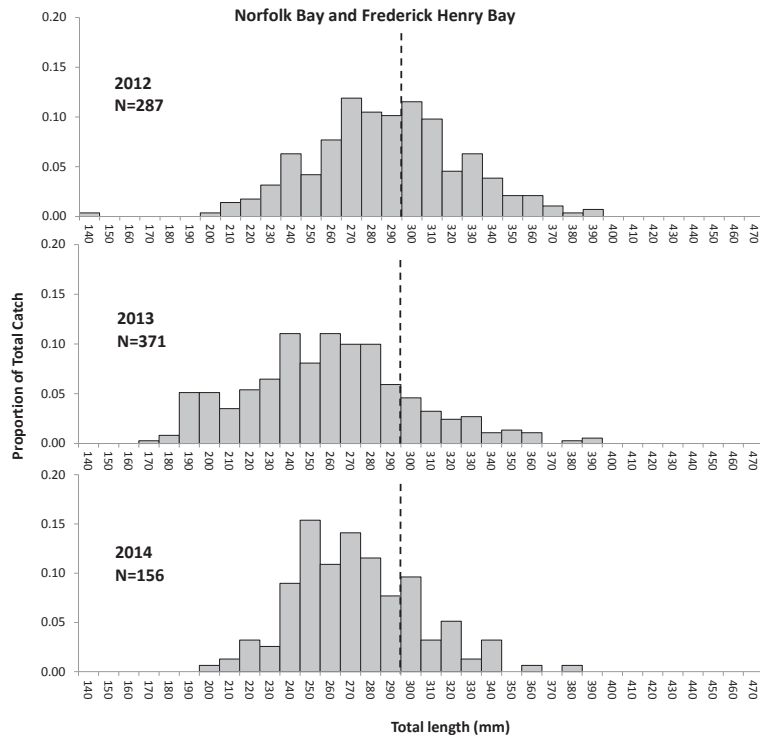
Fig. 3. Length frequency histograms for Sand Flathead captured in the Frederick Henry-Norfolk Bay region. Dotted line is the minimum legal size limit.
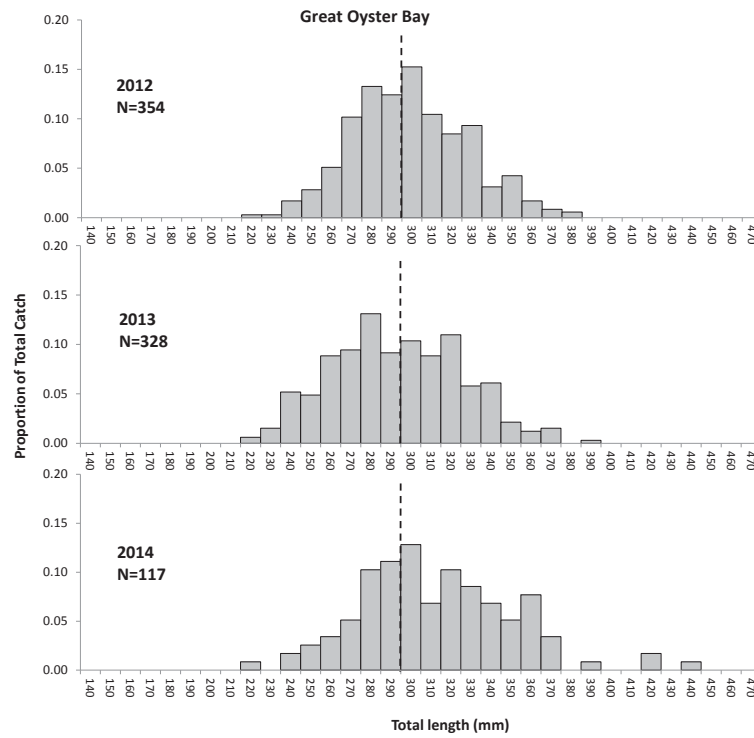
Fig. 4. Length frequency histograms for Sand Flathead captured in the Great Oyster Bay region. Dotted line is the minimum legal size limit.

Table 1. Summary of the size structure (mm) of Sand Flathead sampled.

Area	Parameter	2012	2013	2014	All years
	No. caught	191	296	79	564
	Minimum	205	173	205	173
D'Entrecasteaux Channel	**Maximum**	396	470	390	470
	Mean	284	268	274	274
	Median	285	270	271	274
	No. caught	287	371	156	814
	Minimum	147	171	205	147
Frederick Henry-Norfolk Bay	**Maximum**	408	398	380	408
	Mean	291	263	277	276
	Median	290	262	273	275
	No. caught	354	328	117	799
	Minimum	225	222	220	220
Great Oyster Bay	**Maximum**	397	399	440	440
	Mean	303	297	316	302
	Median	300	296	310	300
	No. caught	832	995	350	2178
	Minimum	147	171	205	147
All Regions	**Maximum**	408	470	440	470
	Mean	295	276	289	285
	Median	295	275	285	285

Table 2. *P*-values from bootstrap Kolmogorov-Smirnov tests for comparisons of Sand Flathead size structure.

"DEC", "FHNB" and "GOB" refer to the D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay, and Great Oyster Bay regions and "All" refers to all regions pooled. A Bonferroni adjustment to *p*-values has been assigned to correct for multiple comparisons. Significant differences are in bold (α= 0.05/20).

Year	Region	2012		2013				2014			
		FHNB	GOB	DEC	FHNB	GOB	All	DEC	FHNB	GOB	All
2012	**DEC**	0.08	**<0.001**	**<0.001**	-	-	-	0.048	-	-	-
	FHNB	-	-	-	**<0.001**	-	-	-	**<0.001**	-	-
	GOB	-	-	-	-	0.008	-	-	-	0.01	-
	All	-	-	-	-	-	**<0.001**	-	-	-	**<0.001**
2013	**DEC**	-	-	-	0.025	**<0.001**	-	0.2	-	-	-
	FHNB	-	-	-	-	**<0.001**	-	-	**<0.001**	-	-
	GOB	-	-	-	-	-	-	-	-	0.001	-
	All	-	-	-	-	-	-	-	-	-	**<0.001**
2014	**DEC**	-	-	-	-	-	-	-	0.5	**<0.001**	-
	FHNB	-	-	-	-	-	-	-	-	**<0.001**	-

2.3.2. Age structure

Transverse sectioned otoliths produced a clear increment structure (Fig. 5) suitable for application of the ageing protocol developed for the species by Jordan (1998). The use of experienced otolith readers and an inter-agency verified Sand Flathead otolith reference library for training and to measure reader precision, confer confidence in the ages estimated in this study.

Age estimates were generated for 307, 248, and 278 Sand Flathead sampled in 2012, 2013, and 2014 respectively. The oldest individual aged was a 13 year old (355 mm TL) male captured in Frederick Henry Bay in 2013 while the largest fish aged was a 470 mm TL (10 year old) female captured in D'Entrecasteaux Channel in 2013. The youngest fish aged were 2 years old and were encountered in samples from each year and region (Table 3).

Age frequency histograms indicate that catches from the D'Entrecasteaux Channel and Frederick Henry-Norfolk Bay were dominated by fish around 4 years of age, and that the abundance and proportion of females in the samples declined rapidly in the older age classes (Fig. 6). Conversely, in the Great Oyster Bay region there was a greater representation of older age classes and a strong year class (born in 2007) that was particularly prevalent in 2013 (6 years olds) and 2014 (7 year olds).

Sex differences were evident in mean lengths at age (Table 4), and indicated that on average females exceeded the MSL at around 6, 5, and 4 years of age in the D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay, and Great Oyster Bay regions respectively. By contrast, males exceeded the MSL at around 7 years of age in both Frederick Henry-Norfolk Bay and Great Oyster Bay regions, whereas relatively few males exceeded the MSL in samples from the D'Entrecasteaux Channel.

Age distribution comparisons using KS tests indicated that there were several significant differences between regions within years, Great Oyster Bay was the only region for which differences were evident between years (2012 -2014 pair wise comparison), influenced by the strong year class which had progressed from 5 to 7 years of age within this timeframe (Table 5).
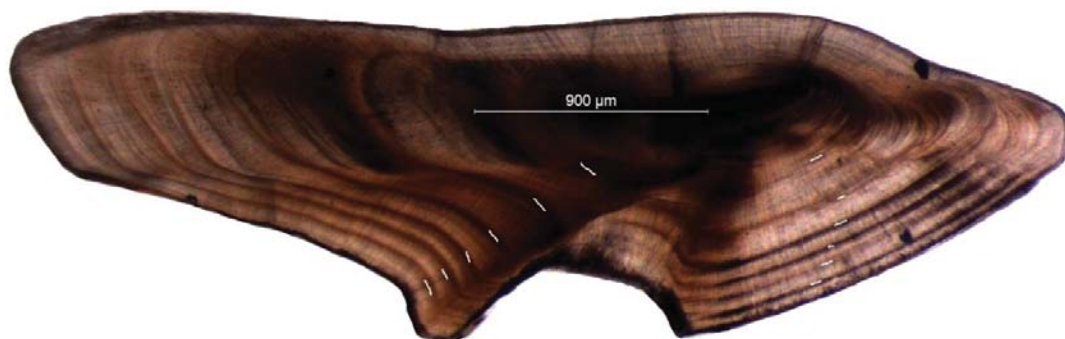

Fig. 5. Image of a representative transverse otolith section with annual increments are marked (aged at 6 years). The radius of the inner zone is consistent with the size of the otoliths of the 1+ cohort.
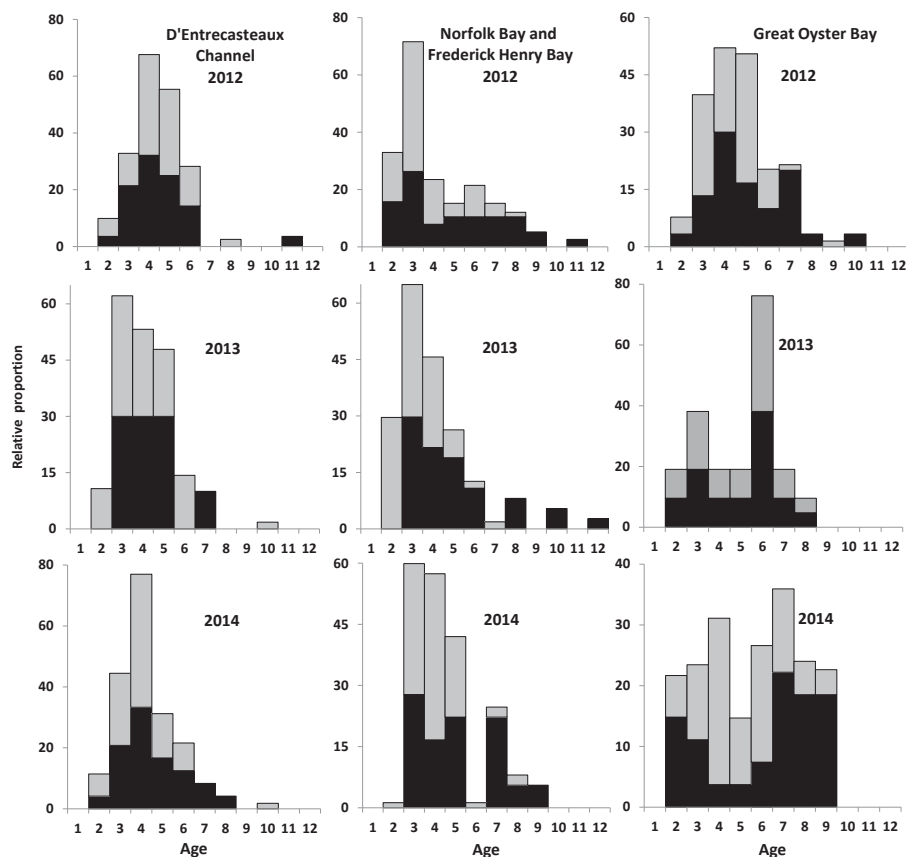

Fig. 6. Age frequency histograms for aged Sand Flathead, by region and year sampled. The black bars are males and grey bars are females.

Table 3. Age structure summary of Sand Flathead.

Area	Parameter	2012	2013	2014	All years
D'Entrecasteaux Channel	No. aged	107	66	79	252
	Minimum	2	2	2	2
	Maximum	11	10	10	11
	Mean	4.5	4.1	4.2	4.3
	Median	4	4	4	4
Frederick Henry-Norfolk Bay	No. aged	102	91	99	292
	Minimum	2	2	2	2
	Maximum	11	13	9	13
	Mean	4.1	4.1	4.2	4.2
	Median	3	3	4	4
Great Oyster Bay	No. aged	98	91	100	289
	Minimum	2	2	2	2
	Maximum	10	8	9	10
	Mean	4.5	4.8	5.4	4.9
	Median	4	4	5	5
All Regions	No. aged	307	248	278	833
	Minimum	2	2	2	2
	Maximum	11	13	10	13
	Mean	4.4	4.3	4.6	4.4
	Median	4	4	4	4

Table 4. Mean length at age of Sand Flathead by region, with years pooled.

"TL" refers to mean total length (mm), "SD" refers to the standard deviation of lengths at age, and "N" refers to the number of fish.

	D'Entrecasteaux Channel						Frederick Henry-Norfolk Bay						Great Oyster Bay					
	Female			Male			Female			Male			Female			Male		
Age	TL	SD	N	TL	SD	N	TL	SD	N	TL	SD	N	TL	SD	N	TL	SD	N
2	218	26	15	223	8.5	2	223	25	28	263	25	6	270	21	15	271	21	7
3	240	19	40	239	23	14	269	26	74	259	26	26	291	23	34	274	23	11
4	273	22	65	261	22	20	288	25	56	265	25	14	305	19	51	284	19	12
5	292	28	42	263	21	14	308	25	23	284	25	15	314	22	44	286	22	8
6	311	25	24	284	34	7	328	30	9	291	30	8	328	31	44	289	31	13
7	-	-	-	275	5	3	333	41	6	306	41	8	334	19	15	308	19	14
8	333	17	2	271	-	1	339	50	3	304	50	8	360	38	4	299	38	7
9	-	-	-	-	-	-	-	-	-	310	-	3	396	28	4	322	28	5
10	427	60	2	-	-	-	-	-	-	312	-	2	-	-	-	328	-	1
11	-	-	-	292	-	1	-	-	-	352	-	1	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	305	-	1	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	355	-	1	-	-	-	-	-	-

Table 5. **P values from bootstrap Kolmogorov-Smirnov tests for comparisons of Sand Flathead age structure.**
"DEC", "FHNB" and "GOB" refer to the D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay, and Great Oyster Bay regions and "All" refers to all regions pooled. A Bonferroni adjustment to *p*-values has been assigned to correct for multiple comparisons. Significant differences are in bold (α= 0.05/20).

Year	Region	2012		2013				2014			
		FHNB	GOB	DEC	FHNB	GOB	All	DEC	FHNB	GOB	All
2012	**DEC**	*<0.001*	0.94	0.05	-	-	-	0.23	-	-	-
	FHNB	-	-	-	0.58	-	-	-	0.01	-	-
	GOB	-	-	-	-	0.03	-	-	-	*<0.001*	-
	All	-	-	-	-	-	0.98	-	-	-	0.34
2013	**DEC**	-	-	-	0.87	0.009	-	0.70	-	-	-
	FHNB	-	-	-	-	*<0.001*	-	-	0.09	-	-
	GOB	-	-	-	-	-	-	-	-	0.004	-
	All	-	-	-	-	-	-	-	-	-	0.13
2014	**DEC**	-	-	-	-	-	-	-	0.99	*<0.001*	-
	FHNB	-	-	-	-	-	-	-	-	*<0.001*	-

2.4. Discussion

Catch size compositions indicate a low relative abundance of Sand Flathead above 300 mm. This phenomenon was the most obvious in the D'Entrecasteaux Channel samples, and particularly in 2014. In the Great Oyster Bay region the decline in the abundance of legal-sized fish was less pronounced, due in part to the presence of a relatively strong year class that had a strong influence on the catch size composition.

Recreational fishing effort is concentrated in the sampled regions and, based on 2007-08 fishing survey data, effort was proportionally higher in the D'Entrecasteaux Channel (24% of state-wide catches), followed by Frederick Henry-Norfolk Bay (23%), and the Central East coast (including Great Oyster Bay) (20%) (Lyle *et al*. 2009). It is likely, therefore, that the relatively low abundance of Sand Flathead above 300 mm in each of these areas can be attributed to the impacts of fishing rather than other factors, such as migration of larger individuals out of the study areas or differential (reduced) catchability of larger fish.

Ageing of Sand Flathead is well documented, with a robust validation protocol, and sectioned otoliths offer clear zonation and interpretable margins (Jordan 1998, Koopman 2005). The use of experienced agers, an inter-agency verified otolith reference library for training and high reader precision (IAPE <3%) confer confidence in the assignment of ages in this study. The presence and progression of a strong year class in samples from Great Oyster Bay site adds further confidence in the precision of age estimation procedures used in this study.

Age distributions from the D'Entrecasteaux Channel and Frederick Henry-Norfolk Bay regions were characterised by a modal age of 3-5 years and a sharp decline in the representation of older age classes. By contrast, the age structure in Great Oyster Bay was strongly influenced by the strong 2007 year class that progressed annually as the

modal age class, from 5 to 7 year olds during the three year sampling period. Based on sex ratio, there was an obvious bias towards males in age classes older than about 7 years in most of the samples. Given that females tend to be larger at age and recruit to the fishery at younger ages than males, it follows that fishing pressure would be greater on females than males and this would explain why males were proportionally more abundant in the age groups that had recruited to the fishery.

Two and three year olds were relatively abundant in all samples, providing evidence of on-going recruitment to the populations. Sand Flathead have a protracted spawning season which represents a reproductive strategy that maximises the likelihood of successful settlement even under the highly variable hydrographic conditions than characterise south eastern Tasmania (Harris *et al*. 1988). The presence of the particularly strong 2007 year class in the Great Oyster Bay samples, however, also indicates periodic variability in recruitment strength, a phenomenon previously reported for the species by Jordan (1998). The strong 2007 cohort was the main factor that was responsible for the significant regional differences between sample age structures and differences between years for Great Oyster Bay.

The fact that the occurrence of the strong cohort was restricted to Great Oyster Bay suggests that the conditions, biotic and/or abiotic, that proved favourable to spawning success were localised and not widespread. Great Oyster Bay is more open and exposed than either Frederick Henry-Norfolk Bay or the D'Entrecasteaux Channel and thus recruitment processes in the former may be influenced by a more variable supply of pelagic larvae due to reduced local area retention of eggs and larvae. However, Jordan (1998) reported evidence of recruitment variability in the D'Entrecasteaux Channel region and found the prevalence of Sand Flathead larvae in Norfolk Bay to be episodic within the spawning season. A longer time-series of age data would be required to examine the role of recruitment variability in structuring populations of Sand Flathead in Tasmania.

Size structure comparisons between regions and between years revealed more differences than comparable comparisons based on age structure. This is in part due to the lower statistical power of comparisons of age structure due to smaller sample sizes of aged fish but also emphasises the importance of considering age structure in the interpretation of trends in size, particularly for unsexed samples of a species which displays significant sex differences in growth (refer Section 4). Under these circumstances, minor changes in the sex ratio of catches which strongly influence size structure, will have a lesser effect on age structure.

3. GROWTH MODELLING

3.1. Introduction

Growth rate is a fundamental biological feature that can be responsive to the exploitation of fish stocks. For instance so-called downsizing of adults due to higher selectivity on fast growing fish (Alos *et al.* 2014), and increased population growth rates arising from reduced competition for resources (Brown *et al.* 2008, Ziegler *et al.* 2007). In addition, growth rates are responsive to environmental conditions such as temperature (Neuheimer *et al.* 2011), and may vary spatially within a population, a phenomenon well-documented in fish species in Tasmanian waters (Ewing 2004), including in Sand Flathead populations on the east coast of Tasmania (Bani 2005). Consequently, monitoring growth rates represent an important facet of any ongoing stock assessment and should be conducted such that trends take account of spatial and/or temporal factors associated with population sampling.

3.2. Methods

The von Bertalanffy growth function (VBGF) was fitted by nonlinear least-squares regression of length at age separately for males and females from each region. The form of the VBGF used was,

$$L_t = L_\infty \left(1 - e^{-K\,(t-t_0)} \right)$$

where L_t is the length at age t, L_∞ is the mean asymptotic total length, K is the growth coefficient or rate at which L_∞ is approached and t_0 is the age at which the fish have a theoretical length of zero. Five young-of the-year and five one year old juvenile Sand Flathead sampled by Jordan (1998) in February were included in each aged dataset to anchor growth functions with realistic juvenile sizes at age (noting that the youngest individuals sampled in the present study were two year olds).

Sex and regional differences in growth rates were examined using the likelihood ratio test (Kimura 1980). This statistic measures (i) the significance of departure from the null hypothesis that the two datasets being compared are sampled from the same population, and (ii) tests the significance of the contribution of each growth parameter to observed differences. A Bonferroni adjustment to *p*-values was applied to correct for multiple comparisons.

3.3. Results

Parameter estimates for the Von Bertalanffy growth functions are presented in Table 6 and length-at-age data are presented by region in Fig. 7. Females grow more quickly to higher asymptotic lengths than males in each of the regions. Estimated age at the MSL also display clear sex differences, with the oldest average female age at MSL (5.0 years in D'Entrecasteaux Channel) less than the youngest average male age at MSL (5.5 years in Great Oyster Bay).

Growth rate comparisons yielded highly significant differences between the sexes within each of the regions, and for the pooled dataset (Table 7). Significant differences in growth rates were explained by differences in the asymptotic length for each pairwise comparison, with the exception of the comparison of female growth rates between the D'Entrecasteaux Channel and Great Oyster Bay where the instantaneous growth constant (K) explained the regional difference.
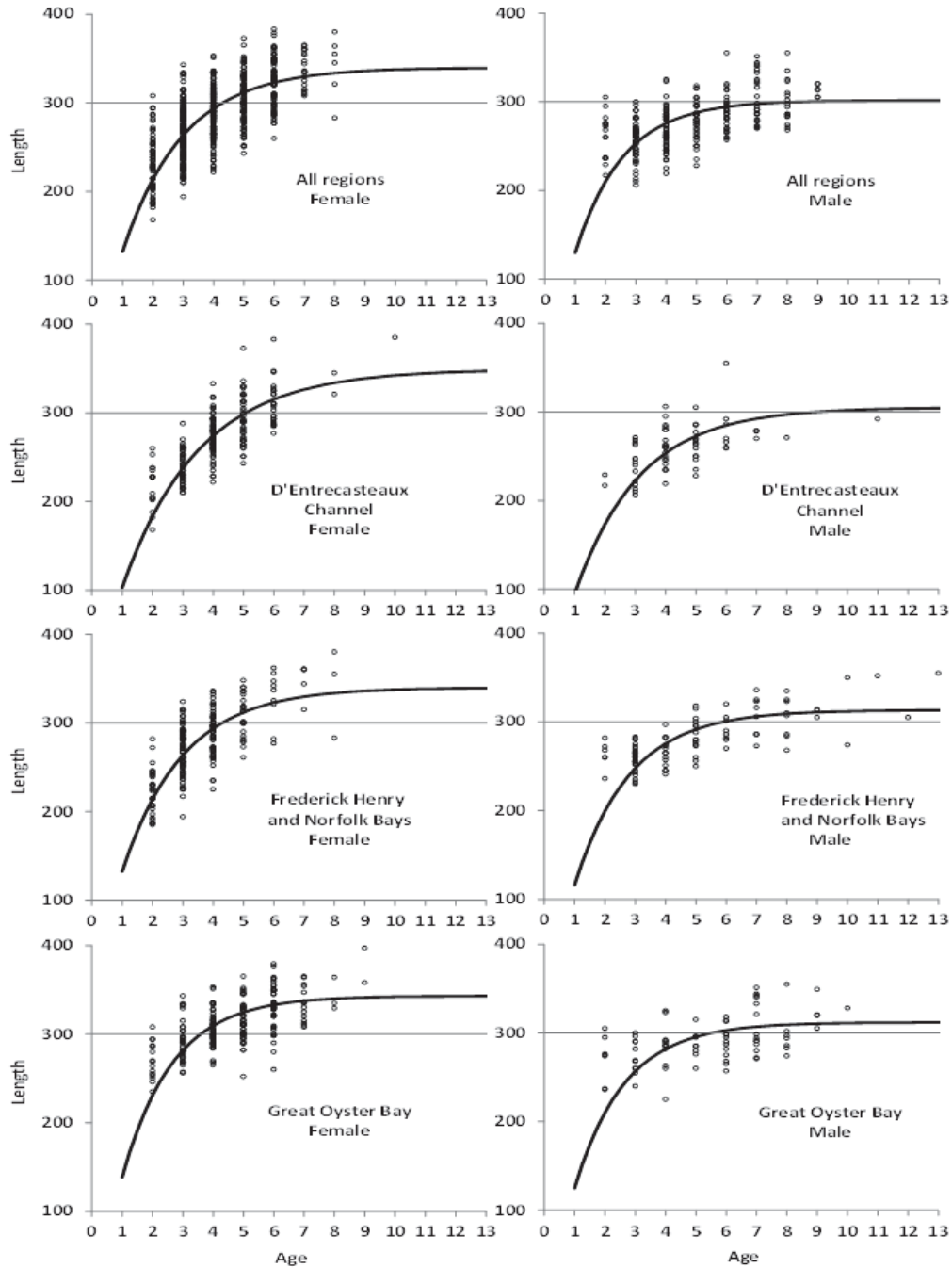

Fig. 7. Von Bertalanffy growth curves fitted to length-at- age data by sex from each of the three sampled regions. The line at 300 mm TL indicates the MSL.

Table 6.Von Bertalanffy growth parameters for Sand Flathead from each region, years pooled including the predicted age at the minimum size limit (MSL age) of 300 mm TL.

Sex	Region	K	L∞	t_0	MSL age	N
Female	Regions pooled	0.50	340	0.015	4.3	598
	D'Entrecasteaux Channel	0.39	349	0.11	5.0	190
	Frederick Henry-Norfolk Bay	0.51	343	0.16	4.2	198
	Great Oyster Bay	0.60	343	0.14	3.6	210
Male	Regions pooled	0.63	302	0.11	8.4	233
	D'Entrecasteaux Channel	0.47	305	0.21	9.0	62
	Frederick Henry-Norfolk Bay	0.55	313	0.16	5.9	93
	Great Oyster Bay	0.61	311	0.16	5.5	78

Table 7. Results from ratio likelihood tests for differences in von Bertalanffy growth models fitted for males and females within regions, and by sex between regions.

P values presented are for differences detected in L∞ as this was the only parameter driving significant differences in base-case comparisons. "DEC", "FHNB" and "GOB" refer to the D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay, and Great Oyster Bay regions and "All" refers to all regions pooled. A Bonferroni adjustment to *p*-values has been assigned to correct for multiple comparisons. Comparisons with significant differences in the L∞ parameter are in bold (α= 0.05/11).

Sex	Region	Male				Female	
		All	DEC	FHNB	GOB	FHNB	GOB
Female	All	**<0.001**	-	-	-	-	-
	DEC	-	**<0.001**	-	-	0.63	**<0.001***
	FHNB	-	-	**<0.001**	-	-	0.99
	GOB	-	-	-	**<0.001**	-	-
Male	DEC	-	-	0.54	0.64	-	-
	FHNB	-	-	-	0.87	-	-

*P value reported for comparison of instantaneous growth constants (k).

3.4. Discussion

Growth rate comparisons confirm that females grow more quickly and to larger maximum sizes than males. This difference has significant implications for Sand Flathead populations in that females become available to the fishery at younger ages than males. The situation is exacerbated in regions where differences in growth rates are greatest, and particularly where male growth rate is slow and maximum sizes are low. For example, the asymptotic length of males in the D'Entrecasteaux Channel region is only 5 mm above the MSL and thus the fishery in this area is primarily based on females (refer also Section 2).

Regionally, there was evidence of a general trend towards increasing growth rate and asymptotic sizes moving northwards from the D'Entrecasteaux Channel, to Frederick Henry-Norfolk Bay, with the highest values at Great Oyster Bay. However, this should be interpreted with some caution since sample sizes were low and the only statistically significant regional difference in growth rates was between the D'Entrecasteaux Channel and Great Oyster Bay for females. Further sampling would be required to allow for a more robust comparison of regional patterns in growth.

Monitoring temporal trends in growth rates can be a useful tool for inferring the impacts of fishing on fish populations. Given that the Sand Flathead fishery in Tasmania has probably been fished heavily for many years, and that anecdotal evidence suggests that catch rates have declined significantly over the past 50-60 years (Frijlink and Lyle 2013), there is also potential that aspects of the population dynamics, beyond size and age structures, have changed. As age and growth information from early in the fishery are not available, there is considerable value in developing a time series of how growth in areas subject to heavy fishing pressure respond when assessing stock status and the efficacy of management measures implemented to promote sustainability and even stock re-building.

4. MORTALITY AND YIELD PER RECRUIT

4.1. Introduction

Age and growth data can be used to infer the theoretical optimal size or age at first capture to maximise yield from populations. Yield per recruit (YPR) analysis examines the trade-offs between loss of biomass through natural mortality and the gains to biomass through the growth of individuals. This analysis is primarily used to assess the risk of growth over-fishing where fish are removed prior to reaching the size or age at optimal yield and involves constructing a model of the development of a cohort through time which takes into account the growth and mortality (natural and fishing) of individuals.

4.2. Methods

Length, sex and age data from the sub-samples of Sand Flathead retained for biological examination were used to generate a sex-length key (SLK) for each region and an age-length key (ALK) by sex and region. The SKL was used to assign sex to the entire (measured) catch sample for each region (based on 10 mm length class bins) and the ALK was used to convert these to an age composition for the entire sample derived from each region.

An estimate of the instantaneous rate of mortality was calculated by applying a catch curve analysis to the re-constructed age data by sex and by region (Pauly 1983, Ricker 1975), where the natural log of the number of fish at each age was regressed against age for the descending limb of the catch curve. The slope of the linear regression is the instantaneous annual mortality rate (Z).

Estimates of the instantaneous rate of natural mortality (M) were calculated by using two empirically based equations. The first uses the parameters from the von Bertalanffy growth equation and annual sea surface temperatures (Pauly 1980), and the second uses the maximum age recorded for the species (Hoenig and Lawing 1982). Natural mortality was assumed to be constant with age and time-invariant.

A yield per recruit analysis was undertaken by sex and by region by simulating growth and mortality for an individual cohort (year class) assuming that total mortality was the sum of natural and fishing mortality (F) (ie. $F = Z - M$), and assuming that F was constant across all age classes exposed to the fishery (Haddon 2001, Thompson and Bell 1934). Length-weight conversion parameters required for the yield per recruit model were based on a power function curve fitted to length and weight data based on fish retained for biological examination.

4.3. Results

Catch curves yielded higher values of Z for females than males in all the regions (Fig. 8, Table 8), and Z values were highest in the D'Entrecasteaux Channel but similar for the other two regions.

Catch curves for regions pooled showed a distinct inflexion in male values at around 6 years of age (Figs. 9 & 10), coinciding with the predicted age at which males generally attain legal size (Table 6). As a consequence two regressions were fitted to the data, providing an estimates of Z for those age classes not yet vulnerable to the fishery (i.e. $F \approx 0$; therefore $Z \approx M$), and an estimate for ages that had recruited to the fishery (≥ 7 years), incorporating both F and M. The former provided an approximation of M of 0.19 year^{-1} and Z for age classes vulnerable to the fishery of 0.61 year^{-1}. The Hoenig (1982) estimate of M using the maximum age recorded for Sand Flathead in Tasmania (17 years, Jordan 1998) was 0.25 year^{-1} (Table 8) and compared with Pauly (1980) estimates of M which ranged between 0.35-0.49 year^{-1}. In some regions the Pauly estimates of M exceeded Z (for males) derived from catch curves, suggesting that some may be implausibly high. For the purpose of modelling, M was estimated as the average of the three natural mortality values (i.e. males 2-6 years, the Hoenig and Pauly approximations).

Estimates of F presented in Table 8 were calculated by subtracting the averaged estimates of M from the catch curve derived estimates of Z. Fishing mortality rates were substantially higher for females (0.52-0.63) compared with males (0.11-0.25), with the highest exploitation rates in the D'Entrecasteaux Channel.

Yield per recruit modelling suggests that at current levels of F, YPR for females in Frederick Henry-Norfolk Bay and Great Oyster Bay are more or less maximised with a size at first capture corresponding to the current MSL (Fig. 11). The generally slower growth rate in the D'Entrecasteaux Channel resulted in the maximum yield being attained at sizes smaller than 300 mm. Optimal yields for males are attained at smaller sizes than 300 mm, reflecting slower growth and smaller maximum sizes attained by males.
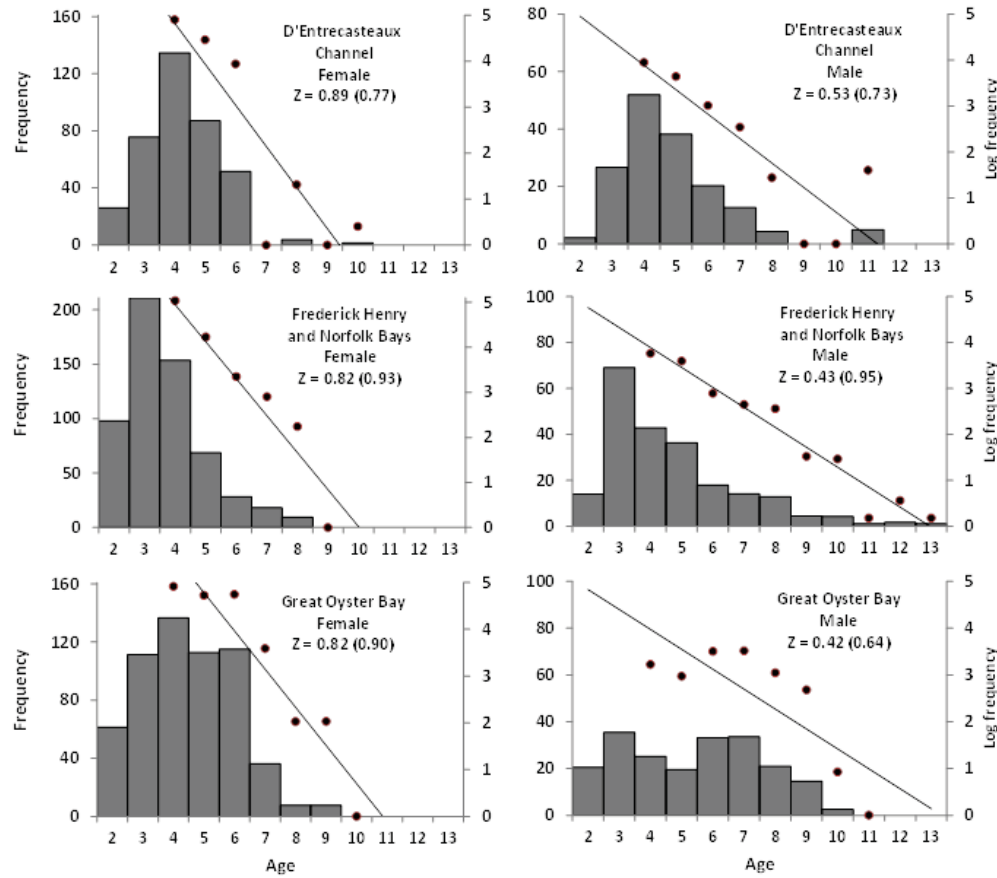
Fig. 8. Age structure and catch curves by sex and region. The left axes are the age frequency and the right axes are the natural log of the age frequency. "Z" (annual instantaneous mortality) is the slope of the regression of post-modal log frequency of age. The value in brackets is R^2 of the regression.

Fig. 9. Age structure and catch curves by sex with regions pooled. "Z" (annual instantaneous mortality) is the slope of the regression of post-modal log frequency of age. The value in brackets is R^2 of the regression.
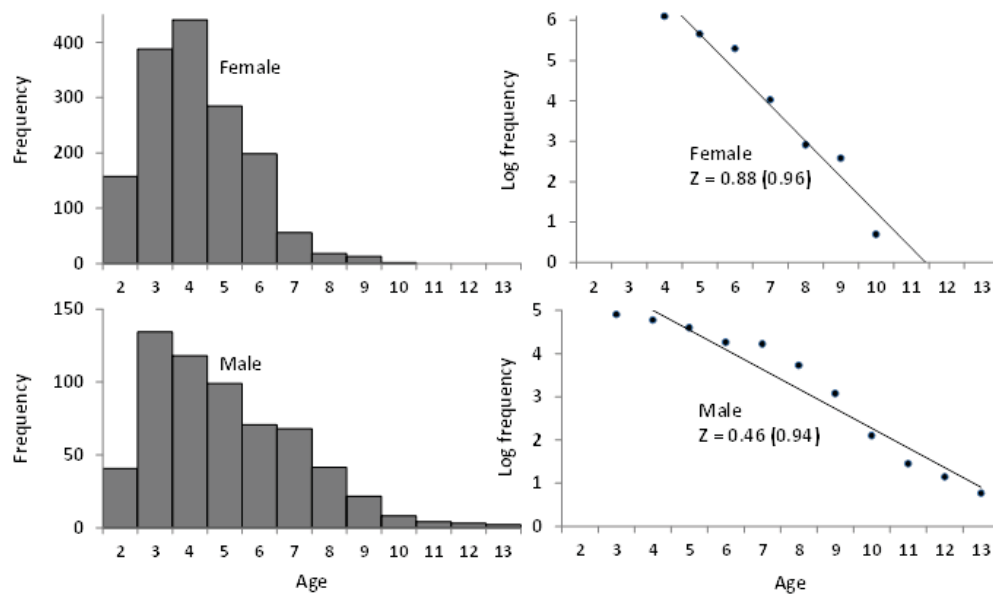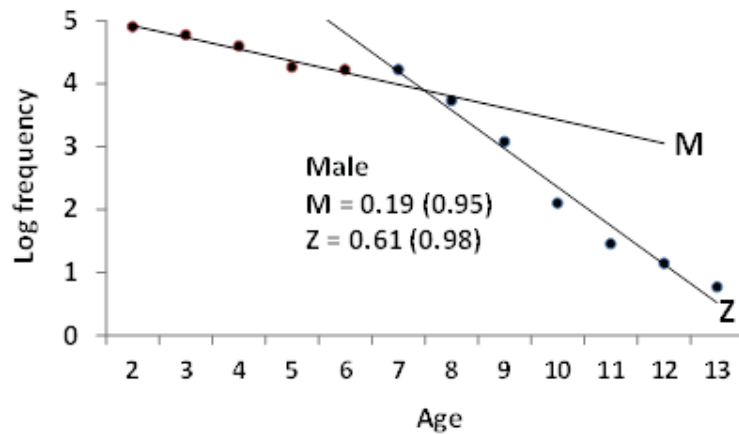
Fig. 10. Male catch curve (regions pooled) regressed in 2 stages around an inflexion at the age at which males become vulnerable to the fishery. "Z" is total mortality after recruitment to the fishery; "M" is an estimate of natural mortality. The value in brackets is R^2 of the regression.

Table 8. Sand Flathead population parameters for yield per recruit modelling.

"ALL" is regions pooled, "DEC" is the D'Entrecasteaux Channel region, "FHNB" is the Frederick Henry-Norfolk Bay region, and "GOB" is the Great Oyster Bay region. "Z" is total mortality derived from catch curves, "M_{Emp}" is natural mortality derived from the male catch curve, "M_{Hoenig}" is natural mortality derived from Hoenig's equation based on maximum age, "M_{Pauly}" is natural mortality derived from Pauly's equation based on growth parameters and sea-surface temperatures, "F" is fishing mortality [Z – (mean of 3 estimates for M)], and "a" and "b" are standard length-weight power curve parameters.

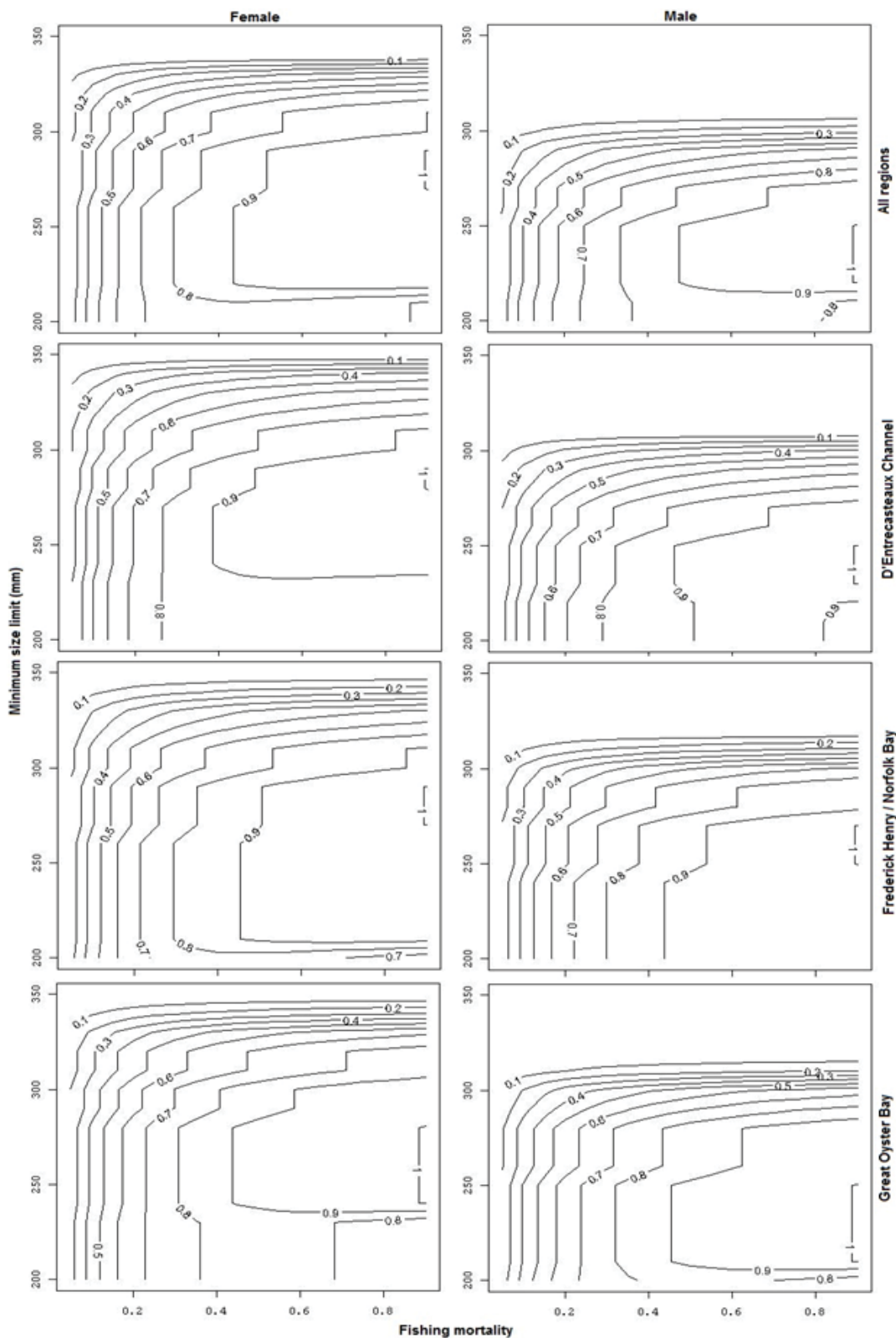| Parameter	ALL		DEC		FHNB		GOB	
	Fem	Male	Fem	Male	Fem	Male	Fem	Male
Z	0.88	0.46	0.89	0.53	0.82	0.43	0.82	0.42
M_{Emp}	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
M_{Hoenig}	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
M_{Pauly}	0.42	0.50	0.35	0.41	0.42	0.45	0.47	0.49
M_{Mean}	0.29	0.31	0.26	0.28	0.29	0.30	0.30	0.31
F	0.59	0.15	0.63	0.25	0.53	0.13	0.52	0.11
a	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
b	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20

Fig. 11. Yield per recruit scenarios by sex and region.

4.1. Discussion

Catch curve analyses have generated plausible estimates of total and fishing mortality, with higher rates for females which is consistent with their longer exposure to the fishery due to faster growth rates and greater maximum sizes. Despite falling well below the Pauly independent estimates of M, the empirical estimate derived from the initial phase of the male catch curve was generally consistent with the Hoenig independent estimate. The averaged estimates of M (ranging between 0.26-0.31, depending on sex and region) were comparable to that reported for the related Tiger Flathead (*Neoplatycephalus richardsoni*) (0.27year^{-1}) (Klaer 2010), and yielded overall rates of F for Sand Flathead of around 0.15 for males and 0.59 for females.

Yield per recruit analyses indicate that at current levels of fishing mortality for females the present legal size limit is appropriate in terms of achieving maximum yield per recruit. The situation for males is, however, quite different, with theoretical maximum yield being achieved at a much smaller size at first capture, reflecting the slower growth rates and smaller maximum sizes. As it is not possible to determine the sex externally in Sand Flathead, different minimum size limits would be impracticable.

In Tasmania, consideration is currently being given to a management initiated proposal to increase the MSL for Sand Flathead to 320 mm TL, the rationale being that harvested fish would, on average, provide a greater yield of edible flesh, noting that the species is primarily targeted for consumption rather than catch and release (Lyle *et al*. 2009). An increase in size at first capture would, however, result in a trade-off in reduced theoretical yield per recruit, mainly because growth has slowed and additional natural mortality will have occurred. This would be balanced by the combined effects of reducing the effective fishing mortality rate for the same level of effort (i.e. more of the catch being released) and conferring additional protection to the adult spawning stock, allowing most females to spawn for an additional year or so before entering the fishery. Clearly, it is desirable to allow more than one spawning season prior to females becoming vulnerable to the fishery, particularly with the high rates of fishing mortality experienced by females. Thus despite a likely reduction in YPR, an assessment of the benefits of an increase in the MSL for egg production using analyses such as egg per recruit or spawner biomass per recruit modelling is warranted. Overall, males are well protected by the current size limit, any increase in MSL would further reduce the fishing pressure on them.

5. CATCH RATE AS AN INDEX OF ABUNDANCE

5.1. Introduction

Catch per unit effort (CPUE) is an important metric in fisheries science and assessment (Maunder *et al*. 2006) that is frequently used as an index of fish abundance and to address management questions such as the status of fish stocks (Myers and Worm 2003), temporal trends in fisheries (Rosenberg *et al*. 2005), and assessment of the benefits to fisheries of marine reserves (Kaunda-Arara and Rose 2004). However, there is not always a direct relationship between catch rates and fish abundance (Harley *et al*. 2001). This is because CPUE is a function of both availability and catchability of the targeted fish species (Engås and Løkkeborg 1994), both of which may vary in space and time (see Wilberg *et al*. (2009) for review).

Availability of Sand Flathead in south eastern Tasmania is known to vary seasonally, largely influenced by the movement of mature fish between shallow and estuarine environments and deeper marine waters (Jordan 1998, Stehfest *et al.* 2014). This is due in part to the seasonal movement of mature fish and also to the influence on feeding motivation of environmental variables such as water temperature (Stehfest *et al*. 2014). Catchability refers to the likelihood that available fish will be captured by fishing gear and can depend on the fishing gear used, fisher skill, life history stage and/or environmental variables. For rod and line gear, which is the predominant method of capture in the Tasmanian fishery, catchability of Sand Flathead is highly dependent on receptiveness to bait and feeding motivation of individual fish, both of which can vary with environmentally mediated changes in fish activity (Stehfest *et al*. 2014). Catchability of Sand Flathead is known to vary seasonally, with higher catch rates towards the end of summer (February to March), and lower catch rates in winter (May to November).

To address the issues around seasonal trends in catchability and availability, Sand Flathead were sampled during the peak in catchability (February and March), allowing valid catch rate comparisons between years.

Catchability will also vary between fishers due to factors such as fisher experience and expertise, and bait presentation. To address such factors catch rates can be standardised for differences between fishers by defining the efficiency of each fisher relative to that of a standard (often hypothetical) fisher. Beverton and Holt (1957) developed a method which calculates the "relative fishing power" of each fisher in a fishery relative to a "reference fisher" on the basis of catches over a period where both the fisher and the reference fisher were fishing simultaneously.

$$RFP_i = \frac{C_i/E_i}{C_s/E_s}$$

Where RFP_i is the relative fishing power for fisher i, C_s and C_i are the total catch by the reference fisher and fisher i during the period in which both were in the fishery,

and E_s and E_i are the total effort by the reference fisher and fisher i during the same period.

The standardised catch rate I is then

$$I = \frac{\sum_i C_i}{\sum_i RFP_i \, E_i}$$

More recent approaches for standardising catch and effort data involve fitting statistical models which deal more effectively with multiple factors, zero catches, and fisheries without a continuity of reference fisher.

5.2. Methods

5.2.1. Raw catch rates

Raw catch rates were calculated as the sum of Sand Flathead catch numbers taken by all fishers at a given site, divided by the total line hours fished at that site (i.e. to calculate fish per line hour). Raw catch rates were then averaged across sites within a region and compared across years for the total catch of Sand Flathead and for the legal-sized catch (i.e. above the MSL of 300 mm TL).

5.2.2. Standardisation of catch rates

To correct for fisher effects, that is, variation in catches due to fisher skill rather than differences in fish abundance, catches were standardised using a modified version of the "Relative Fishing Power" method which involved adjusting each fisher's catches on the basis of the distribution of their catches relative to a reference fisher. As there was no single fisher that participated in sufficient fishing events to overlap with every other fisher, the fisher hosting the highest effort and the highest total catch (F1, 94 fishing events), was assigned as the reference fisher. Catches of the fisher with the second highest effort (F2, 66 fishing events) were standardised by the product of each raw F2 catch and the median from the distribution of ratios of F1/F2 coincident catches. The median value was chosen as a measure of central tendency because the distribution of ratios of coincident catches was highly skewed. Fisher F2 also had the highest overlap of fishing events with F1 (>50% of F2 fishing events). Catches of the fisher with the third highest effort (F3, 63 fishing events) were converted to standard catches by first converting fishing events that overlapped with F1 by the product of each raw F3 catch and the median from the distribution of ratios of F1/F3 coincident catches. Every other F3 fishing event coincided with an F2 event, so the remainder were converted to standard catches by the product of each raw F3 catch and the median from the distribution of ratios of standardised F2/F3 coincident catches. Catches from remaining fishers were standardised in the same manner giving preference to the fisher with the highest effort for coincident fishing events.

Standardised catch rates were calculated as the sum of standardised catches of all fishers at a site in a sample year, divided by the total number of line hours (i.e. standardised number of Sand Flathead per line hour). Standardised catch rates were compared by region and across sample years for the total catch and for the legal sized catch of Sand Flathead. It was assumed that relative fisher skill based on total catch also applied to catches of legal-sized fish. Levene's test was used to assess the

equality of variances; all standardised catch rate comparisons were significantly heteroscedastic. Consequently, standardised catch rates were compared using the non-parametric pairwise Mann-Whitney U test with a Bonferroni adjustment to *p*-values to correct for multiple comparisons.

5.2.3. Generalised linear model

Raw catch rates were fitted to a GLM (negative binomial error distribution) with fisher as a factor to compare a GLM model of relative fisher performance with standardised fisher catch rates. Raw catch rates were also fitted to a GLM (negative binomial error distribution) with fisher as a factor and an interaction between sample year and region. Tukey's post-hoc tests were conducted across sample years and regions with a Bonferroni adjustment to *p*-values to correct for multiple comparisons.

5.3. Results

Over the three years at total of 2178 Sand Flathead were captured, with minimal by-catch of other species (Table 9). In total 310, 249, and 278 Sand Flathead were retained for biological examination in 2012, 2013, and 2014 respectively. A further 323, 235 and 72 Sand Flathead were tagged and released in each of the three years; there were only four recaptures reported, precluding any quantitative analysis of movement, growth or fishing pressure on the released fish (a secondary project objective).

Sand Flathead catches for regions other than Great Oyster Bay were dominated by undersized fish (Table 10) and overall proportionally fewer undersized fish were captured in 2012 (55%), compared with 2013 (73%) and 2014 (65%). Females dominated the catch of legal sized fish in each region and year (Table 10).

Raw catch rates indicate some variability between regions and years, with lowest catch rates consistently recorded in the D'Entrecasteaux Channel, and lowest overall catch rates in all areas during 2014 (Fig. 12a). Highest raw catch rates were recorded in 2012 in Great Oyster Bay and 2013 in the D'Entrecasteaux Channel and Frederick Henry-Norfolk Bay regions. When standardised, however, the main change to this pattern was that 2013 catch rates were reduced to levels more comparable to those for 2014, reflecting the influence that two highly skilled fishers who only participated in 2013 had on the raw catch rate data (Fig. 12b). These two highly skilled fishers (both with a median catch ratio of >2 relative to the reference fisher) both participated in >75% of fishing events in 2013.

Overall, standardised catch rates in all regions were higher in 2012 than in successive sampling years for both total catch and for legal sized fish (Fig 12b,c). For the D'Entrecasteaux Channel, the 2012 standardised catch rate of legal-sized fish was significantly higher than for either 2013 or 2014. Furthermore, 2014 standardised catch rates (total and legal-sized) were significantly lower than for the two preceding years (Table 11). Whereas standardised total catch rates for Frederick Henry-Norfolk Bay did not differ significantly between years, legal-sized catch rates were significantly higher in 2012 than in both 2013 and 2014 (Table 11). In Great Oyster Bay, standardised total catch rates were significantly higher in 2012 compared with

2013 and 2014, and legal-sized catch rates were significantly higher in 2012 compared with 2013 but not 2014 (Table 11).

As an alternative to the catch rate standardisation reported above, a generalised linear model with fisher as the only factor yielded coefficients that were consistent with the ratios from the standardisation of the catch rates ($R^2 = 4.6$); and reported highly significant differences in catch rates between the reference fisher and the three fishers with the lowest catch rates. A second generalised linear model with fisher as a factor and an interaction between region and year also yielded fisher coefficients that were consistent with the ratios from the standardisation of the catch rates ($R^2 = 5.6$). Tukey's post-hoc tests, with a Bonferroni adjustment to *p*-values to correct for multiple comparisons yielded significantly lower catch rates in both total and legal-sized catches in the D'Entrecasteaux Channel in 2014 when compared with 2012 and 2013 (Table 12).
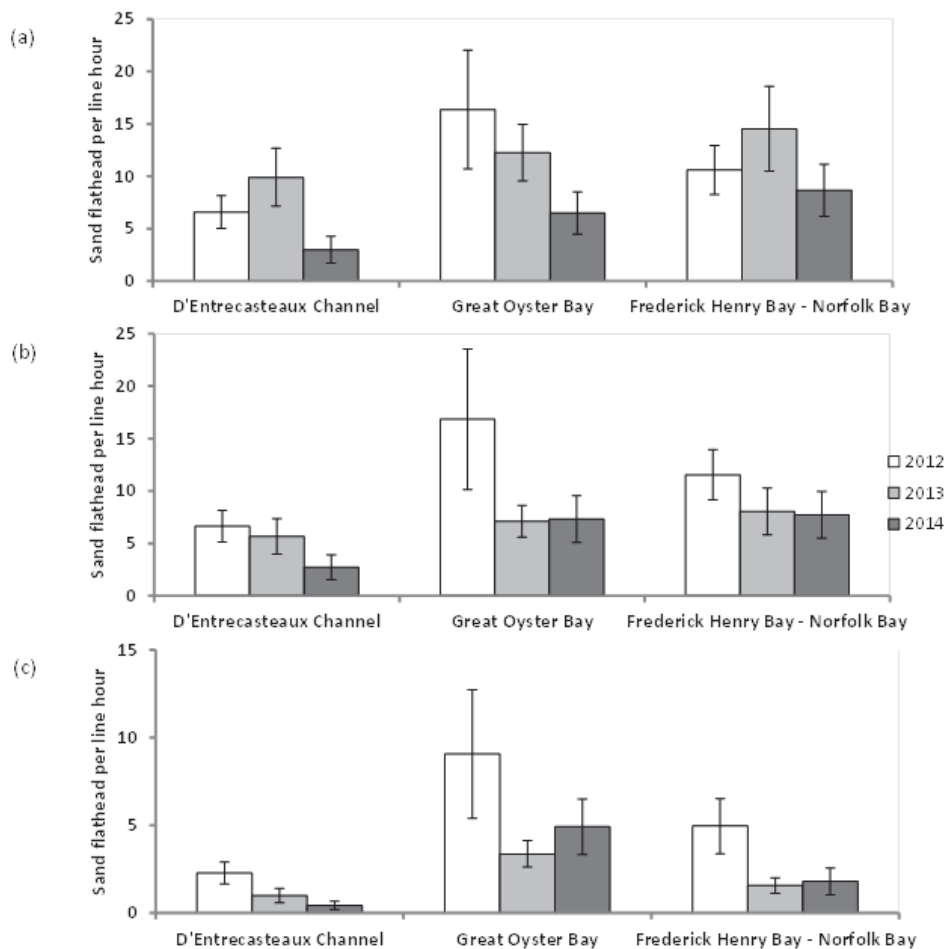

Fig. 12. Mean catch rates (fish per line hour) by region and year for Sand Flathead: (a) raw catch rates; (b) standardised catch rates; and (c) standardised catch rates for fish above MLS. Error bars represent 95% confidence intervals.

Table 9. Catch composition (numbers) from line fishing trials by year.

		Year		
Common Name	**Scientific Name**	**2012**	**2013**	**2014**
Sand Flathead	*Platycephalus bassensis*	833	995	350
Blue Throated Wrasse	*Notolabrus tetricus*	5	12	4
Barracouta	*Thyrsites atun*	6	9	7
Eastern School Whiting	*Sillago flindersi*		10	
School Shark	*Galeorhinus galeus*	4	6	
Red Gurnard Perch	*Helicolenus percoides*	6	9	6
Tiger Flathead	*Platycephalus richardsoni*	4	5	5
White Spotted Dogfish	*Squalus acanthias*	6	1	
Gummy Shark	*Mustelus antarcticus*	2	3	2
Red Cod	*Pseudophycis bachus*	3		
Jackass Morwong	*Nemadactylus macropterus*		2	
Australian Salmon	*Arripis trutta*		1	1
Barber Perch	*Caesioperca razor*		1	
Black Bream	*Acanthopagrus butcheri*		1	
Brown Striped Leatherjacket	*Meuschenia australis*	1		
Thornback Skate	*Dipturus whitleyi*			1
Latchet	*Pterygotrigla polyommata*			1
Senator Fish	*Pictilabrus laticlavius*		1	
Grand total		**870**	**1056**	**377**

Table 10. Numbers of Sand Flathead caught, mean number of fishers per site, ratio of legal to sub-legal sized individuals, and sex ratio (females to males) of Sand Flathead above MLS (based on samples retained for biological examination).

Year	Area	No. of fish	Mean N fishers	Legal size ratio	Female	Male	Legal size Sex Ratio
	D'Entrecasteaux Channel	191	2.76	0.45	20	3	6.67
2012	**Frederick Henry-Norfolk Bay**	287	2.67	0.73	26	15	1.73
	Great Oyster Bay	354	2.33	1.17	41	13	3.15
	D'Entrecasteaux Channel	296	2.95	0.20	12	0	-
2013	**Frederick Henry-Norfolk Bay**	371	2.68	0.20	11	5	2.20
	Great Oyster Bay	328	2.94	0.90	44	1	44.00
	D'Entrecasteaux Channel	77	2	0.15	10	0	-
2014	**Frederick Henry-Norfolk Bay**	156	2	0.31	19	4	4.75
	Great Oyster Bay	117	2	1.85	50	8	6.25

Table 11. The *p* values from pairwise comparisons of standardised catch rates (CPUE) for total catches and catches above the MSL using the Mann Whitney U test with a Bonferroni adjustment to *p*-values to correct for multiple comparisons.
Significant differences are in bold (α= 0.05/9).

Year	Area	Standardised CPUE		Standardised >MSL CPUE	
		2013	**2014**	**2013**	**2014**
	D'Entrecasteaux Channel	0.94	**0.002**	0.02	**<0.001**
2012	Frederick Henry-Norfolk Bay	0.12	0.09	0.008	0.02
	Great Oyster Bay	**0.002**	**0.002**	**0.002**	0.09
	D'Entrecasteaux Channel	-	0.02	-	0.2
2013	Frederick Henry-Norfolk Bay	-	0.9	-	0.9
	Great Oyster Bay	-	0.8	-	0.7

Table 12. The *p* values from Tukey's *post hoc* tests of the year and regions interaction of the GLM model of raw catch rates with a Bonferroni adjustment to *p*-values to correct for multiple comparisons.
Significant differences are in bold (α= 0.05/9).

Year	Area	Standardised CPUE		Standardised >MSL CPUE	
		2013	**2014**	**2013**	**2014**
	D'Entrecasteaux Channel	0.99	**<0.001**	0.99	**0.001**
2012	Frederick Henry-Norfolk Bay	0.94	0.65	0.13	0.02
	Great Oyster Bay	0.75	0.21	0.34	0.025
	D'Entrecasteaux Channel	-	**<0.001**	-	**<0.001**
2013	Frederick Henry-Norfolk Bay	-	0.11	-	0.99
	Great Oyster Bay	-	0.98	-	0.91

5.4. Discussion

Standardisation of catches for fisher effects had a marked impact on the 2013 catch rates, reducing them to levels comparable to those experienced in 2014 and highlighting the importance of taking fisher effects into account when calculating indices of abundance. Overall, standardised catch rates were substantially higher in 2012 than in subsequent years, some of the inter-annual catches rate comparisons being statistically significant, particularly for catch rates of legal sized fish. These results suggest that within the three year timeframe of this study there may have been a decline in Sand Flathead abundances in the D'Entrecasteaux Channel and Great Oyster Bay when compared with the abundance in 2012. Generalised linear model post-hoc tests supported the significant decline in catch rates for the D'Entrecasteaux Channel but not Great Oyster Bay. This difference is partly a result of the GLM model partitioning more of the variation in catch rates to regional and annual differences, which reduced the negative adjustment to catch rates in 2013.

Trends in CPUE infer that Sand Flathead abundances have declined in all regions since 2012; as a gradual decline over the three years in the D'Entrecasteaux Channel, as a

sharp fall to a lower level in the Great Oyster Bay region since 2012, and as a steep fall in legal-sized abundance in the Frederick Henry-Norfolk Bay region. The significance of the observed variation in CPUE for the Sand Flathead populations are uncertain because of the limited time series available and there may be alternative explanations for these patterns that are unrelated to variation in abundance. For instance, despite standardising for fisher effects and minimising seasonal influences by sampling at the same time each year, catchability may be influenced by the availability of natural prey and environmental factors such temperature, salinity and tidal movements (Stehfest *et al*. 2014), factors that could not be controlled in this study.

Given that environmental conditions are known to affect catchability and that fish populations can vary considerably over short temporal scales (Brewer *et al*. 1994, Pierce *et al.* 1998), an extended time series of monitoring catch rates, coupled with biological sampling, will greatly improve the utility of CPUE as an indicator of trends in population abundance and status. The present CPUE analyses therefore, should be seen as a baseline against which future changes in the populations can be measured.

6. SUMMARY AND RECOMMENDATIONS

Assessment of the stock status of Sand Flathead in Tasmania is desirable for a number of reasons, including the species role as an important predator in inshore coastal ecosystems; their high importance to the Tasmanian recreational fishery; high exploitation rates in the southeast and east coasts; anecdotal evidence of substantial declines in catch rates over the history of the fishery; and a perception among many recreational fishers that the quality of the fishery has fallen dramatically in recent years.

This study has established that the size structure of Sand Flathead is characterised by a sharp reduction in the abundance of size classes greater than the legal size limit (300 mm TL), along with a sharp fall in the relative abundance of age classes that have reached legal size. This pattern suggests that fishing pressure on legal sized biomass is high and/or that the larger and older sizes classes are less vulnerable to the sampling methods deployed in this study; other indicators presented in this study suggests that the former may be the primary factor influencing population structure.

Female Sand Flathead grow more quickly and to larger maximum sizes than males, reaching the MSL at younger ages than males. As a consequence, females have greater vulnerability to the fishery than males, and this was evidenced by a bias in the catch of legal-sized fish towards greater numbers of females as well as the age classes above the age at which females reached the legal size limit being dominated by males. Catch curve analysis confirmed the fact that due to these differences in growth, the rates of fishing mortality were significantly higher on females than males, that is the female segment of the adult population bears the brunt of the fishing pressure.

Sand Flathead stocks in D'Entrecasteaux Channel appear to be the most heavily depleted of the study regions. This is plausible since in 2008-09 the region attracted higher fishing effort and catches of Sand Flathead than either of the other study areas (Lyle *et al*. 2009). Exploitation rates were lower but comparable for both Frederick Henry-Norfolk Bay and Great Oyster Bay regions, the latter receiving some population benefit from the presence of a strong year class that recruited to the fishery in the area at around the time sampling for this project commenced.

Catch rates are routinely used as an index of relative abundance in many stock and fishery assessments. In this study we applied two methods to standardise for fisher effects, the relative fishing power and GLM methods. Standardised catch rates were lowest in the D'Entrecasteaux Channel and highest in the Great Oyster Bay region, which is consistent with the former area experiencing higher rates of fishing mortality than either of the other two regions. Catch rates were also highest in the first year of sampling (2012) in all regions. In subsequent years catch rates either declined steadily (D'Entrecasteaux Channel) or stabilised at a lower level (Frederick Henry-Norfolk Bay and Great Oyster Bay). These data suggest that even within the short timeframe of this study abundances appear to have declined; the limited timeframe does not, however, make it possible to determine whether this is part of a long-term trend or inter-annual variability. As environmental conditions are known to affect the catchability of Sand Flathead, and as fish populations can vary considerably over short temporal scales (Brewer *et al.* 1994, Pierce *et al*. 1998), caution needs to be exercised in making inferences about abundances. This uncertainty underscores the necessity to accrue a

longer time-series to provide greater confidence in significance of any trends in catch rates as indicators of changes in stock abundance.

A secondary objective of this project was to examine movement patterns based on conventional tagging to inform on factors such as seasonal variability in availability and mixing between areas important to the fishery. Despite the release of 630 tagged flathead over the course of this project, no tag recaptures were recorded in research fishing, and only four were reported from recreational fisher catches. The maximum time at liberty of a recaptured Sand Flathead was 308 days and the longest distance travelled was 8 km. This represents an exceptionally low recapture rate (< 1%), which could be due to high mortality rates of tagged fish (or significant tag loss), underreporting of tag recaptures and/or indicative of very low exploitation rates (i.e. a very large population of Sand Flathead). Fishing mortality rates (especially for legal-sized fish) would suggest that the latter was unlikely and post release survival studies (coupled with tagging of individuals >290 mm) would also suggest that survival of tagged fish is likely to be high (Lyle *et al*. 2007), leaving low reporting rates of recaptures a distinct possibility. Greater promotion of the tagging program amongst recreational fishers would appear to be a priority if tagging were to be continued.

Yield per recruit analyses suggest that at current levels of fishing mortality, the present legal size limit is appropriate in terms of achieving maximum yield per recruit for females. The situation for males is, however, quite different, with maximum yield being achieved at a smaller size at first capture. As it is not possible to determine the sex externally in this species, differential minimum size limits would be impracticable.

Evidence of heavy depletion over the history of the fishery (Frijlink and Lyle 2013), the observed decline in catch rates over the term of this study, the limited number of spawning seasons before many females recruit to the fishery, and the dominance of females in retained catches indicate a need to reduce fishing pressure (especially on females) and provide additional protection for spawning females. Management options to achieve this include increasing the minimum size limit, reducing bag and possession limits, and/or closures during the spawning season.

An increase in the minimum size limit to 320 mm TL which has been proposed by management would have immediate benefits to the Sand Flathead stocks. These include a reduction in the effective rate of fishing mortality for the same level of effort (i.e. more of the catch would be undersized and released[2]) and additional protection conferred to the adult spawning stock, allowing females to spawn for an additional year or so before entering the fishery. These benefits would be offset by a reduction in the theoretical yield per recruit, a greater bias in catches towards the retention of females and reduction in harvest rates and potentially an associated reduction fisher

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[2] Lyle *et al*. (2007) have established that post release survival rates are very high in Sand Flathead, so incidental mortality associated with the increased numbers of released fish is expected to be low.

satisfaction. These latter effects are likely to be more short-term, allowing time for the fish to grow from the current to the new size limit.

High exploitation rates, the significance of the species to the recreational fishery and uncertainty about population status emphasise the importance of monitoring of stock trends and implementing options to reduce fishing pressure. In the absence of fishery-based indicators, noting that recreational surveys are conducted sporadically (every five years or so) and commercial catches (and catch rate data) for Sand Flathead are limited and may not be representative of trends in population status, fishery-independent catch sampling represents a viable option to monitor trends in stock status and population structure. The present catch sampling regime has provided important information about the stock status in the main regions of the fishery and a baseline against which future changes in abundance and management initiatives could be assessed. Being able to standardise for fisher effects also supports the cost-effectiveness of this method as it allows a larger number of fishers, including volunteer fishers, to be utilised opportunistically for data collection.

In summary, the present study has demonstrated that research surveys based on up to 10 days of field sampling per year have the potential to provide a low-cost (less than $10,000 per annum in operating costs) index of population and fishery status for Sand Flathead. It is recommended, therefore, that the monitoring regime developed in this study be implemented to support the on-going monitoring and assessment of Sand Flathead in Tasmania, with data to contribute to the annual assessment of the scalefish fishery.

7. ACKNOWLEDGEMENTS

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