Fishery-independent monitoring of sand flathead population dynamics

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Contents

Background

Southern sand flathead (*Platycephalus bassensis*; hereafter, sand flathead) have been assigned a depleting stock status in the past three scalefish fisheries assessment reports (Fraser et al 2021). Recreational catches dominate landings of sand flathead, and populations are subject to heavy fishing pressure in southeast and eastern Tasmania. The Fishwise project *Developing a low-cost monitoring regime to assess relative abundance and population characteristics of sand flathead* (Ewing and Lyle 2014) recommended the establishment of an annual fishery-independent survey of sand flathead. This methodology uses the fishing gear and targeting practices typical of recreational fishers, conducting sampling in the areas of significant effort of the fishery, and during the highest catchability period (January – March). Annual sampling commenced in 2015 (Ewing and Lyle 2015). Also on the basis of recommendations in Ewing and Lyle (2014) the Department of Natural Resources and Environment applied an increase to the size limit for sand flathead from 300mm to 320mm total length (TL), and a decrease in the daily bag limit from 30 to 20 (sand and tiger flathead combined) for the Tasmanian recreational fishery; effective from 1st November 2015. While the increase in the minimum size limit in 2015 and a reduction in the bag limit seemed to initially reduce catches, current levels of fishing pressure, particularly on females, could still cause the stock to become recruitment impaired (Fraser et al 2021).

Methods

Size structure

Sand flathead were sampled from three regions: D'Entrecasteaux Channel, Frederick Henry-Norfolk Bay and Great Oyster Bay (Fig. 1) from January until April 2022. Fishing was generally conducted within a maximum of three (not necessarily consecutive) days per region, with between 18-21 sites fished in each region. Sites sampled in 2022 were those originally established in Ewing and Lyle (2014) and represent a range of suitable habitats (including depths) for targeting sand flathead and provide wide spatial coverage within the given region (Fig. 1).

Sampling was 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 three fishers for 30 minutes, with the vessel allowed to drift. All fish caught were measured (sand flathead were measured for total length, other species were measured for fork length) and the name of the fisher recorded. The first 100 sand flathead landed within each region, regardless of size, were retained for biological assessment including total length, weight, sex, gonad stage, gonad weight, and age estimation.

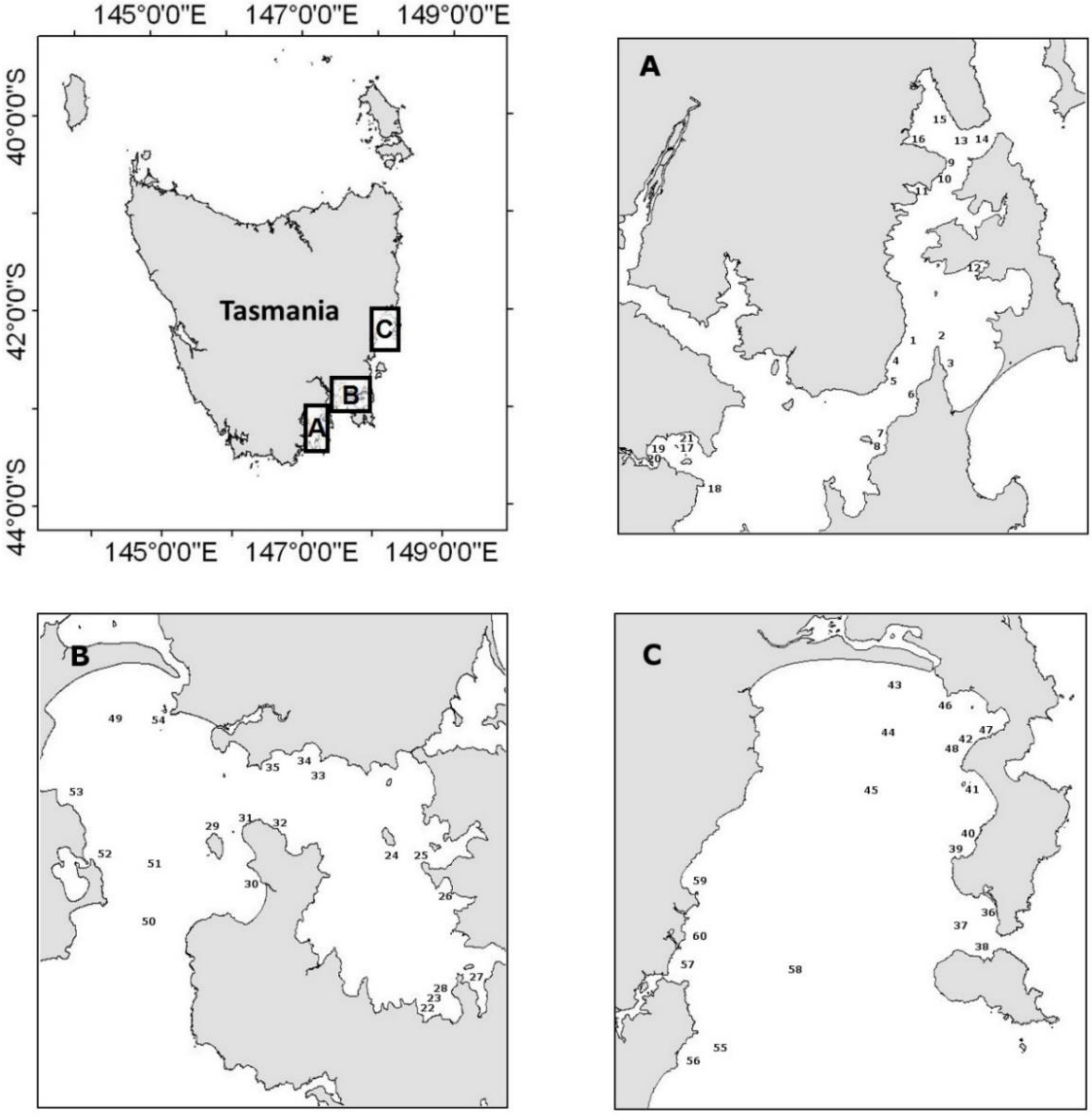

Fig. 1. Map showing sampling regions; (A) D'Entrecasteaux Channel, (B) Frederick Henry-Norfolk Bay and (C) Great Oyster Bay. Sample sites within regions are numbered.

Age structure

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 following the ageing protocol established by Jordan (1998). A library of 100 randomly selected otoliths were 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.

The von Bertalanffy growth function (VBGF) was fitted, by nonlinear least-squares regression, to the length at age for both 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 estimated total 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.

Mortality

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 SLK was used to assign sex to the entire (measured) catch sample for each region (based on 10 mm length classes) 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 (Ricker 1975, Pauly 1983), 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 three empirically based equations. The first uses the parameters from the von Bertalanffy growth equation and annual sea surface temperatures (Pauly 1980), the second was estimated from catch curves of male flathead prior to the age at which they are targeted by the fishery (Ewing and Lyle 2014), and the third uses the maximum age recorded for the species (Hoenig and Lawing 1982). Natural mortality was assumed to be constant with age and time-invariant. Total mortality was calculated as the sum of natural and fishing mortality (F) (i.e., $F = Z - M$), and assuming that F was constant across all age classes exposed to the fishery (Thompson and Bell 1934, Haddon 2001). Z is derived from catch curves and F is fishing mortality [Z – (mean of two estimates for M)].

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 the catch of legal-sized individuals (i.e., above the MSL of 320 mm TL).

Catch rates were also standardised relative to a reference fisher. The fisher hosting the highest effort and the highest total catch in six of the previous eight years of sampling (F1, 406 fishing events), was present for every fishing event of the 2022 sampling season. Consequently, 2022 catches for each fisher (F_n) were standardised by the product of each of their raw catches and the median from the distribution of ratios of F1/ F_n coincident catches.

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). It was assumed that relative fisher skill based on total catch also applied to catches of legal-sized fish for the MSL (320 mm).

Results

Size structure

Sampling conducted in 2022 yielded 497 sand flathead with very low bycatch (Table 1). The smallest individual encountered in the 2022 sampling was 119 mm and captured in the Frederick Henry-Norfolk Bay region. The largest fish encountered was 515 mm and captured in Great Oyster Bay (Table 2).

Sand flathead catches were dominated by undersized fish and, as in previous years, females dominated the catch of legal sized fish in each region (Tables 3 and 4).

The length structure of sand flathead in the D'Entrecasteaux Channel and Frederick Henry-Norfolk Bay is still dominated by fish smaller than minimum size limit, i.e., 320 mm (Figs 2, 3, 4). However, catches in 2022 at Great Oyster Bay show a higher proportion of fish ≥ 320 mm than in 2021, with a ratio of undersize (< 320 mm) to size sand flathead increasing form 0.07:1 in 2021 to 0.29:1 in 2022 (Table 3).

Age structure

Ages were estimated for 301 sand flathead sampled in 2022. The oldest individual was an 11-year-old male captured in Frederick Henry Bay (315 mm). The largest fish aged was 408 mm (9-year-old) female, also caught in Frederick Henry Bay. The youngest fish encountered were 2-year-olds, caught in the D'Entrecasteaux Channel and Great Oyster Bay (Table 5).

The abundance and proportion of females declines rapidly in the older age classes reflecting the earlier exposure of this sex to the fishery due to their faster growth rate (Figs. 5a, b).

Estimates of the von Bertalanffy growth parameters are presented in Table 6a, b and length-at-age data are presented by region in Fig. 6a, b. The higher estimates of *k* for males demonstrate that they grow more quickly to their asymptotic lengths, which are 10 - 20% smaller than their females (Table 6a, b). Estimated age at the MSL (320 mm TL) also display clear sex differences. Based on the von Bertalanffy growth curves, females, on average, do not attain the MSL until between 5 and 8 years and males in the three regions in south-eastern Tasmania and males in the D'Entrecasteaux Channel and Greater Oyster Bay, on average, never attaining a size greater than the MSL.

Table 1. The composition (abundance) of teleost, shark and cephalopod species caught while line fishing for sand flathead between 2012 and 2022.

Common Name	**Scientific Name**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Sand flathead	*Platycephalus bassensis*	833	995	350	562	418	709	902	654	753	915	497
Blue mackerel	*Scomber australasicus*							1		15		
School shark	*Galeorhinus galeus*	4	6		3	3	4	19	6	9		
Blue throated wrasse	*Notolabrus tetricus*	5	12	4	8	9	14	6	8	6	2	1
Barracouta	*Thyrsites atun*	6	9	7	13	11	6		2	6	1	
Jack mackerel	*Trachurus declivis*											
Eastern school whiting	*Sillago flindersi*		10		4	6	4	10		1	7	1
Common gurnard perch	*Neosebastes scorpaenoides*	6	9	6	2		2	1	1	2	1	2
Tiger flathead	*Platycephalus richardsoni*	4	5	5	1		6					
Blue spotted Flathead	*Platycephalus speculator*											
Jackass morwong	*Nemadactylus macropterus*		2				2					
White spotted dogfish	*Squalus acanthias*	6	1		2		10	2		1	2	
Sixspine leatherjacket	*Meuschenia freycineti*						1			1		
Elephant fish	*Callorynchus millii*		1			1						
Senator fish	*Pictilabrus laticlavius*					1						
Gummy shark	*Mustelus antarcticus*	2	3	2	1			4		3	2	1
School shark	Galeorhinus galeus											8
Red cod	*Pseudophycis bachus*	3								1	3	2
Australian salmon	*Arripis trutta*		1	1								
Barber perch	*Caesioperca razor*		1									
Snapper	*Chrysophrys auratus*											1
Brown striped leatherjacket	*Meuschenia australis*	1			1							
Thornback skate	*Dipturus whitleyi*			1								
Latchet	*Pterygotrigla polyommata*			1						1		
Smooth toadfish	*Tetractenos glaber*							1				1
Arrow squid	*Nototodarus gouldi*										1	1
Grand total		**870**	**1056**	**377**	**597**	**449**	**758**	**946**	**671**	**805**	**934**	**515**

Table 2. The total number (*n*) and the minimum (min), maximum (Max), mean and median size (total length, mm) of sand flathead caught in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2012 and 2022.

Area	Parameter	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	All years
D'Entrecasteaux Channel	***n***	191	296	79	161	141	301	372	232	396	425	119	2656
	Min.	205	173	205	175	222	195	168	190	145	180	224	145
	Max.	396	470	390	366	365	410	402	338	390	365	397	470
	Mean	284	268	274	282	281	282	277	265	270	273	281	275
	Median	285	270	271	283	279	280	280	266	270	275	280	275
Frederick Henry-Norfolk Bay	***n***	287	371	156	211	87	192	283	200	175	158	178	2356
	Min.	147	171	205	200	202	119	109	175	170	200	205	119
	Max.	408	398	380	375	378	430	393	401	436	385	420	436
	Mean	291	263	277	279	282	278	281	282	283	279	293	279
	Median	290	262	273	280	278	280	282	282	285	270	290	280
Great Oyster Bay	***n***	354	328	117	190	190	216	247	222	182	331	196	2574
	Min.	225	222	220	195	215	232	200	223	230	208	215	195
	Max.	397	399	440	515	385	455	442	404	405	410	385	515
	Mean	303	297	316	312	304	310	304	309	294	300	299	304
	Median	300	296	310	310	302	307	303	306	290	300	300	302
All Regions	***n***	832	995	350	562	418	709	902	654	753	914	493	7584
	Min.	147	171	205	175	202	119	168	175	145	180	205	119
	Max.	408	470	440	515	385	455	442	404	436	410	420	515
	Mean	295	276	289	291	292	290	286	285	279	285	292	286
	Median	295	275	285	290	288	290	287	286	280	285	290	285

Table 3. The total number of sand flathead caught in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2012 and 2022, the mean number (N) of fishers per site and ratio of fish ≥ legal size (i.e., 320 mm) to fish < legal size.

Year	Area	No. of fish	Mean N fishers	MSL ≥ 320
2012	**D'Entrecasteaux Channel**	191	2.76	0.15
	Frederick Henry-Norfolk Bay	287	2.67	0.26
	Great Oyster Bay	354	2.33	0.39
2013	**D'Entrecasteaux Channel**	296	2.95	0.03
	Frederick Henry-Norfolk Bay	371	2.68	0.10
	Great Oyster Bay	328	2.94	0.39
2014	**D'Entrecasteaux Channel**	77	2	0.10
	Frederick Henry-Norfolk Bay	156	2	0.12
	Great Oyster Bay	117	2	0.83
2015	**D'Entrecasteaux Channel**	161	2.75	0.14
	Frederick Henry-Norfolk Bay	211	3	0.10
	Great Oyster Bay	190	5	0.83
2016	**D'Entrecasteaux Channel**	141	3	0.07
	Frederick Henry-Norfolk Bay	87	3	0.18
	Great Oyster Bay	190	3	0.48
2017	**D'Entrecasteaux Channel**	301	3.18	0.14
	Frederick Henry-Norfolk Bay	216	3.33	0.18
	Great Oyster Bay	192	3	0.56
2018	**D'Entrecasteaux Channel**	372	2.7	0.13
	Frederick Henry-Norfolk Bay	283	3	0.16
	Great Oyster Bay	247	3	0.39
2019	**D'Entrecasteaux Channel**	232	2.4	0.04
	Frederick Henry-Norfolk Bay	222	2	0.25
	Great Oyster Bay	200	2	0.60
2020	**D'Entrecasteaux Channel**	396	3	0.07
	Frederick Henry-Norfolk Bay	175	3	0.18
	Great Oyster Bay	182	3	0.23
2021	**D'Entrecasteaux Channel**	425	3	0.09
	Frederick Henry-Norfolk Bay	158	3	0.15
	Great Oyster Bay	331	3	0.3
2022	**D'Entrecasteaux Channel**	119	2.9	0.09
	Frederick Henry-Norfolk Bay	178	2.6	0.18
	Great Oyster Bay	196	3	0.29

Table 4. The numbers of sand flathead caught in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2012 and 2022 that were retained for biological analysis and the sex ratio of females to males in those fish ≥ legal size (i.e., 320 mm). "NM" refers to no males captured.

Year	Area	No. of fish	MSL ≥ 320 Sex Ratio
2012	D'Entrecasteaux Channel	107	10:1
	Frederick Henry-Norfolk Bay	103	2:1
	Great Oyster Bay	100	2.7:1
2013	D'Entrecasteaux Channel	67	NM
	Frederick Henry-Norfolk Bay	121	8:1
	Great Oyster Bay	61	NM
2014	D'Entrecasteaux Channel	79	NM
	Frederick Henry-Norfolk Bay	99	8:1
	Great Oyster Bay	100	7.6:1
2015	D'Entrecasteaux Channel	107	7:1
	Frederick Henry-Norfolk Bay	101	2.5:1
	Great Oyster Bay	103	15.5:1
2016	D'Entrecasteaux Channel	98	NM
	Frederick Henry-Norfolk Bay	80	NM
	Great Oyster Bay	100	NM
2017	D'Entrecasteaux Channel	106	11:1
	Frederick Henry-Norfolk Bay	102	14:1
	Great Oyster Bay	107	23:1
2018	D'Entrecasteaux Channel	101	NM
	Frederick Henry-Norfolk Bay	100	1.5:1
	Great Oyster Bay	102	NM
2019	D'Entrecasteaux Channel	100	NM
	Frederick Henry-Norfolk Bay	100	3.25:1
	Great Oyster Bay	99	22:1
2020	D'Entrecasteaux Channel	101	NM
	Frederick Henry-Norfolk Bay	101	2:1
	Great Oyster Bay	99	NM
2021	D'Entrecasteaux Channel	110	NM
	Frederick Henry-Norfolk Bay	109	NM
	Great Oyster Bay	102	NM
2022	D'Entrecasteaux Channel	68	NM
	Frederick Henry-Norfolk Bay	123	10:1
	Great Oyster Bay	109	NM

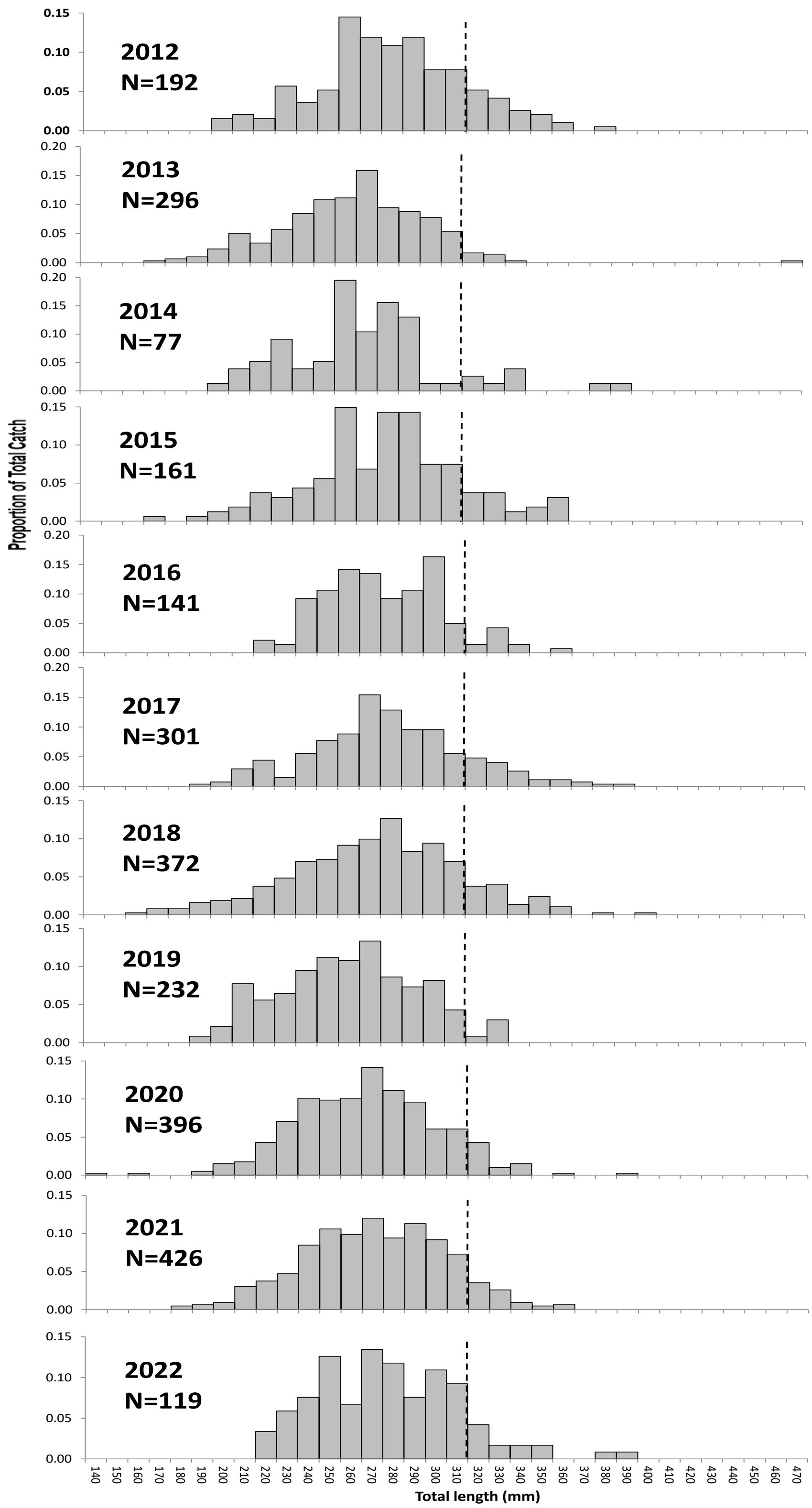

Fig. 2. Length frequency histograms for sand flathead captured in the D'Entrecasteaux Channel region between 2012 and 2022. Dotted lines indicate the minimum legal-size limit (320 mm).

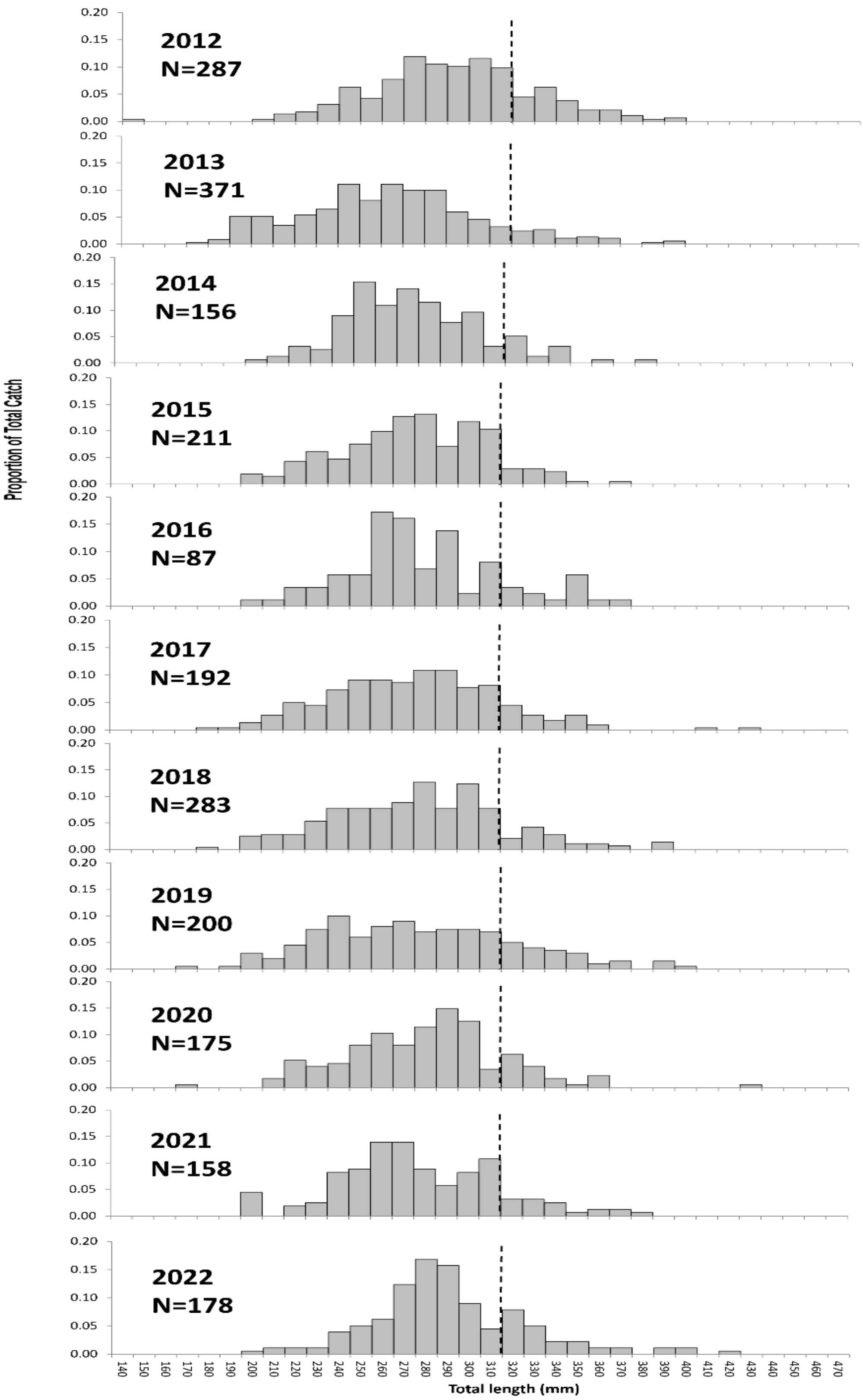

Fig. 3. Length frequency histograms for **s**and flathead captured in the Frederick Henry-Norfolk Bay region between 2012 and 2022. Dotted lines indicate the minimum legal-size limit (320 mm).

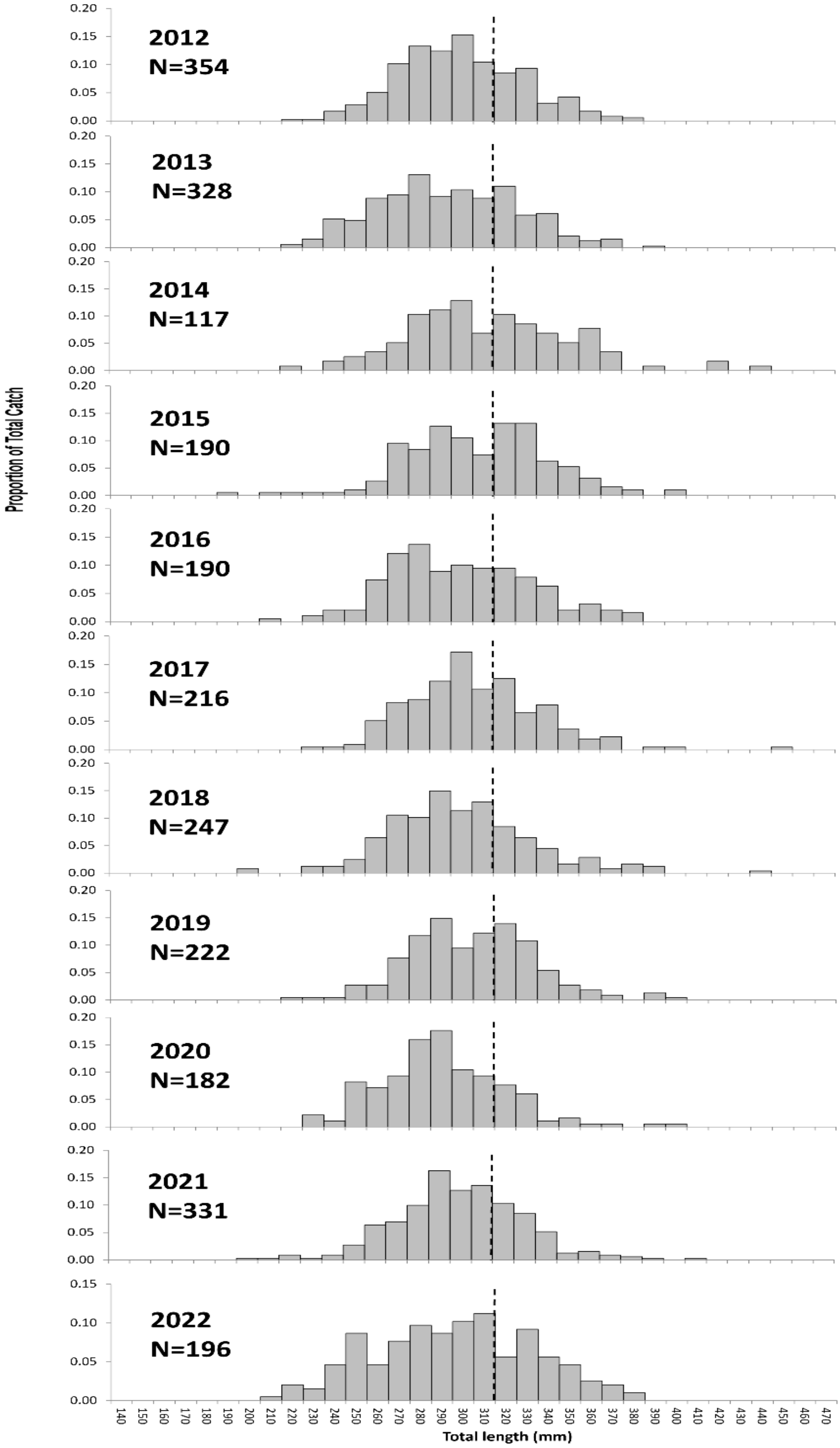

Fig. 4. Length frequency histograms for sand flathead captured in the Great Oyster Bay region between 2012 and 2022. Dotted lines indicate the minimum legal-size limit (320 mm).

Table 5. The total number (*n*) of fish aged, and the minimum (Min), maximum (Max), mean and median age (years) of sand flathead caught in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2012 and 2022.

Area	Parameter	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	All years
D'Entrecasteaux Channel	***n***	107	66	79	106	100	106	101	100	101	110	68	1045
	Min.	2	2	2	2	2	2	2	2	1	2	2	1
	Max.	11	10	10	11	9	10	9	9	8	9	8	11
	Mean	4.5	4.1	4.2	4.3	4.3	4.9	4.3	4.3	4.5	4.1	5.7	4.5
	Median	4	4	4	4	4	5	4	4	4	4	6	4
Frederick Henry-Norfolk Bay	***n***	102	91	99	102	81	103	100	100	101	109	110	1110
	Min.	2	2	2	2	1	2	2	2	2	2	2	1
	Max.	11	13	9	12	9	9	9	12	11	10	10	16
	Mean	4.1	4.1	4.2	4.6	4.4	4.9	4.9	4.5	4.4	4.9	4.9	4.6
	Median	3	3	4	4	4	5	5	5	4	5	5	4
Great Oyster Bay	***n***	98	91	100	103	101	107	102	99	99	102	124	1111
	Min.	2	2	2	2	2	3	2	2	2	2	3	2
	Max.	10	8	9	12	9	11	9	14	8	9	11	14
	Mean	4.5	4.8	5.4	5.2	4.1	5.3	4.1	5.1	4.4	5.1	5.6	4.8
	Median	4	4	5	5	4	5	4	5	4	5	6	5
All Regions	***n***	307	248	278	311	282	316	303	299	301	321	301	3264
	Min.	2	2	2	2	1	2	2	2	1	2	2	1
	Max.	11	13	10	12	9	11	9	14	11	10	11	16
	Mean	4.4	4.3	4.6	4.7	4.2	5.0	4.4	4.6	4.5	4.9	5.4	4.7
	Median	4	4	4	4	4	5	4	5	4	5	5	4

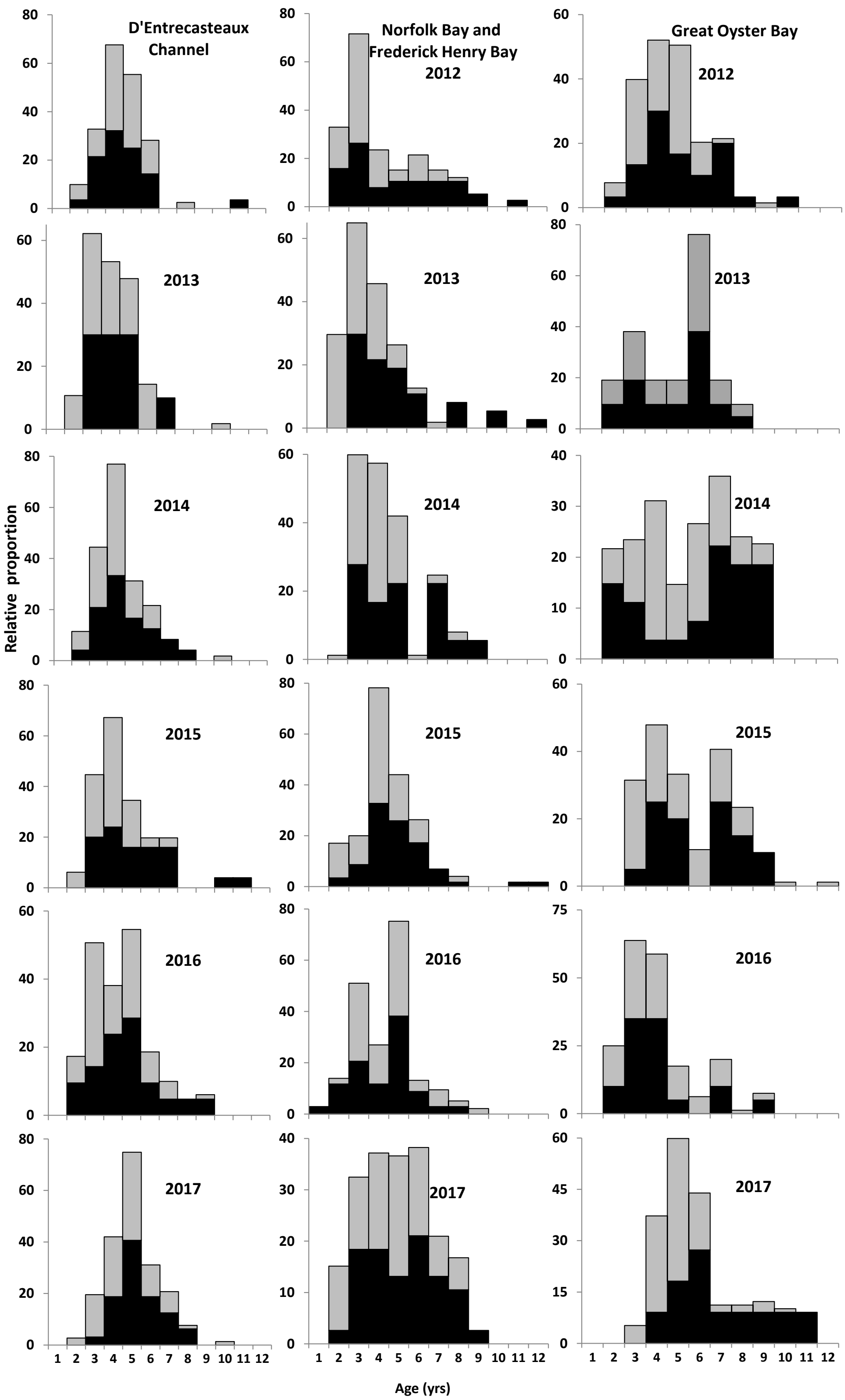

Fig. 5a. Age frequency histograms for sand flathead in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2012 to 2017. The black bars are males and grey bars are females.

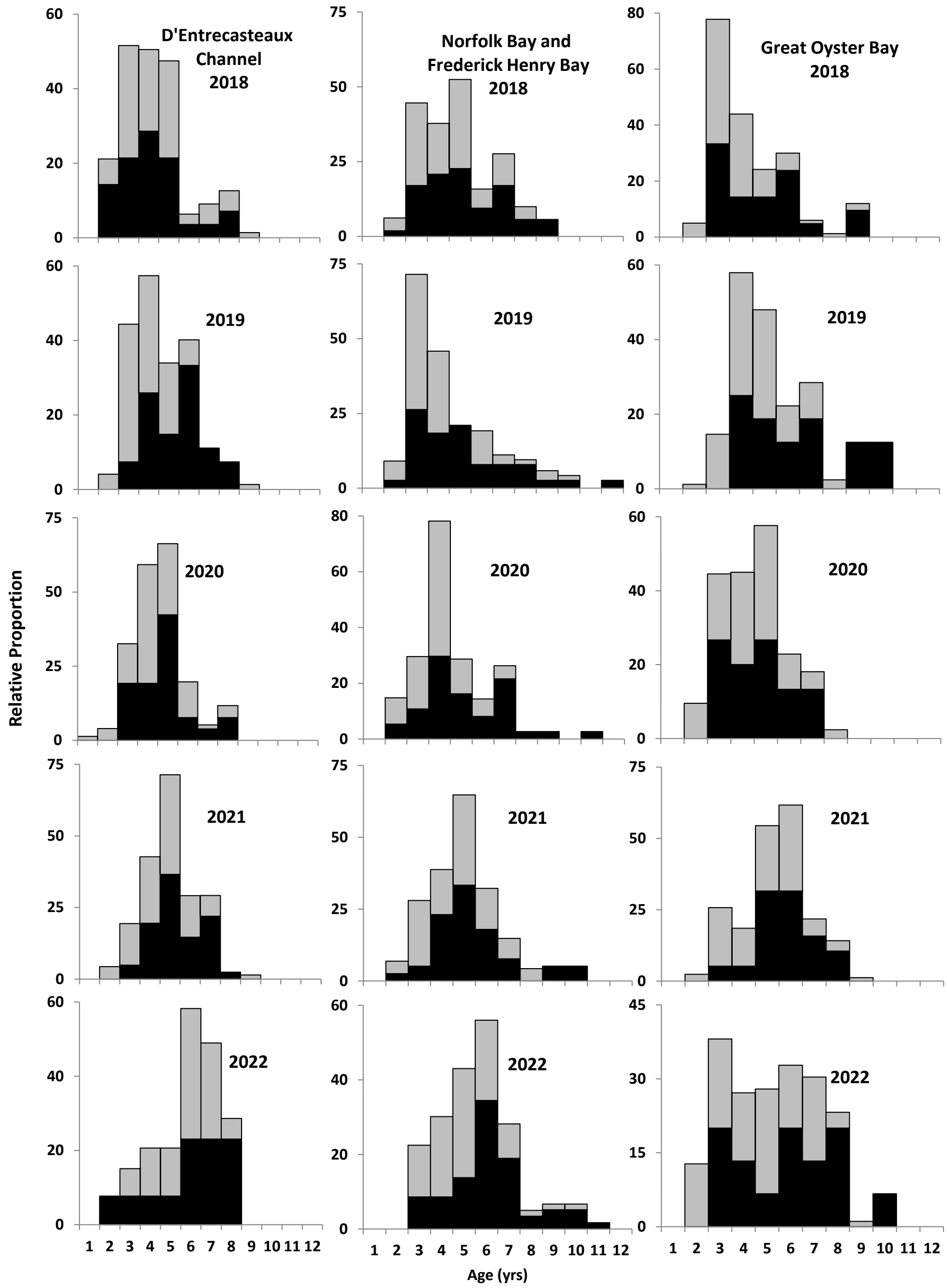

Fig. 5b. Age frequency histograms for sand flathead in the D’Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania between 2018 to 2022. The black bars are males and grey bars are females.

Table 6a. Estimates for the von Bertalanffy growth parameters L_∞ (mm), k (year^{-1}) and t_0 (year^{-1}) for sand flathead from each region, years pooled including the predicted age at the minimum size limit (MSL, 320 mm). n = sample sizes

Sex	Region	*K*	L_∞	t_0	Age @ MSL	*n*
Female	**Regions pooled**	0.24	367	-2.0	6.3	2321
	D'Entrecasteaux Channel	0.34	333	-0.8	8.5	767
	Frederick Henry-Norfolk Bay	0.35	351	-0.7	6.2	660
	Great Oyster Bay	0.49	337	-0.7	5.5	894
Male	**Regions pooled**	0.38	303	-1.3	10.5	939
	D'Entrecasteaux Channel	0.47	285	-0.6	-	274
	Frederick Henry-Norfolk Bay	0.41	306	-0.8	8.7	488
	Great Oyster Bay	0.62	298	-0.4	-	216

Table 6b**.** Estimates for the von Bertalanffy growth parameters L_∞ (mm) and k (year^{-1}) and t_0 (year^{-1}) for sand flathead from each region, years pooled including the predicted age at the minimum size limit (MSL, 320 mm). Note, the von Bertalanffy growth parameter t_0 has been constrained to 0. n = sample sizes

Sex	Region	*K*	L_∞	t_0	Age @ MSL	*n*
Female	**Regions pooled**	0.55	325	0	7.5	2321
	D'Entrecasteaux Channel	0.50	314	0	-	767
	Frederick Henry-Norfolk Bay	0.50	332	0	6.6	660
	Great Oyster Bay	0.68	327	0	5.7	894
Male	**Regions pooled**	0.63	290	0	-	939
	D'Entrecasteaux Channel	0.62	278	0	-	274
	Frederick Henry-Norfolk Bay	0.59	296	0	-	488
	Great Oyster Bay	0.82	293	0	-	216

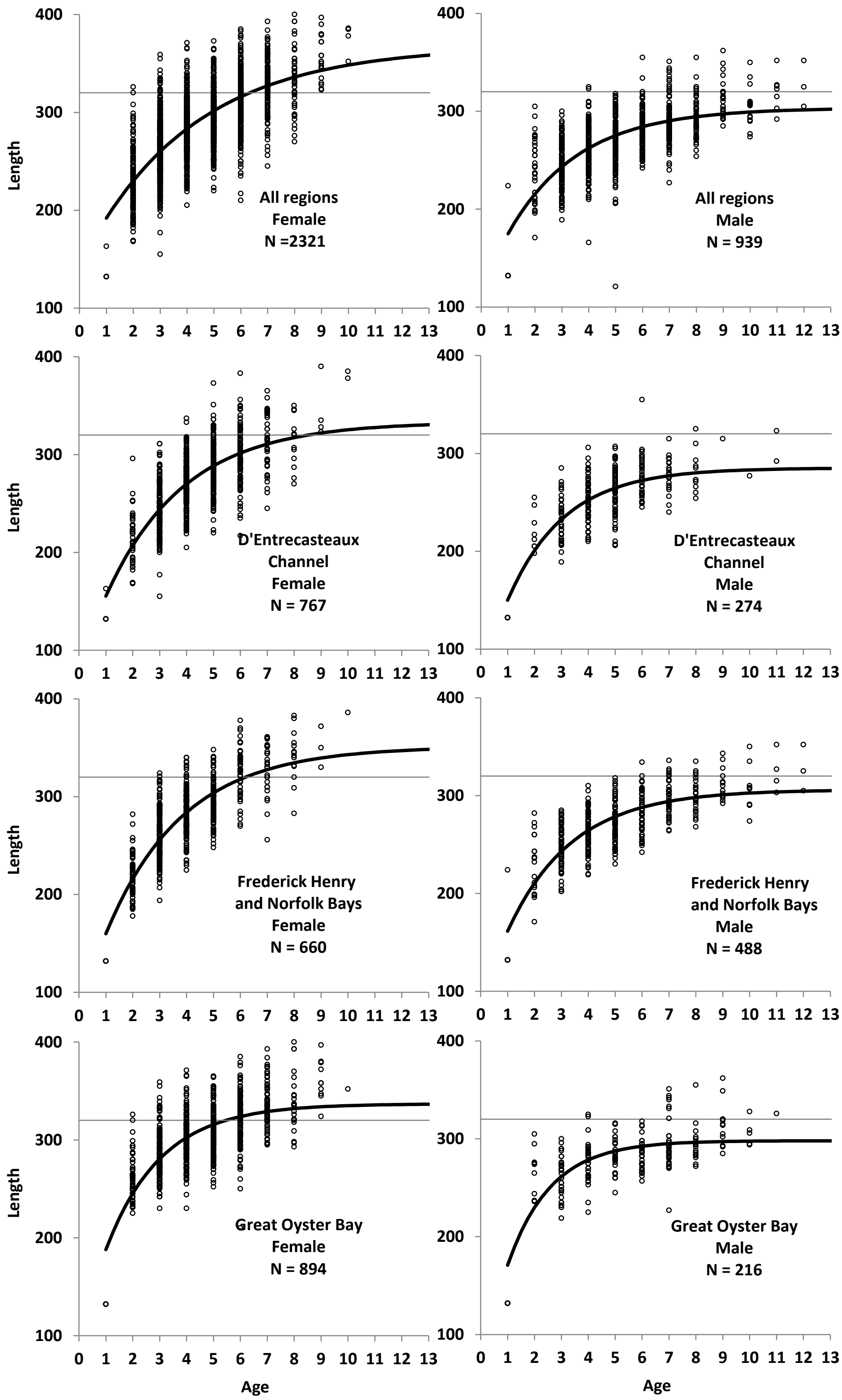

Fig. 6a. von Bertalanffy growth curves (***t_0* unconstrained**) fitted to lengths-at-age of female and male sand flathead in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania and pooled across those three regions. The horizontal line at 320 mm indicates the MSL.

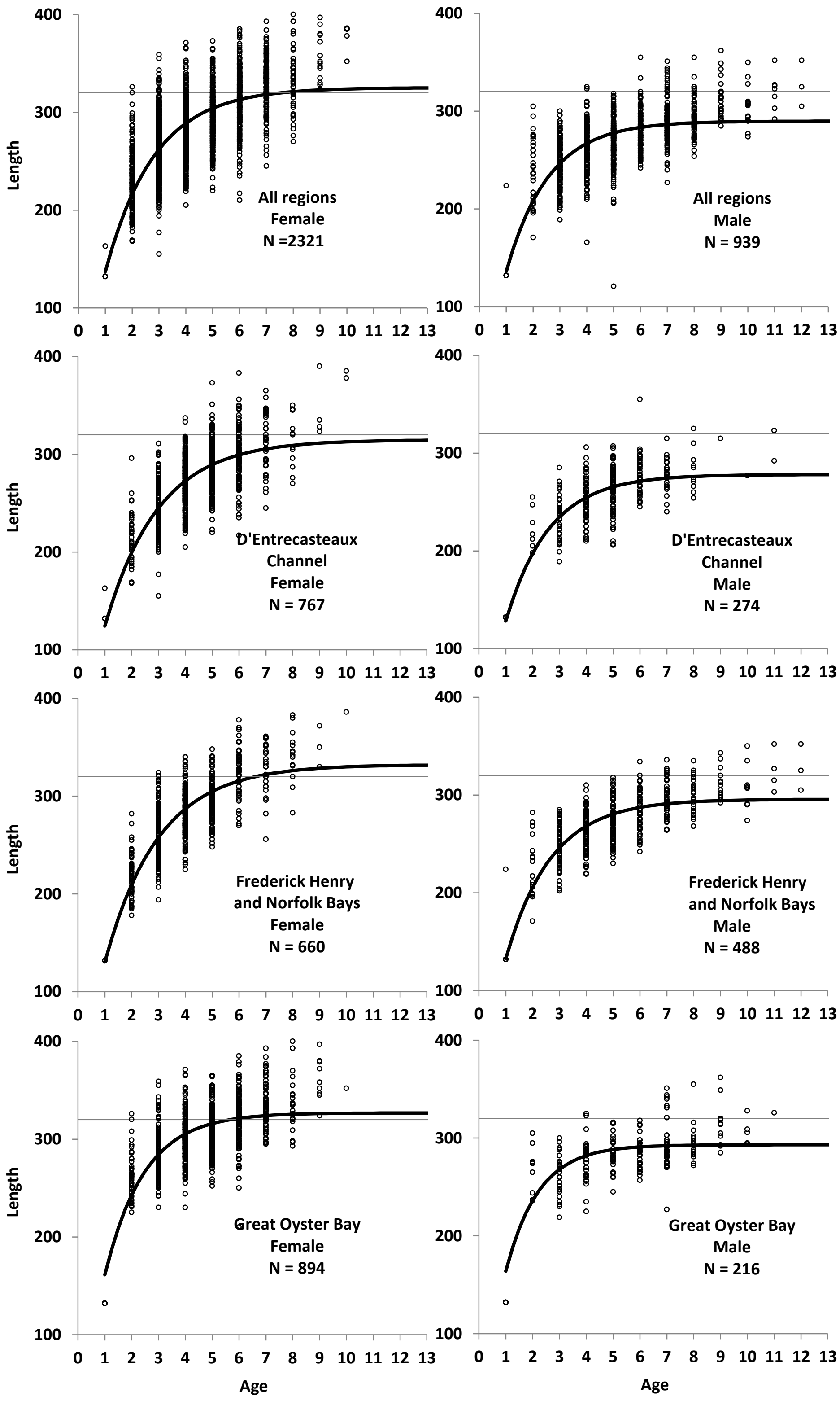

Fig. 6b. von Bertalanffy growth curves (***t_0*** **constrained to = 0**) fitted to lengths-at-age of female and male sand flathead in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania and pooled across those three regions. The horizontal line at 320 mm indicates the MSL.

Mortality

Catch curves yielded higher values of total mortality (*Z*) for females than males in all regions (Fig. 7, Table 7a, b) and when the age data were pooled for all regions. For the most recent period (i.e., 2019 - 2022), the highest *Z* values for females (0.75 year^{-1}) and males (0.46 year^{-1}) were obtained for individuals from Great Oyster Bay the Frederick Henry-Norfolk Bays, respectively (Table 7a)

The estimate of natural mortality (*M*) obtained using the Hoenig and Lawing (1982) method and employing the maximum age recorded for Sand Flathead in Tasmania (17 years, Jordan 1998) was 0.25 year^{-1}. Ewing and Lyle (2014) estimated *M* for male Sand Flathead in Tasmania at 0.16 year^{-1}. Values of *M* for Sand Flathead estimated from the Pauly (1980) method ranged between 0.30-0.49 year^{-1} which, in the case of males in Great Oyster Bay, exceeded the value for *Z*. As some Pauly estimates were implausibly high, *M*, for the purpose of modelling, was taken as the average of the estimates derived from the Hoenig (1982) and Ewing and Lyle (2014) methods (Table 7a).

Estimates of fishing mortality (*F*) from the periods prior to the increase in the MSL (2012 - 2015), immediately following the increase (2017 & 2018), and in the four most recent assessment years (2019 - 2022), are presented in Table 7a and Fig. 9. The overall *F* for females was highest in those years prior to the increase in the MSL (over three times *M*) but has stabilised at a lower level (about two times *M*) in subsequent years (Table 7a). While the *F* estimate for females in the D'Entrecasteaux Channel did not decline in those years immediately following the increase in the MSL, it has declined markedly in the most recent four-year period. The estimates for *F* for males in this region followed a similar trend as did the estimates for females in the Frederick and Henry-Norfolk Bays region (Fig. 8, Table 7a). However, although the estimates of *F* for males in the Frederick and Henry-Norfolk Bays and in Great Oyster Bay declined in those years immediately following the increase in the MSL, estimates have increased the most recent period and are higher than prior to the implementation of the high MSL for sand flathead. In Great Oyster Bay, estimates of *F* have increased in both periods following the increase in the MSL (Fig. 8, Table 7a).

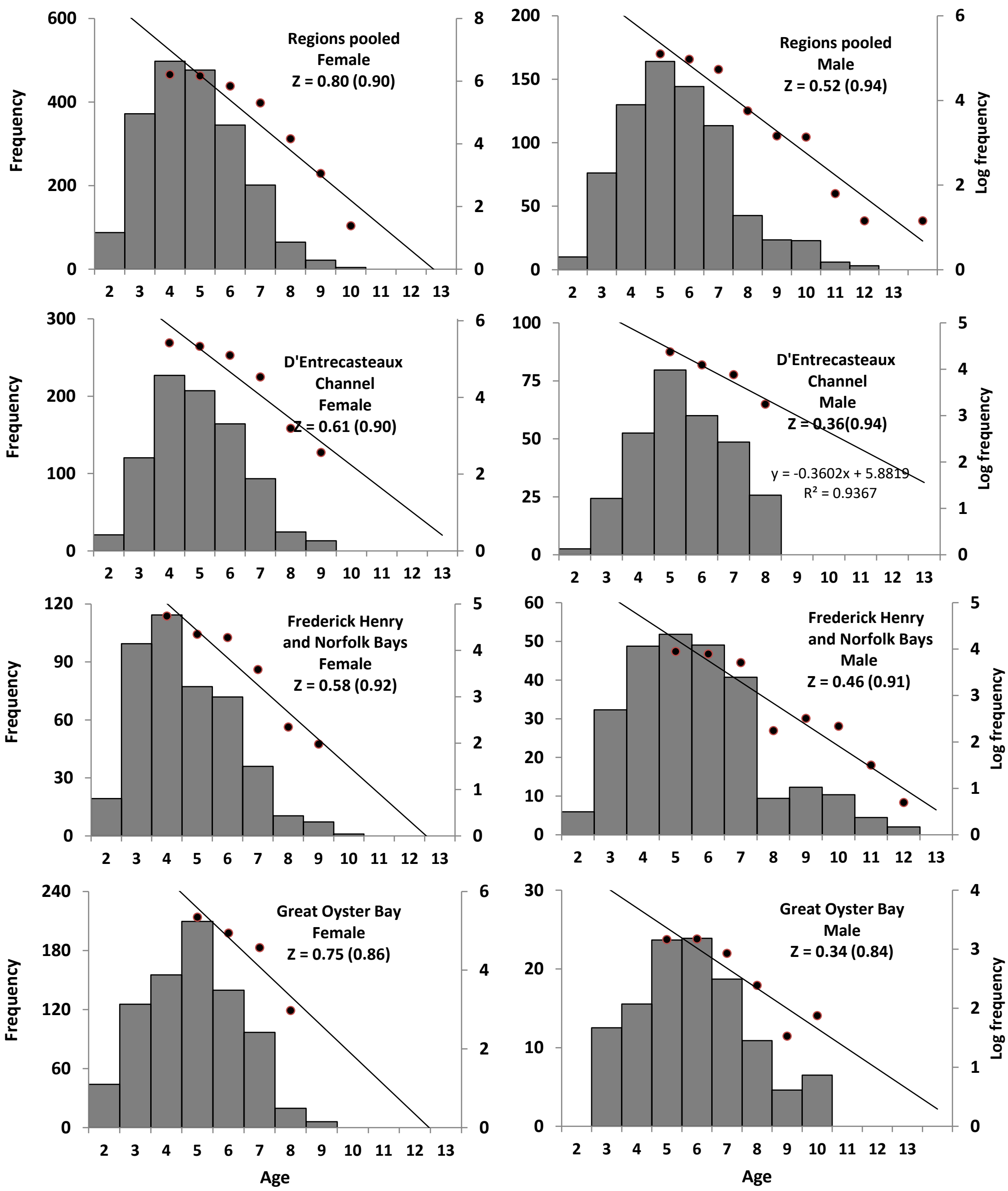

Fig. 7. Age structure and catch curves for females and males from the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania and pooled across the three regions. The left axes indicate the frequency of individuals in each age class (grey bars) and the right axes indicates the natural log of the age frequency (black dots) from the peak in the age frequency. "*Z*" (annual instantaneous mortality) is the slope of the regression (diagonal line) of log frequency of age. The value in brackets is R^2 of the regression.

Table 7a**.** Estimates of natural mortality (*M*) for female and male sand flathead and total (*Z*) and fishing (*F*) mortality estimates for each sex by region, and for all regions combined, in the years prior to the increase in the MSL (i.e., 2012/15), the years immediately following the increase (i.e., 2017/18) and in the last four seasons (i.e., 2019/22). *M* is the mean of two estimates of natural mortality (Hoenig 1983 and Ewing and Lyle 2014), *Z* is derived from catch curves and *F* is fishing mortality [*Z* – (mean of two estimates for *M*)].

Parameter	**D'Entrecasteaux Channel**		**Frederick Henry-Norfolk Bays**		**Great Oyster Bay**		**All regions**	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
$\mathbf{M_{Mean}}$	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
$\mathbf{Z_{2012-15}}$	0.92	0.44	0.67	0.42	0.63	0.34	0.90	0.46
$\mathbf{Z_{2017/18}}$	0.92	0.45	0.68	0.29	0.67	0.24	0.70	0.54
$\mathbf{Z_{2019/22}}$	0.61	0.36	0.58	0.46	0.75	0.34	0.80	0.52
$\mathbf{F_{2012-15}}$	0.72	0.24	0.47	0.22	0.43	0.14	0.70	0.26
$\mathbf{F_{2017/18}}$	0.72	0.25	0.48	0.09	0.47	0.04	0.50	0.34
$\mathbf{F_{2019/22}}$	0.41	0.16	0.38	0.26	0.55	0.14	0.60	0.32

Table 7b. Annual estimates of natural mortality (*M*) for female and male sand flathead and total (*Z*) and fishing (*F*) mortality estimates for each sex by region, and for all regions combined. *M* is the mean of two estimates of natural mortality (Hoenig 1983 and Ewing and Lyle 2014), *Z* is derived from catch curves and *F* is fishing mortality [*Z* – (mean of two estimates for *M*)].

Year	Parameter	D'Entrecasteaux Channel		Frederick Henry-Norfolk Bays		Great Oyster Bay		All regions	
		Female	Male	Female	Male	Female	Male	Female	Male
	M_{Mean}	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2012	Z	0.80	0.23	0.56	0.20	0.72	0.37	0.70	0.42
	F	0.60	0.03	0.36	0.00	0.52	0.17	0.50	0.22
2013	Z	0.65	0.36	0.92	0.26	0.29	0.02	0.76	0.29
	F	0.45	0.16	0.72	0.06	0.09	-0.18	0.56	0.09
2014	Z	0.46	0.49	0.84	0.28	0.38	-0.19	0.73	0.10
	F	0.26	0.29	0.64	0.08	0.18	-0.39	0.53	-0.10
2015	Z	1.04	0.30	0.99	0.46	0.41	-0.04	0.74	0.44
	F	0.84	0.10	0.79	0.26	0.21	-0.24	0.54	0.24
2016	Z	0.42	0.62	0.47	1.22	0.49	0.19	0.53	0.47
	F	0.22	0.42	0.27	1.02	0.29	-0.01	0.33	0.27
2017	Z	0.73	0.56	0.88	0.51	0.62	0.08	0.62	0.53
	F	0.53	0.36	0.68	0.31	0.42	-0.12	0.42	0.33
2018	Z	0.76	0.36	0.65	0.36	0.58	0.12	0.49	0.24
	F	0.56	0.16	0.45	0.16	0.38	-0.08	0.29	0.04
2019	Z	0.83	0.25	0.53	0.32	0.52	0.10	0.59	0.35
	F	0.63	0.05	0.33	0.12	0.32	-0.10	0.39	0.15
2020	Z	0.64	0.62	0.89	0.34	0.86	0.16	0.71	0.48
	F	0.44	0.42	0.69	0.14	0.66	-0.04	0.51	0.28
2021	Z	0.48	0.68	0.70	0.38	1.13	0.40	0.85	0.56
	F	0.28	0.48	0.50	0.18	0.93	0.20	0.65	0.36
2022	Z	0.84	0.18	1.04	0.51	0.77	0.12	0.96	0.53
	F	0.64	-0.02	0.84	0.31	0.57	-0.08	0.76	0.33

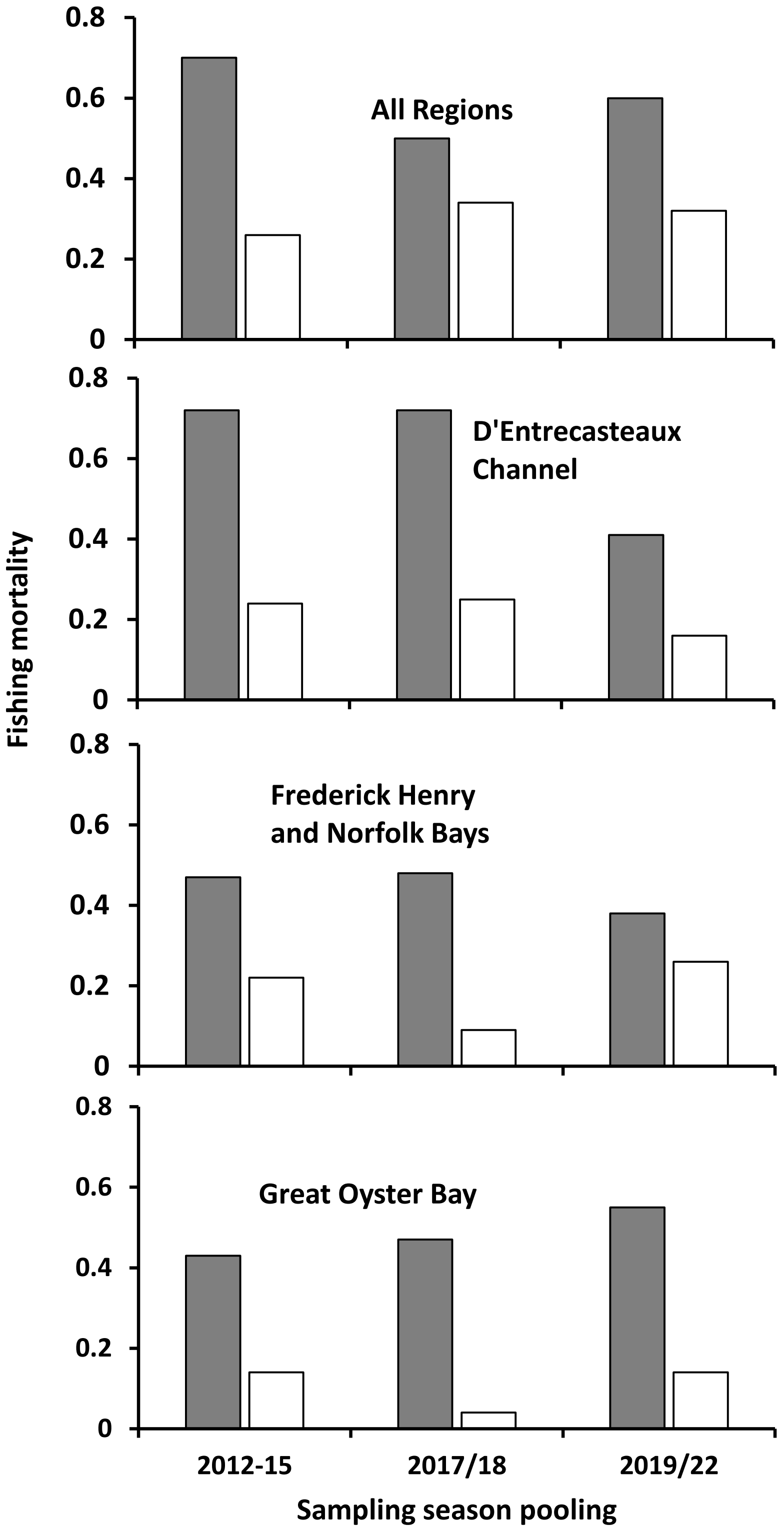

Fig. 8. Fishing mortality (*F*) estimates for female (grey bars) and male (white bars) Sand Flathead from the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania in the years prior to the increase in the MSL (2012 - 15), immediately following the increase (2017/18) and in the last four seasons (2019 - 22).

Catch rates

Catch rates in each of the regions initially declined to their lowest levels between 2014 and 2016 before recovering to levels comparable to, or greater than, those in 2012 in the following years (Fig. 9). Standardised catch rates of sand flathead in the D'Entrecasteaux Channel 2022 have continued to decline from the from a peak in catch rate in 2020. Standardised catch rates of sand flathead Henry-Norfolk Bays and Great Oyster Bay in 2022 remained similar to 2021 rates or slightly higher (Fig. 9).

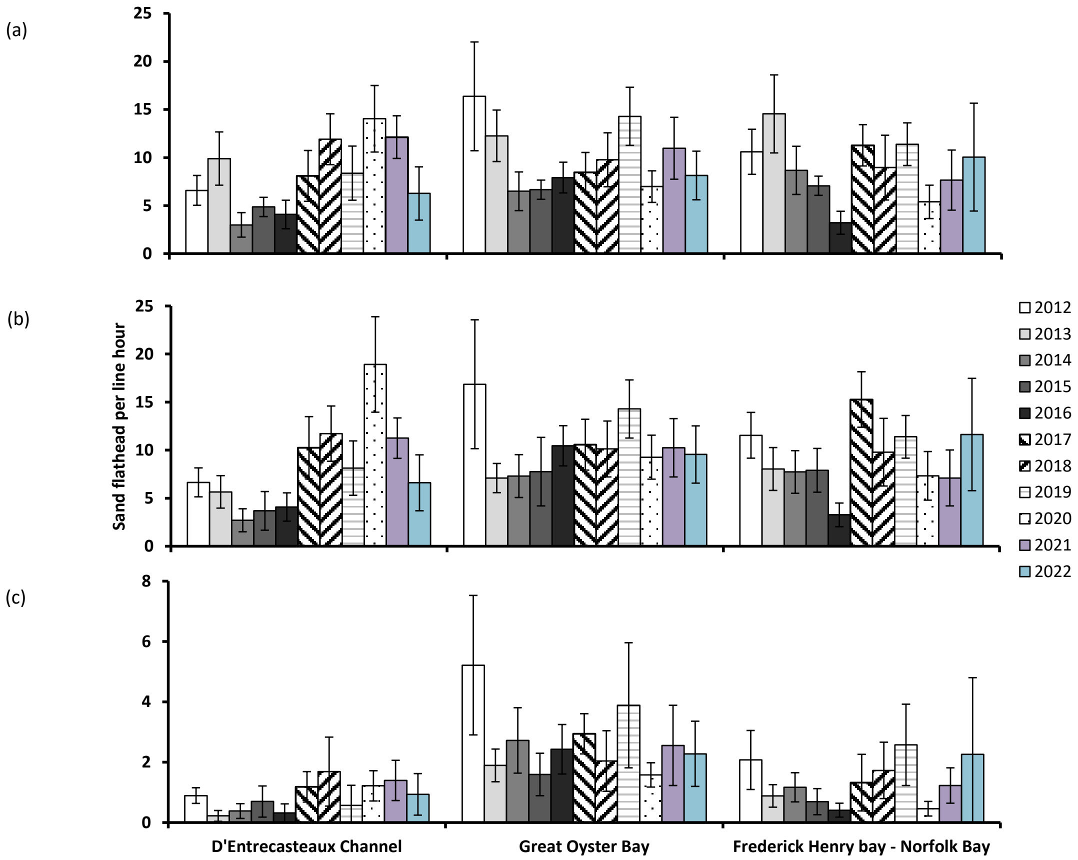

Fig. 9. Mean catch rates (fish per line hour) by region and year for sand flathead in the D'Entrecasteaux Channel, Frederick and Henry-Norfolk Bays and Great Oyster Bay in south-eastern Tasmania: (a) raw catch rates; (b) standardised catch rates; and (c) standardised catch rates for fish above the 320mm MLS. Error bars represent 95% confidence intervals.

Response to the increased MSL

Earlier assessments of the recreational sand flathead fishery (Ewing and Lyle 2014) showed evidence of a reliance on new recruits with sharp declines in the proportion of fish above the minimum size limit (300 mm), and dominance of slower growing males in the older age classes where the faster growing females had become exposed to the fishery. These effects were particularly strong in the D'Entrecasteaux Channel. The minimum size limit was increased from 300 mm to 320 mm in November 2015 with the intention of improving yield per recruit, reducing fishing mortality and increasing egg production (by extending the period prior to recruitment to the fishery). The minimum size limit increase was expected to offer mature females an additional 1.5 to 2 years of protection prior to recruiting to the fishery.

Regional data provide no clear signals of changes in age or size structures in 2022 to indicate variability in recruitment potentially linked to increased protection of spawners (Figs. 2 - 5). There is, however, an increase in the representation of fish in the 300-320 mm size range in most regions since the size limit increase.

Discussion

Annual fishery-independent surveys of the population characteristics of sand flathead in areas of significant recreational fishing effort commenced in 2012 in response to concerns of depletion in the most heavily exploited regions of the fishery (Ewing and Lyle 2014). In response to recommendations in Ewing and Lyle (2014), the Department of Natural Resources and Environment increased the size limit for sand and tiger flathead to 320 mm and reduced the recreational bag limit from 30 to 20 flathead per person per day, effective from 1st November 2015.

Trends in catch rates, size and age structure since the management changes suggest limited stock rebuilding has occurred; particularly in the D'Entrecasteaux Channel, the most heavily exploited region of the fishery. This trend is less obvious in the Great Oyster Bay region, masked by high catches early in the time-series (influenced by a particularly dominant age class), and lower catch rates in recent years. Strong year class variability no longer appears to structure catches in Great Oyster Bay.

Catch curve analysis has generated plausible estimates of total and fishing mortality, with higher rates for females, reflecting their longer exposure to the fishery due to faster growth rates and greater maximum sizes. Comparison of fishing mortality from the sample period prior to the increase in the MSL, against fishing mortality after the recovery period, show limited change in the fishing mortality of females, particularly in the males. This is consistent with the expectation that the relative size-selectivity of males will decrease under the new MSL due to slower growth and smaller maximum sizes than females. The reduction in the fishing mortality of females is also expected and is likely to be due to the decrease in the daily bag limit and higher yield per fish.

In addition to conferring protection to the adult spawning stock by allowing females to spawn for up to an additional two years prior to entering the fishery, the increased MSL has also provided a higher average yield per fish; noting that the species is primarily targeted for consumption rather than catch and release (Lyle *et al*. 2009). However, due to slowing growth and additional natural mortality, the gains of a higher MSL come with a reduced theoretical yield per recruit (Ewing and Lyle 2018). This trade-off is warranted due to 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 of conferring additional protection to the adult spawning stock (important given that females experience significantly higher levels of fishing mortality than males).

Summary

Trends over the time series suggest that sand flathead stocks have benefitted from the increase in MSL, with populations now displaying a greater proportion of fish in older age classes. This recovery was clearest in the three years following the increase size limit, and especially in the D'Entrecasteaux Channel region (the region with slowest growth rates and highest fishing mortality). The pattern has been less clear in Great Oyster Bay (the region with the highest growth rates) where strong cohort structure early in the time-series and (unexpectedly) low catch rates in 2020 – 2022 have tended to obscure any obvious trend in population change.

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