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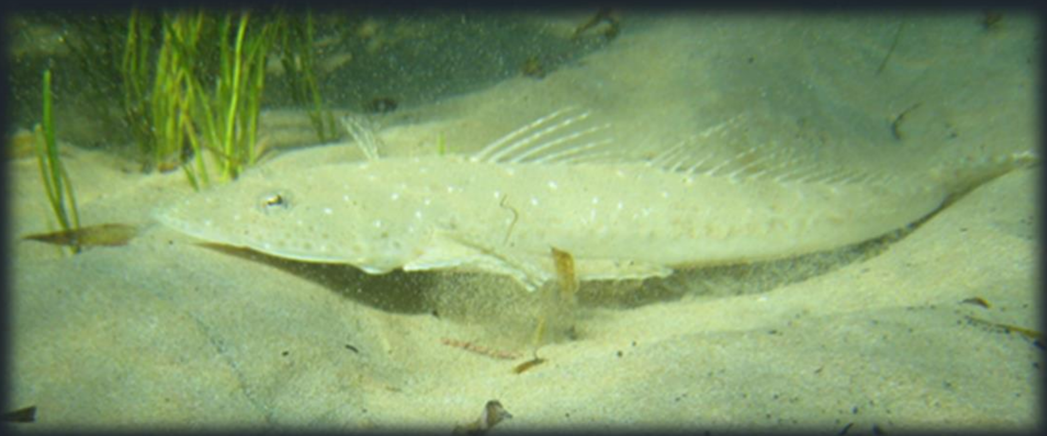

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Fisheries biology of the southern bluespotted flathead (*Platycephalus speculator*) in Victoria

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Executive Summary

As the first detailed investigation into the biology of southern bluespotted flathead (SBF) in Victoria, the present study considered age and growth, maturation, various mortality components (Total mortality – Z; natural mortality – M; and fishing mortality – F), spatial distribution, trends in abundance, the catch composition of the Port Phillip Bay recreational fleet (both size and numbers), and undertook modelling to investigate how various management interventions would influence recreational landings, and hence overall F and the population dynamics of the stock.

The results suggest that SBF are distributed throughout Port Phillip Bay, however large individuals appear to be more abundant in shallow waters, whereas SBF in deeper regions tend to be smaller, often sub-adults and juveniles. As few very large individuals were sampled, the relationship between very large, and potentially very old, SBF and particular habitats (e.g. estuarine habitats) was unable to be confirmed. Nevertheless, there is considerable evidence that this is the case with most reports of very large SBF being from Swan Bay and the Grammar School Lagoon in Port Phillip Bay, and estuaries such as Shallow and Anderson Inlets. More work is required to understand whether these individuals are particularly long-lived or whether they grow to larger sizes as a result of the environs they inhabit: both hypotheses are plausible given the biological plasticity of Platycephalids.

Similar to previous studies on SBF undertaken in Tasmania and Western Australia, SBF in Port Phillip Bay grow rapidly, with females and males maturing at 28cm and 26cm respectively, generally at less than two years of age. The oldest individual observed was 14 years of age, weighed 4.2kg and measured 81cm, with the bulk of the population being 3–7 years of age, and 30–50cm.

Using the observed age structure in Port Phillip Bay, Z was estimated to be 0.37 (95% CI: 0.28, 0.47), which is relatively low considering the productivity of the species. Given their biology, M was unsurprisingly estimated to be fairly high at 0.30 (95% CI: 0.22, 0.41) and the resulting estimate of F was therefore quite low at 0.07 (95% CI: 0.03, 0.11), implying that the stock is currently exploited at a relatively low level.

Based on relative abundance derived from fishery independent surveys, SBF abundance appears to have been reduced during much of the 2000s increasing between around 2010–2020 as a result of increased recruitment. The period of low abundance in the 2000s can be linked to a period of low recruitment, quite possibly arising from the millennium drought, which also negatively affected sand flathead recruitment. Recruitment has been lower since around 2018, which, given the rapid growth rate, has already seen larger cohorts begin to reduce in abundance, but levels remain well above those observed in the 2000s. The reason behind the reduced recruitment in recent years cannot be linked to climatic conditions and the data required to further investigate causation are currently lacking. It should be noted, however, that the above trends in abundance, derived from the snapper prerecruit surveys, are only likely to accurately reflect the abundance of juvenile, sub-adult and relatively young mature cohorts, and the fact that the relatively low mortality estimates are derived from the adult component of the stock, suggests that even under a lower recruitment regime the stock is still being lightly exploited.

A variety of alternative bag and size limit scenarios were investigated to determine how the different options would impact recreational fishers' landings, and hence F. Given that few anglers catch large numbers of SBF, the greatest reduction in F would occur if the LML was increased substantially e.g., to 35–40cm total length, especially if incorporated with a narrow upper slot-limit e.g., 50cm total length with few (e.g. 0–2), SBF able to be retained above the slot. All scenarios retaining the current LML, or large upper slot-limit sizes e.g., 60cm maximum limit, had little impact on landings.

Given the Port Phillip Bay SBF stock is currently lightly exploited, because few anglers target SBF and therefore few anglers catch large numbers of SBF, there appears to be little value in altering current management arrangements, both in terms of the sustainability of the species and potential benefits to the fishery by reducing F. Moreover, the buyout of commercial net fishing in Port Phillip Bay is expected to reduce F, with some 25,000–37,500 fewer individuals being captured by this sector as they are rarely captured and/or retained by the remaining longline commercial fishery.

Introduction

Southern bluespotted flathead (Platycephalus speculator), often referred to as yank flathead, are a large Platycephalid (flathead family) distributed from central Western Australia to eastern Victoria, including northern Tasmania. Southern bluespotted flathead (hereafter SBF) are common in shallow, inshore waters, particularly around seagrass (Edgar, 2000). This species is reported to grow to 90cm and 6–8kg, but while these measurements are frequently reported in the literature, there appears to be no reliable information source for the maximum size that the species can attain. SBF are caught in both commercial and recreational fisheries where seagrass is abundant: in Victoria, this includes Port Phillip Bay, Western Port, Corner Inlet and many estuaries. Although infrequently targeted, SBF is often caught as a byproduct by both commercial and recreational fishers.

Flathead of all species are a relatively popular target generally in Port Phillip Bay for recreational fishers, accounting for around 12% of the main target species observed in creel surveys and are a common secondary target species for anglers primarily fishing for snapper and King George whiting. Most anglers do not know that there are multiple Platycephalid species present in Port Phillip Bay so do not differentiate in their targeting of particular flathead species. Thus, it is difficult to draw many conclusions about fishing behaviour aimed towards SBF from creel surveys as it appears to be somewhat of a niche fishery, with anecdotal reports that their popularity is increasing amongst lure and soft plastic fishers. Recreational spear fishers also take SBF, though the degree of targeting, and magnitude of the take, is unknown. Of the SBF caught and measured during 20 years of the ongoing Port Phillip Bay creel survey program, the average length is 38 cm and the maximum was 72 cm.

Historically, in Victoria most of the SBF commercial landings were taken from Port Phillip Bay, with generally 10 – 20 t landed per year. In recent years, landings from Corner Inlet have increased to 20 – 30 t per year, though it is believed that until recently this species was inaccurately identified (i.e. reported as sand flathead of 'unspecified flathead') so landings in Corner Inlet may have been historically higher than reported.

There has been relatively little scientific scrutiny directed towards SBF in Victorian waters, or indeed elsewhere throughout their range, with only their basic biology known. In Western Australia and Tasmania, the species lives to at least 12 years of age, matures at 1–2 years of age and 25–32cm total length, and is highly fecund (Costelloe and Haddy, 2014; Hyndes et al. 1992). Given the plasticity of Platycephalid biology, where individuals can mature and grow to very different sizes depending on the location they inhabit (e.g. sand flathead in Port Phillip Bay compared to Bass Strait), reliance on studies from interstate could be misleading, it was therefore deemed necessary to investigate the biology of SBF in Port Phillip Bay.

At present in Victoria, SBF are managed within the combined flathead regulations (excluding dusky flathead) with a minimum legal length of 27cm and a daily bag limit of 20 fish per person. These arrangements were similar in Tasmania until recently, however due to increased targeting of the resource in Tasmania, the DPIPWE recently introduced new bag, size and slot limits for SBF and rock flathead combined. There is currently no information on how successful these changes have been, and it will inevitably take time for these changes to have a measurable effect, if any occurs.

In recent years, there has been some interest from recreational fishers in adjusting Victorian SBF management regulations in line with those in Tasmania (combined rock flathead and SBF, LML = 40cm, bag-limit = 5, with only one >60cm total length). This has arisen not only from a conservation perspective in which some anglers believe a bag-limit of 20 SBF is excessive, but also from the notion that it may be possible to increase the abundance of very large female SBF thereby increasing the probability of anglers catching trophy-sized individuals.

Given the interest in reviewing SBF regulations, and the above uncertainties about the species' general biology, the current project was commissioned by the Victorian Fisheries Authority in order to answer the following questions:

- What is the current size/age structure of the SBF population in Port Phillip Bay?

- At what size do SBF mature?
- Can the results of the prerecruit surveys (for snapper) provide any insight into SBF recruitment dynamics?
- How are SBF distributed within Port Phillip Bay?
- Using existing creel survey information, what are the characteristics of the catch at present in terms of targeting, bycatch, and byproduct?
- What would be appropriate size, bag, and slot limits if considered to be beneficial as a set of management arrangements for the SBF fishery?

- What would be appropriate size, bag, and slot limits if considered to be beneficial as a set of management arrangements for the SBF fishery?

Sample collection and available data

To obtain the samples required to answer the above questions, anglers, and to a lesser extent, commercial fishers, provided SBF frames to VFA scientists. In addition, very small SBF captured during snapper prerecruit surveys were retained as these were unavailable from fishery dependent sampling. A total of 346 samples were subsequently dissected and their reproductive status identified, both in terms of maturation and spawning stage, and their otoliths were removed for ageing. Otoliths were sent to Fish Ageing Services along with associated metadata where the otoliths were embedded in resin, sectioned at ~250 µm, mounted on glass slides, and viewed with a microscope to count alternating opaque and translucent annuli assumed to represent regular age increments. Intra-reader error, as measured by the Index of Average Percentage Error was only 0.4%, which is very low indicating that the samples were aged with a high degree of precision and certainty. Age and growth information was then subsequently used to determine the population dynamics, including fishing/natural/total mortality, of SBF stocks in Port Phillip Bay.

Several sources of ancillary data were available to add value to the current project. These included:

- SBF abundance and size composition from the annual Port Phillip Bay snapper prerecruit trawl survey;
- Historic spatio-temporal commercial landings information, which were used to investigate spatial abundance of SBF and also the extent of historic landings to inform the reduction in mortality associated with this fishery after net fishing ceased;
- Information from the recreational fishery collected during routine creel surveys undertaken at 20 boat ramps around Port Phillip Bay. These data were used to investigate the frequency that SBF are captured by recreational anglers and also to model the influence of various changes to bag, legal minimum length, and slot lengths based on the observed landings of anglers.

Age and growth

Age composition of SBF from both Port Phillip Bay and Corner Inlet-Nooramunga was dominated by individuals between two and six years of age (Figure 1) but ranged from zero to fourteen years old. There were insufficient samples from Corner Inlet-Nooramunga to statistically test whether growth rates varied between the two locations, however, there was no indication this was the case from the available age-at-length data, so the samples were pooled for further analysis, excepting mortality modelling, which was undertaken specifically for Port Phillip Bay using age composition from there alone. Age-at-length was modelled using a standard von Bertalanffy growth function fitted using non-linear least squares regression with the NLS R package.

Both sexes displayed rapid growth until around three years of age before male growth began to asymptote, whereas females continued to grow rapidly until around seven years of age before their growth rate began to slow (Figure 2). While growth rate, and maximum size, were clearly sexually dimorphic, overall longevity appears to be similar between the sexes with males typically reaching nine years of age, with an eleven and a fourteen-year-old female observed in the present study, whereas a twelve-year-old male was the oldest SBF observed in Tasmania (Costelloe and Haddy, 2014).

Using individual ages, it is possible to back-calculate the year that each specimen was born, which can provide insight into the recruitment dynamics of the species i.e., if a large proportion of individuals are born only in certain years this indicates sporadic recruitment that is likely to be heavily influenced by environmental conditions. Given SBF spawn throughout summer (i.e., spanning two calendar years in a single spawning season), birth year was calculated in fiscal years to incorporate all individuals from a single spawning season into a single twelve-month period. Birth year was relatively normally distributed around a maximum during 2016 (Figure 3). While this provides some evidence that 2016 had a particularly successful spawning event, this was not supported by the snapper prerecruit survey (detailed later) and is more reflective of the relative abundance of year classes in the stock: individuals spawned during earlier years are rarer due to the combined influence of M and F, not necessarily reduced recruitment. However, given fewer individuals born from 2017 until about 2020 were observed, at which age they should have fully recruited to the fishery, there is some evidence that there has been relatively lower recruitment in recent years, which is discussed in more detail in conjunction with the results from the snapper prerecruit survey later herein.

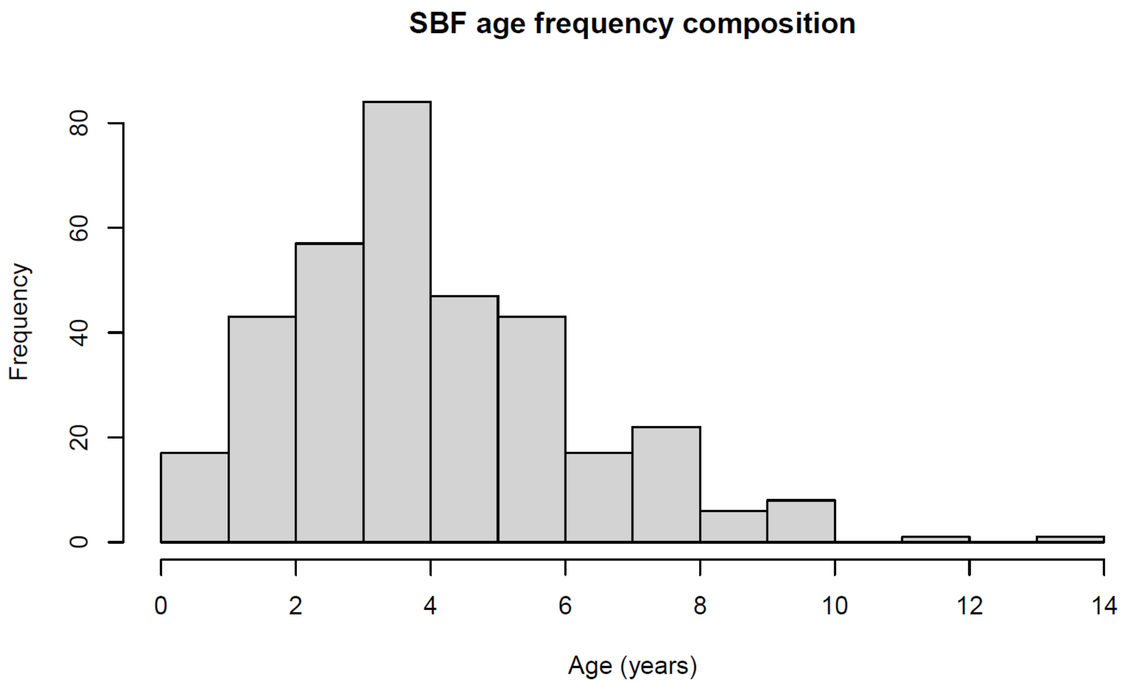

Figure 1 Age-frequency histogram of SBF from Port Phillip Bay and Corner Inlet-Nooramunga combined.

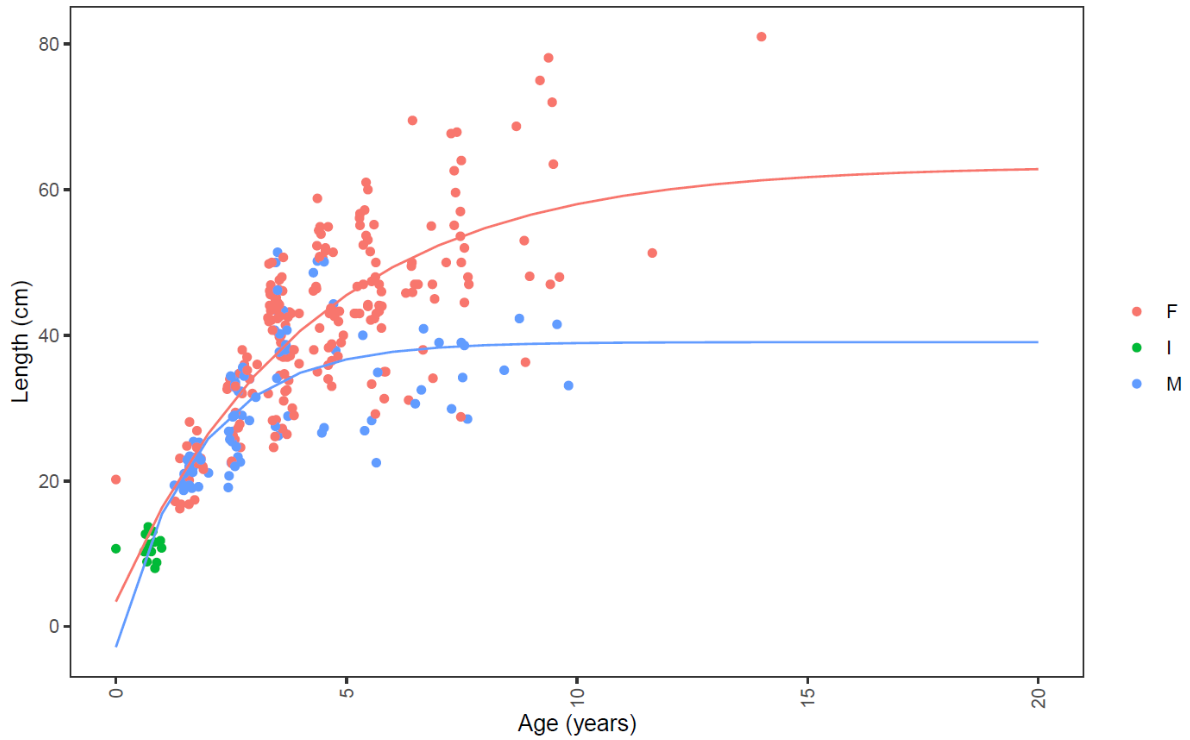

Figure 2 Age-at-length, by sex (F = female. M = male, I = indeterminate), and fitted von Bertalanffy growth functions of SBF from Port Phillip Bay and Corner Inlet-Nooramunga combined

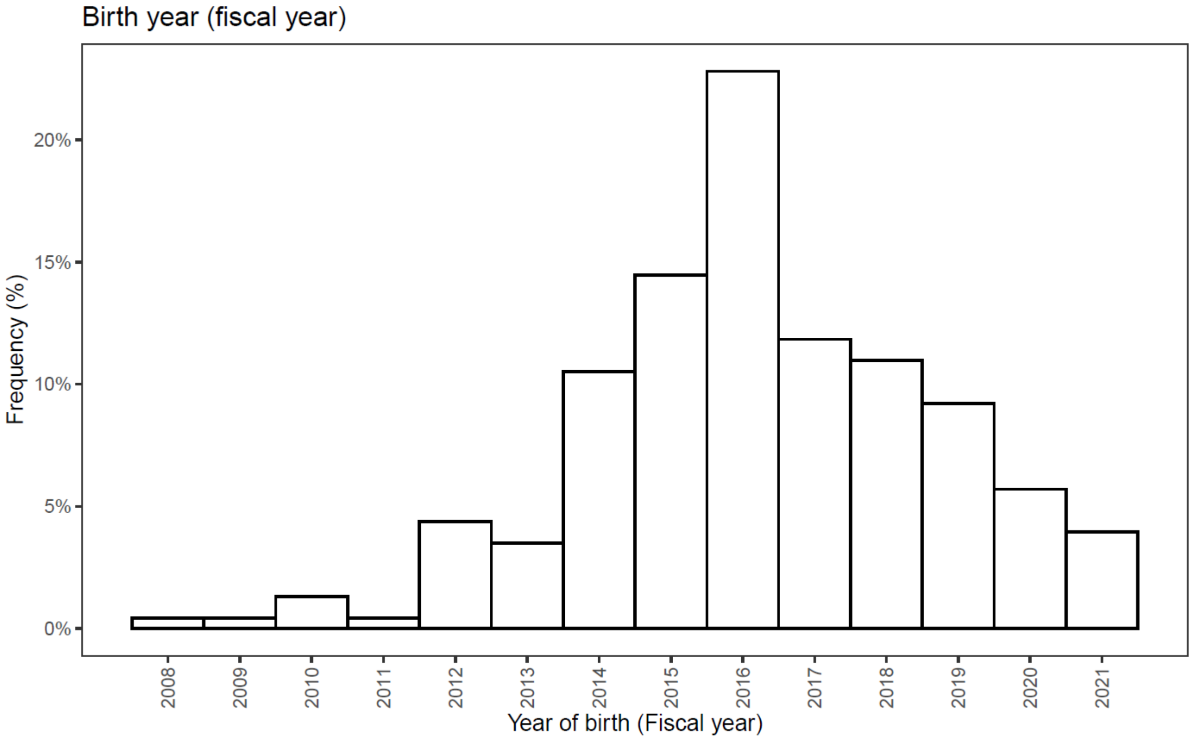

Figure 3 Back calculated year of birth of SBF from Port Phillip Bay and Corner Inlet-Nooramunga combined. Year is fiscal year with the number corresponding to the first year, i.e. 2021 = 2021/22.

Maturation

To investigate the size and age at which SBF mature, samples were dissected, the sex identified, and the reproductive status of the ovary/testes was assigned. A reproductive stage of one represented an immature individual, whereas stages 2–5 represented varying levels of reproductive activity. To determine size at maturation, a binomial logistic regression analysis was applied in which the maturation status of each fish was assigned as zero if reproductively immature (stage one) or one if mature (stage 2–5). Following this, a logistic generalised linear regression (link = “logit”) was fitted in R, with sex included as a factor to determine whether sex has a significant influence on the size at maturation.

Both size (unsurprisingly) and sex significantly influenced maturation ($p = <0.05$), with 50% maturity attained at 279mm and 258mm for females and males respectively (Figure 4). While easily undertaken, a logistic regression of age and maturity is not presented herein as it results in a fractional under-estimate of age-at-maturation between one and two years, and in reality, SBF are only able to reproduce when around two years of age during the first spawning season in which they are mature (i.e., SBF likely contribute to spawning when about two years of age). However, newly mature SBF, although possessing what appears to be ‘mature’ ovaries, contain noticeably smaller ovaries and it is therefore likely that they only meaningfully contribute to spawning from about three years of age onwards when their ovaries are larger and more fecund. This is supported by research in Tasmania that showed batch fecundity increases rapidly as SBF increase in age, being relatively low when small (Costelloe and Haddy, 2014).

Unfortunately, all the individuals that were in reproductively active condition (i.e., either about to spawn or spent) were provided by fishers without a date of capture. In addition, most of the specimens provided for this study had been filleted with the gonadal tissue largely absent in most instances, which, although generally enabling sex to be assigned, and sometimes the maturity stage could be determined, it was insufficient to determine the overall reproductive status of the sample. Consequently, it was not possible to determine the spawning season from these specimens. Research from Tasmania suggests that SBF have a protracted spawning season from about December to March (Costelloe and Haddy, 2014), and from what we were able to determine, the season in Port Phillip Bay is likely to be similar, and almost certainly extends until at least March given some females still had vitellogenic ovaries in March. It should be noted, however, that the study by Costelloe and Haddy (2014), and the information gathered in this study, both found relatively few actively spawning females, and both only explored reproductive seasonality macroscopically, which is subjective in its interpretation. Given that the information about maturation and spawning seasonality gathered to date could be misleading, there is scope to further investigate SBF reproduction histologically. Nevertheless, all the available evidence suggests spawning occurs throughout summer and into autumn.

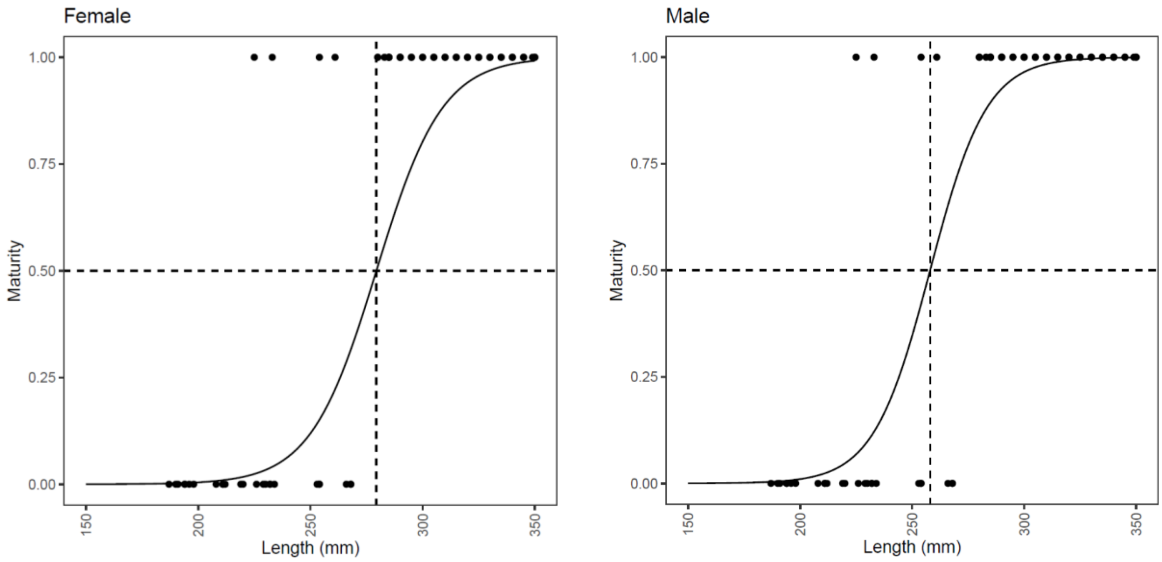

Figure 4 Maturity ogives for male and female SBF with vertical lines displaying the length at which 50% of individuals are reproductively mature.

Spatial distribution

The most comprehensive data available to investigate the distribution of SBF in Port Phillip Bay are from the commercial seine fishery prior to its closure. This gear has a relatively low level of selectivity, catching all fish within a given area that are unable to swim through the mesh size used. Commercial seine fishing was also historically undertaken over inshore seagrass habitats targeting King George whiting, which SBF also frequent, but this only represents SBF abundance within several hundred meters of the shore and does not provide information about their abundance in central, or deeper, regions of the Bay.
Notwithstanding the limitations of data acquisition, analyses suggest SBF are distributed throughout Port Phillip Bay, but are particularly abundant in the northern and western regions of the Bay (Figure 5). This largely mirrors the abundance of seagrass as the preferred habitat of SBF (Edgar, 2000), which is most abundant in the northern and western regions of the Bay where it is protected from the prevailing westerly frontal systems (Jenkins et al. 2015).
Although SBF are found in the deeper waters of Port Phillip Bay, they are rarer in these sparse habitats of predominantly bare sand and mud, which appear to be more important to juveniles and mid-sized individuals. For example, of the 923 SBF captured during the Port Phillip Bay snapper prerecruit survey in Port Phillip Bay, the average size encountered was 24.3cm, and the maximum was 59cm, generally lower lower those among anglers catches, with most of the larger specimens encountered in the few shallower sites in Hobsons Bay and Corio Bay.
While it would be theoretically possible to create a similar species distribution map using data from creel surveys, anglers rarely target SBF, and anglers targeting other species typically use fishing practices (e.g., small hooks and baits targeting King George whiting), and fish in habitats (deep areas targeting snapper),

that are not particularly conducive to catching SBF. Thus, there is little value in intensively analysing anglers' catch rates to spatially resolve SBF abundance.

Overall, the available evidence suggests SBF are distributed throughout Port Phillip Bay, including deeper waters, but are more abundant in shallow habitats, particularly associated with seagrass. The species, particularly large individuals, is also well known to inhabit sheltered bays and estuaries such as Swan Bay and the Geelong Grammar School Lagoon, as well as several estuaries (e.g. Anderson and Shallow Inlets in Victoria, various estuaries in northwest Tasmania and southern Western Australia) from which most anecdotal reports of exceptionally large individuals stem. Under these circumstances it appears that very large individuals adopt habitats and likely behaviours, reminiscent of dusky flathead.

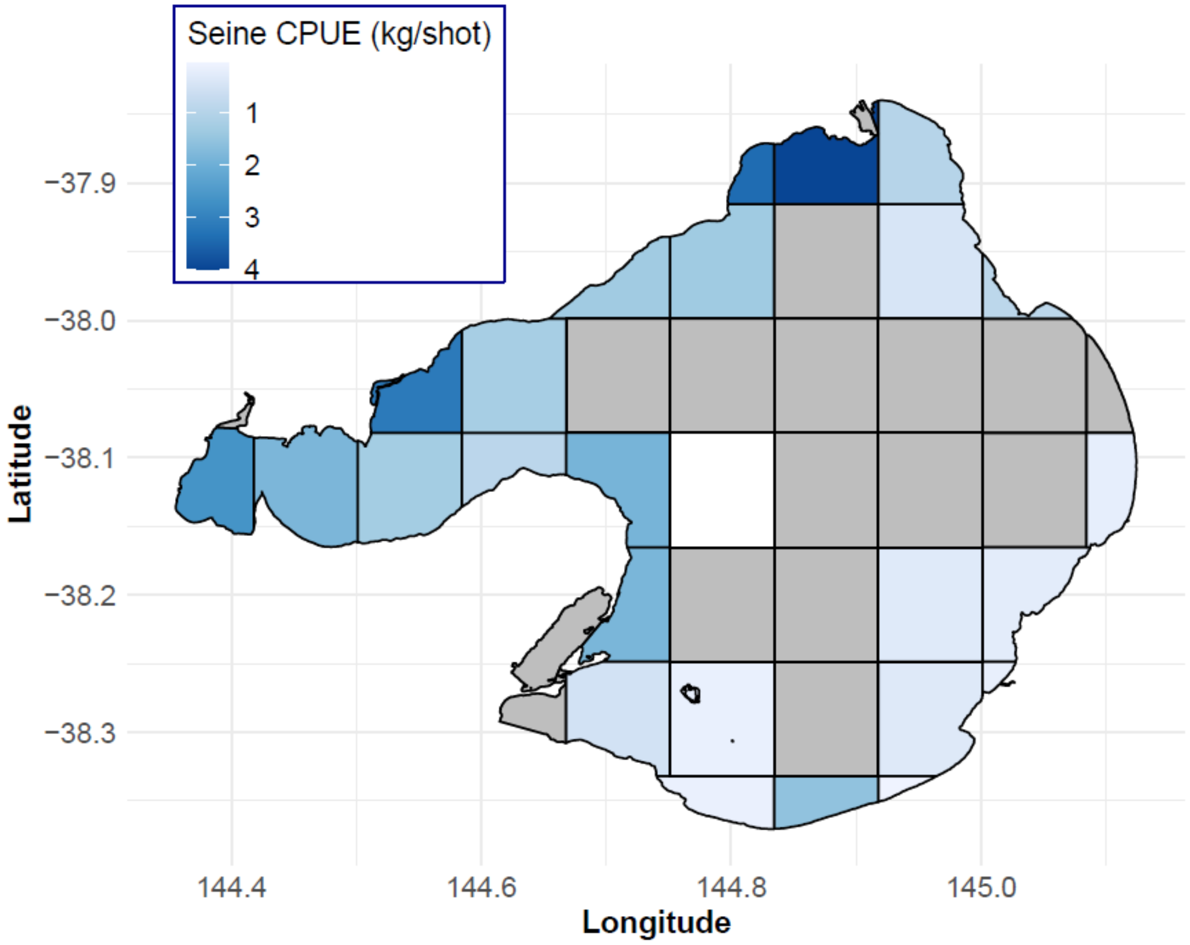

Figure 5 Catch rate of commercial seine fishers (kg/shot) providing a proxy for relative abundance.

Mortality

Mortality of fish occurs for a range of reasons such as old age, disease, predation and fishing. The following section reports estimates of various mortality components for SBF in Port Phillip Bay: historic commercial fishing landings (no recreational landings information are available), Z derived from a catch curve, and estimates of M (model based on biology), in turn enabling the back-calculation of F so that the relative impact of fisheries on the species abundance can be determined.

Total mortality

Historically, SBF were a byproduct of commercial fisheries in Port Phillip Bay, being taken by both seine and mesh net methods in roughly similar quantities, with lower landings from the longline fishery. Annual landings were generally 10–20t (Figure 6), increasing at times when a larger amount of mesh netting occurred, which was usually a result of periods of low King George whiting abundance forcing commercial fishers to target other species with mesh nets.

Total mortality (Z) can be estimated relatively easily using a catch curve, which fits a model to the descending abundance of fish beginning from the age of full selectivity through to older aged fish, thereby deriving an estimate of the rate at which fish are eliminated from the population. Using available age composition data, and an estimate of age at full selectivity of two years (i.e. the age at which most individuals are captured in the age composition data), a Chapman-Robson catch curve, fitted using the R FSA package, estimated Z to be 0.37 (95% CI: 0.28, 0.47), or in other terms, if exponentiated (i.e. exp-0.373), an annual survival rate of 68.8% once SBF have fully recruited to the fishery (Figure 7). This is considerably lower than was observed in northern Tasmania where estimates of Z ranged from 0.62 and 0.67 for females and males respectively (Costelloe and Haddy, 2014). There was no notable difference in the age structure of males and females in the present study so there was little value in estimating Z independently, particularly given that the relatively small sample size for older individuals could introduce bias.

It should be noted that the catch curve estimates of Z rely on several assumptions, all of which impact the representativeness of the age sample with respect to the broader population. In this instance, we know that recruitment appears to be relatively consistent during the time frame analysed, and there is no reason to believe that catchability of SBF changes drastically within the age classes investigated (mostly 2–9 year of age), so there is no reason to believe that this estimate is heavily biased. In addition, the present study sampled fish from a variety of sources, both fishery dependent and independent, and from a range of locations throughout their range, which should to some extent further reduce bias.

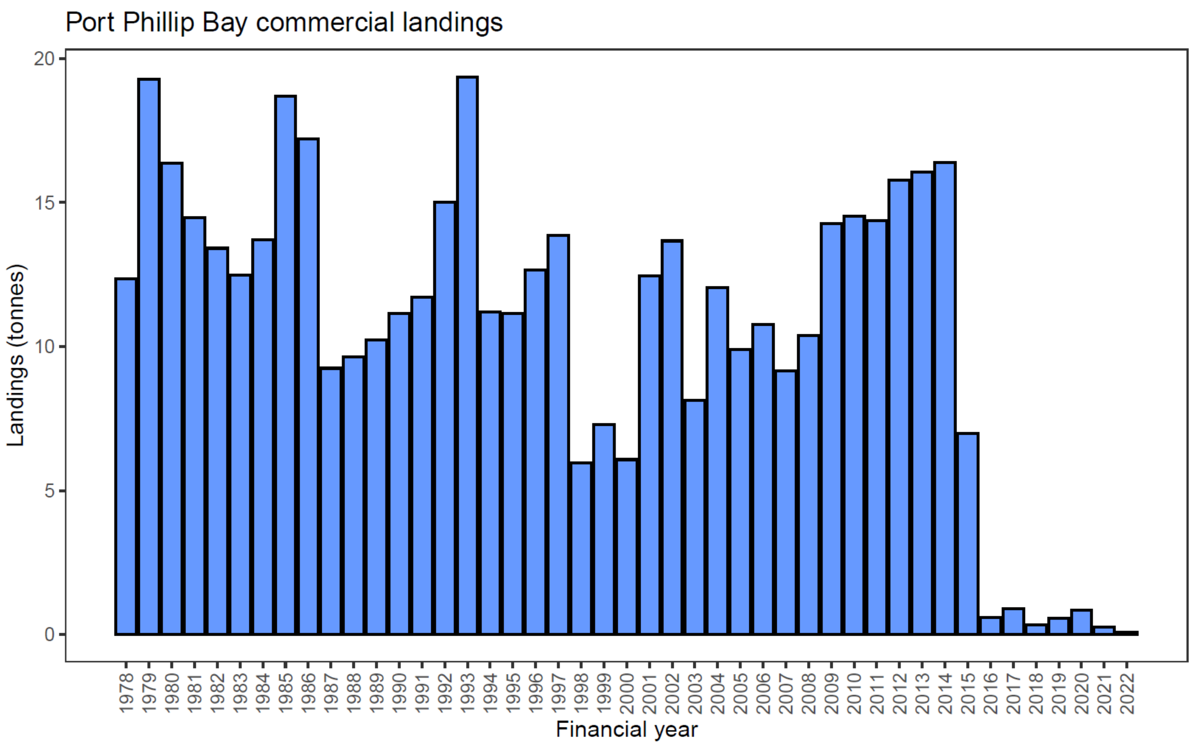

Figure 6 Landings from the Port Phillip Bay commercial fishery (all fishing gears) until the end of the 2022/23 fiscal year.

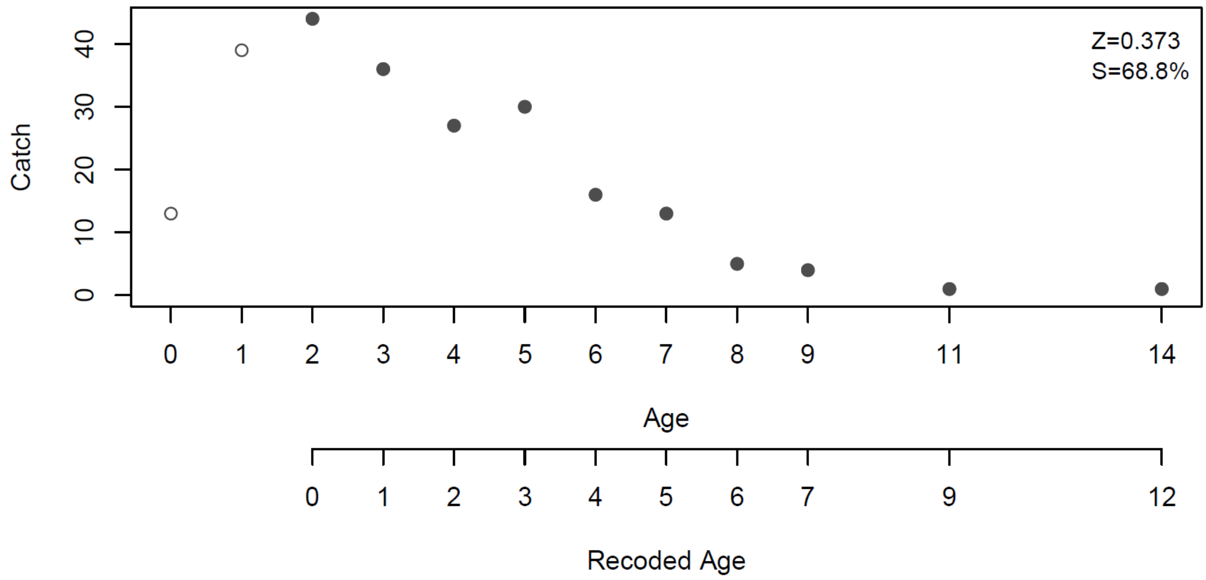

Figure 7 Chapman-Robson estimate of total mortality (Z) of SBF in Port Phillip Bay

Natural mortality

Natural mortality (M) is a difficult, but important, parameter to estimate in fisheries because it enables fishing mortality (F) to be estimated by excluding M from Z. Directly estimating M was beyond the scope of the present study, so instead it was necessary to rely on empirical modelling techniques. Two techniques are frequently used for this purpose, the first involves using von Bertalanffy growth parameters and temperature (various methods by Pauly et al.), the second the maximum age of the species (various methods by Hoenig et al.), with both techniques having been demonstrated to be highly correlated with M. However, estimates using von Bertalanffy growth parameters and temperature produced unreasonably high M estimates arising from the SBF growing atypically fast for a temperate species, and as a result, only estimators using maximum age are presented herein. Twelve models were fit using the 'FSA' R package, assuming a maximum age of fifteen years, which enabled an ensemble modelling approach, whereby a median estimate of M and 95% confidence intervals (mean ± 1.96*SD) were generated. The median was used as the best measure of central tendency due to the largest estimate disproportionately skewing the mean towards an implausibly high value of M.

Modelled M estimates ranged from 0.24 – 0.41 (Table 1; Figure 8), with most roughly between 0.25 and 0.35, with a median of 0.30 (95% CI: 0.22, 0.41). Unsurprisingly, given the fast growth and short life span, these M estimates are relatively high indicating that the Port Phillip Bay SBF stock, is likely to exhibit relatively fast turn-over rates and relatively high productivity.

Table 1 Natural mortality (M) estimates using the 'FSA' R package.

Method	M
Tmax1	0.34
HoenigNLS	0.41
HoenigO	0.30
HoenigOF	0.28
HoenigOM	0.36
HoenigOC	0.24
HoenigO2	0.30
HoenigO2F	0.26

HoenigO2M	0.35
HoenigO2C	0.31
HoenigLM	0.36
HewittHoenig	0.28

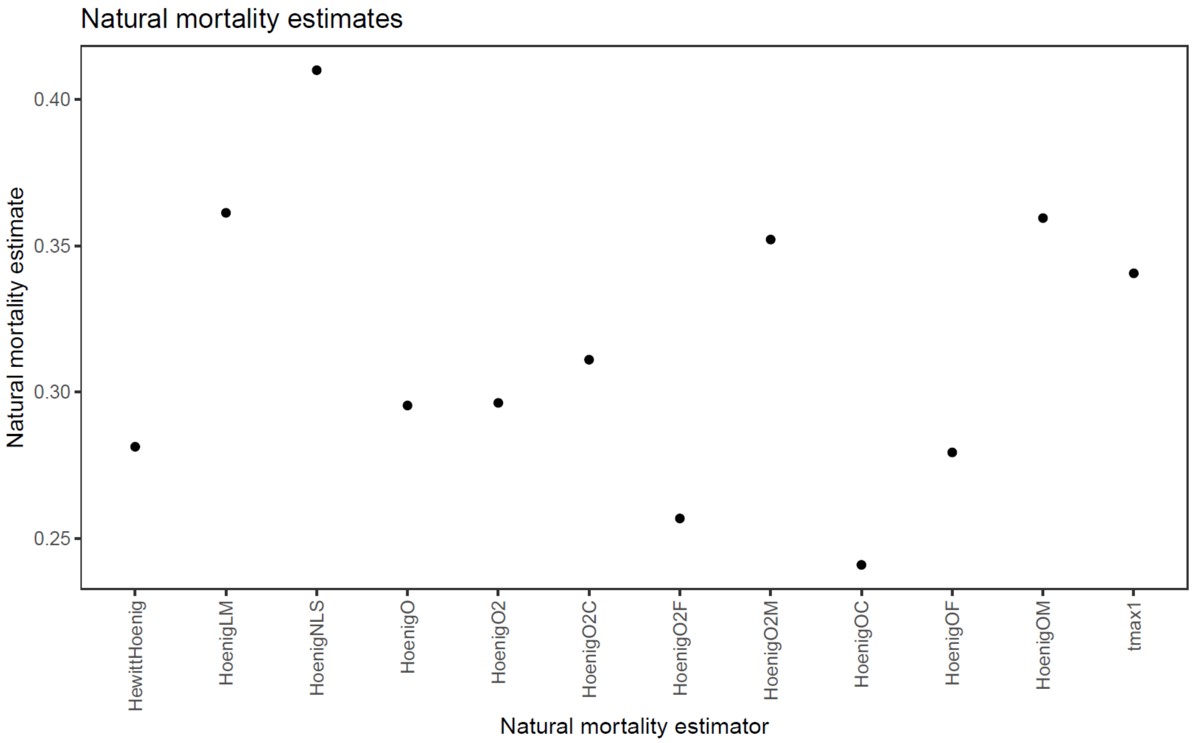

Figure 8 Natural mortality (M) estimates from different models for SBF in Port Phillip Bay.

Fishing mortality

Given that Z and M were estimated above, it becomes possible to derive estimates on F with simple algebra (i.e., F = Z - M). However, M was not directly measured so there is some uncertainty in its accuracy, thus confidence intervals bounding the F estimates were calculated using the variance surrounding the M and Z estimates by implementing standard propagation of variance techniques. This resulted in F estimates of 0.07 (95% CI: 0.03, 0.11), which is relatively low. Using these mortality estimates, it is possible to model a cohort of individuals (1000 in this case) to predict the number, or percentage, that will reach various ages by applying current mortality (i.e. Z) and M (i.e. with no F). Under such a low range of F, there is very little change in the population structure even if fishing completely abated (Figure 9), with 0.54% of individuals currently predicted to reach fifteen years of age at F = 0.07, and 1.42% predicted to reach fifteen years of age in the absence of fishing mortality (F = 0).

While there has been great debate surrounding appropriate levels of F to achieve maximum sustainable yields from a fishery, there is little debate surrounding the fact that it is species specific and dependent on the relative biological productivity of the species in question. An oft assumed appropriate level of F is that it remains around, or below, M (reviewed by Zhou et al. 2012). In the case of SBF, this appears to be clearly the case with F estimated to be around four times lower than M estimates suggesting that the stock is being fished relatively lightly and certainly within sustainable bounds, even if F is approaching the upper bound of its confidence interval. Further, the buyout of commercial net fishing methods in Port Phillip Bay, concluded in 2022, reduced the SBF catch by around 10–15t, which equates to around 25,000–37,500 individuals. While the magnitude of the recreational fishery cannot be estimated, SBF represent a relatively minor catch so the reduction in landings by the commercial fishery should have a noticeable influence on both the abundance, and size, of SBF in Port Phillip Bay.

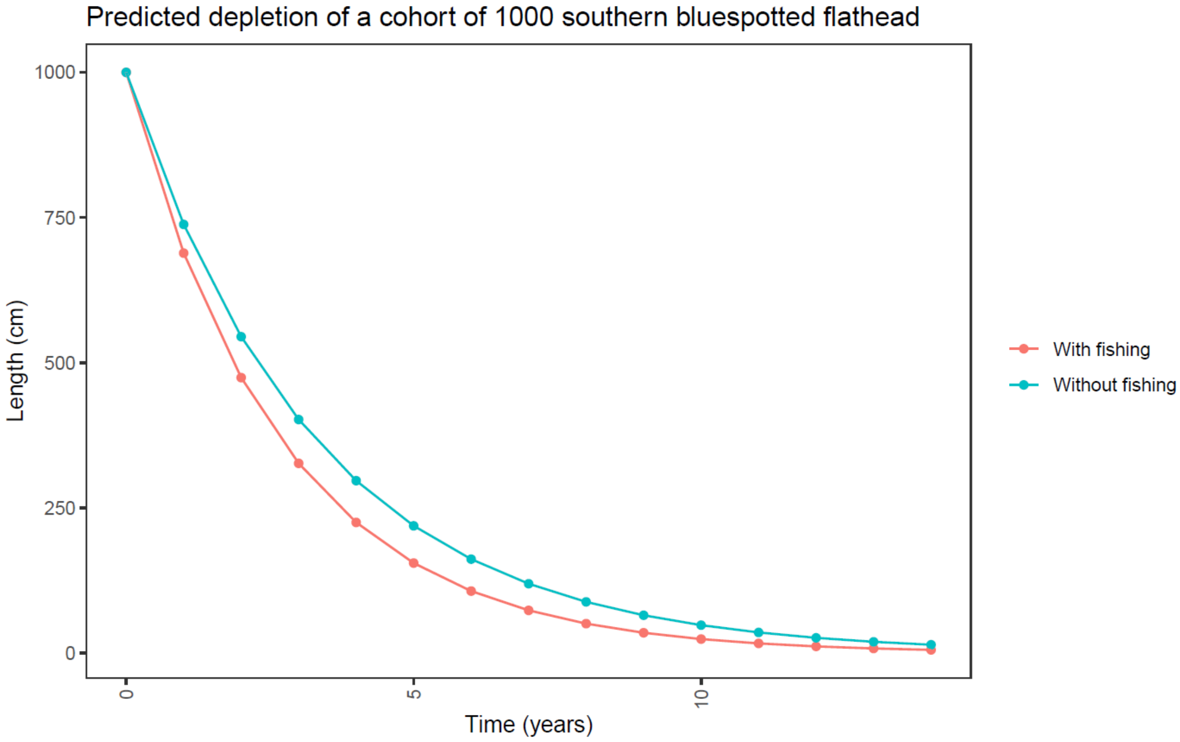

Figure 9 A cohort of 1000 SBF with projections based on Z and M (i.e. with no F).

Trends in abundance

As SBF is largely a byproduct of anglers targeting other species, occurring relatively rarely among recreational landings, insufficient information exists from creel surveys to develop a meaningful time series of recreational catch rate. This limitation is, unfortunately, also true to some extent for the commercial sector, but a larger issue in this instance is that some commercial fishers did not specify flathead species in their landings historically, meaning that despite the time series of SBF catch rates, the trend could be misleading. One data source, the annual Port Phillip Bay snapper prerecruit survey, does identify all flathead to the species level so this has been used to estimate relative abundance more accurately in this study. Although the prerecruit survey is largely targeted towards juvenile snapper in the deeper regions of eastern Port Phillip Bay, it does provide a consistent approach. Although not amenable to being used quantitatively in an absolute sense, it can be used as a relative measure of abundance. As all SBF are measured during this survey, the analysis was undertaken for various size classes in order to determine whether there were changes in the size structure evident through time, and in particular, whether there was evidence of episodic recruitment.

The abundance of all SBF size classes exhibited a similar trend through time, with abundance being low during the 2000s, increasing to the mid-2010s before declining again since about 2015 (Figure 10). The magnitude of change has been greatest among larger size classes (>20cm). The declining trends in the abundance of SBF during the 2000s follow a similar trajectory to that of sand flathead, which due to poor recruitment as a result of the millennial drought declined by 80–90% between 2000 and 2010 (Hirst et al. 2014). The decline in abundance of SBF appears to have occurred earlier, which is perhaps not surprising given that the species is far shorter lived than sand flathead which can live to >20 years, and it appears that low recruitment of SBF continued into the early 2000s with no individuals <20cm observed between 2000 and 2004. The increased SBF abundance observed during the early to mid-2010s can be traced back to increased recruitment (individuals <15cm) over several years between 2006 and 2018, which appears to have rebuilt the SBF stock sufficiently to maintain relatively stable adult abundance. However, from 2019 onward there has been a decline in all size classes following reduced recruitment. As it takes only around two years for new recruits to reach the 25cm size class, reduced recruitment over this relatively short time frame has been sufficient to results in a decline in the abundance of larger (>25cm) SBF. With the prerecruit survey mostly confined to deeper waters (>10m), very few large specimens are captured so the trend in these samples is unable to provide a meaningful index of abundance for larger cohorts, which will be more resilient to short term fluctuations in recruitment, particularly under the relatively low fishing pressure they appear to receive.

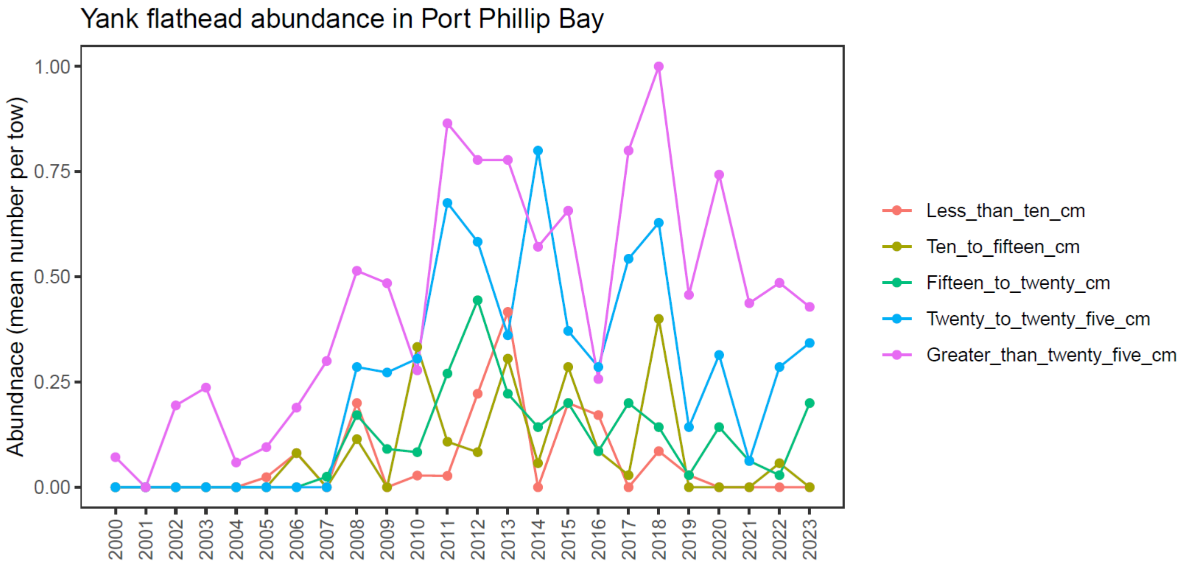

Figure 10 Catch rate (SBF per tow) of SBF during prerecruit surveys undertaken at 35 sites throughout Port Phillip Bay.

Trends in Catch composition of SBF and how management intervention will affect anglers' landings

Before undertaking modelling to reveal how changes to management regulations might alter F, and therefore affect what anglers are able to land, it is useful to investigate the size and catch composition of SBF landings, using creel survey data, as these data are used to undertake the bag and size limit modelling (i.e. the number and size of landings dictates what would need to be released under various scenarios). The Port Phillip Bay creel survey program has operated, in various forms, since December 1989, through to the present day. During this time, more than 21,500 interviews have been conducted at boat ramps throughout Port Phillip Bay. Currently (2023/24), the creel survey is still underway, so the analysis which follows utilises data from the program's conception through until the end of the previous year's survey, 31st April 2023.

Size and catch rate of SBF by the Port Phillip Bay recreational fleet

As very few anglers nominate SBF as their target species, the catch rate of SBF (number per angler hour) was investigated for anglers targeting all other species for which more than fifty creel survey interviews have taken place. There was a statistically significant difference in SBF catch rate depending on the main target species during each trip (Kruskal-Wallis chi-squared = 35.255, df = 4, p-value = <0.001). Multiple pairwise comparisons were subsequently made using a Dunn's test, with p-value corrected using the Benjamini-Hochberg method (Dinno, 2015).

Perhaps unsurprisingly, the highest catch rates, which were significantly higher than for most other species, were obtained by anglers when targeting flathead, despite most anglers targeting sand flathead in habitats deeper than those SBF, particularly larger specimens, tend to inhabit (Table 2; Figure 11). This is perhaps reflective of anglers' preference to drift while targeting sand flathead, covering large areas so that they are more likely to encounter SBF, even when they occur in relatively low abundance, as they are predominantly an ambush predator waiting for prey to come to them.

Catch rates of SBF when anglers are targeting King George whiting, gummy shark and snapper are similar, which is likely the result of the former predominantly taking place inhabited by SBF inhabit despite anglers employing fishing techniques not particularly conducive to catching SBF (i.e. small hooks and baits). In contrast gummy shark and snapper are not necessarily found in prime habitat for SBF, but the use of larger hook sizes, and baits (often involving burley) for these two target species is likely to increase catchability and also draw SBF to the area from a distance, thereby increasing the relative catch rate. Despite this, SBF catch rates when anglers are targeting King George whiting were significantly higher than for snapper or "anything", as recorded during creel surveys.

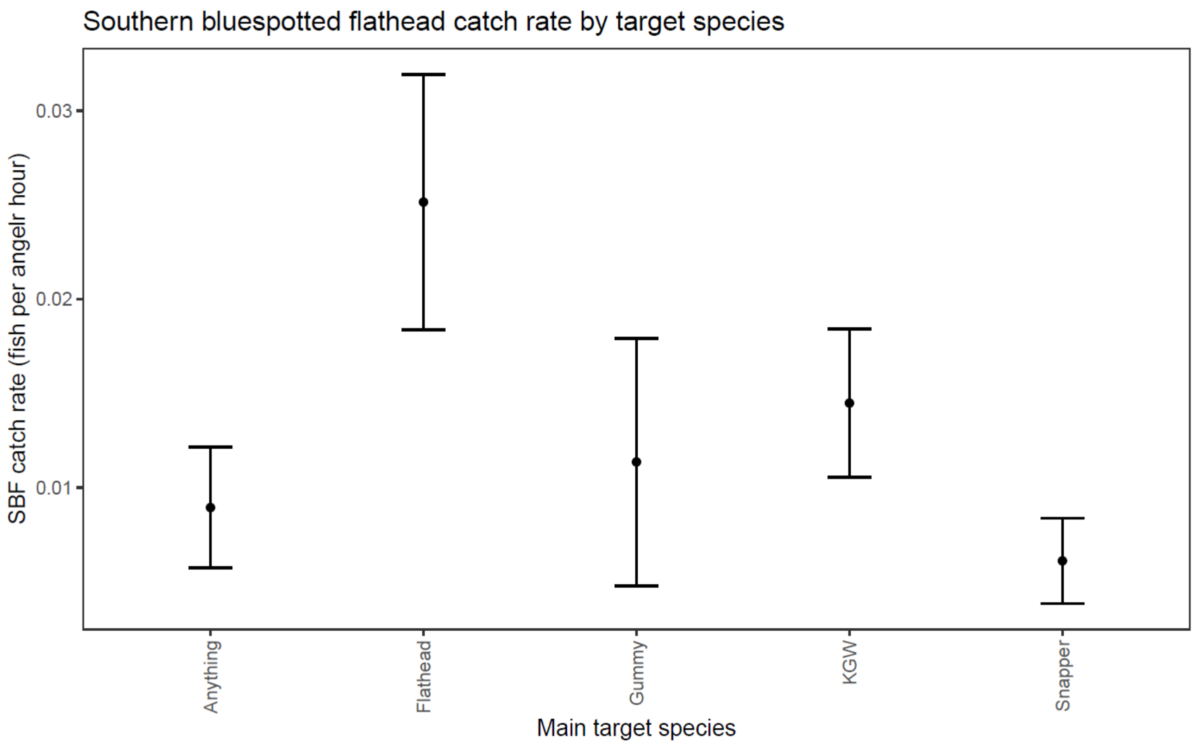

Figure 11 Catch rate (fish per angler hour) of SBF by anglers targeting their main target species (n = >50) in Port Phillip Bay.

Table 2 Multiple pairwise comparison of BSF catch rate by anglers targeting the main target species in Port Phillip Bay.

Comparison	Z	Adjusted p-value
Anything-Flathead	-2.74	0.02***
Anything-Gummy	-0.92	0.51
Flathead-Gummy	0.27	0.88

Anything-KGW	-2.18	0.07***
Flathead-KGW	0.55	0.72
Gummy-KGW	-0.03	0.98
Anything-Snapper	1.20	0.38
Flathead-Snapper	4.86	<0.001***
Gummy-Snapper	1.39	0.33
KGW-Snapper	4.08	<0.001***

Analysis of SBF size composition was undertaken in the same manner as for catch rates as detailed above. The size of SBF differed significantly depending upon the target species (Kruskal-Wallis chi-squared = 43.347, df = 4, p-value = <0.001), with SBF caught while targeting snapper being significantly larger than those caught while targeting other species (Table 3; Figure 12). Those caught by anglers targeting King George whiting or “anything” tended to be smaller than for other species, perhaps because of the gear used, particularly for King George whiting that involves small hooks and baits which are not particularly conducive to the capture of large SBF, despite occurring in depths and habitats they favour.

Despite the statistically significant differences outlined above, the actual size range captured while targeting all species was relatively similar, with means in the range 37.25–39.25), implying that any change to size limits will affect most anglers similarly regardless of which species they target. This also means that it is possible to explore length-frequency independently of target species, which suggests the size structure of SBF in Port Phillip Bay has changed little through time, with most individuals caught being 30–50cm in length (Figure 13). However, in all years which had an adequate sample size, some individuals >50cm were present, indicating that a reasonable proportion have grown to a relatively large size throughout the time series. This is consistent and reinforces the veracity of low value of F estimated in this study.

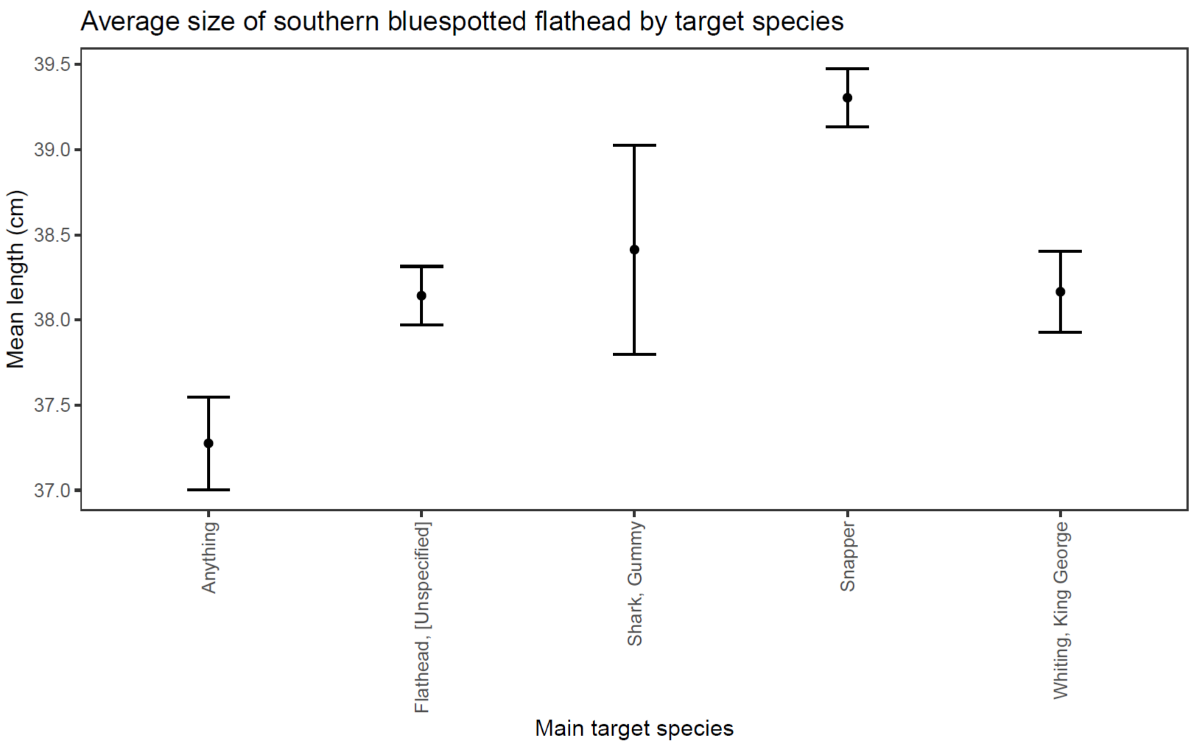

Figure 12 Mean size of SBF landed by anglers depending on the main species targeted during a trip (n > 100 trips).

Table 3 Multiple pairwise comparison of the size of BSF caught by anglers targeting the main target species in Port Phillip Bay.

Comparison	Z	Adjusted p-value
Anything-Flathead	-3.16	<0.001
Anything-Gummy	-1.75	0.13
Flathead-Gummy	-0.10	0.92
Anything-Snapper	-6.08	<0.001
Flathead-Snapper	-3.63	<0.001
Gummy-Snapper	-1.35	0.25
Anything-KGW	-2.53	0.02
Flathead-KGW	0.44	0.83
Gummy-KGW	0.31	0.84
Snapper-KGW	3.54	<0.001

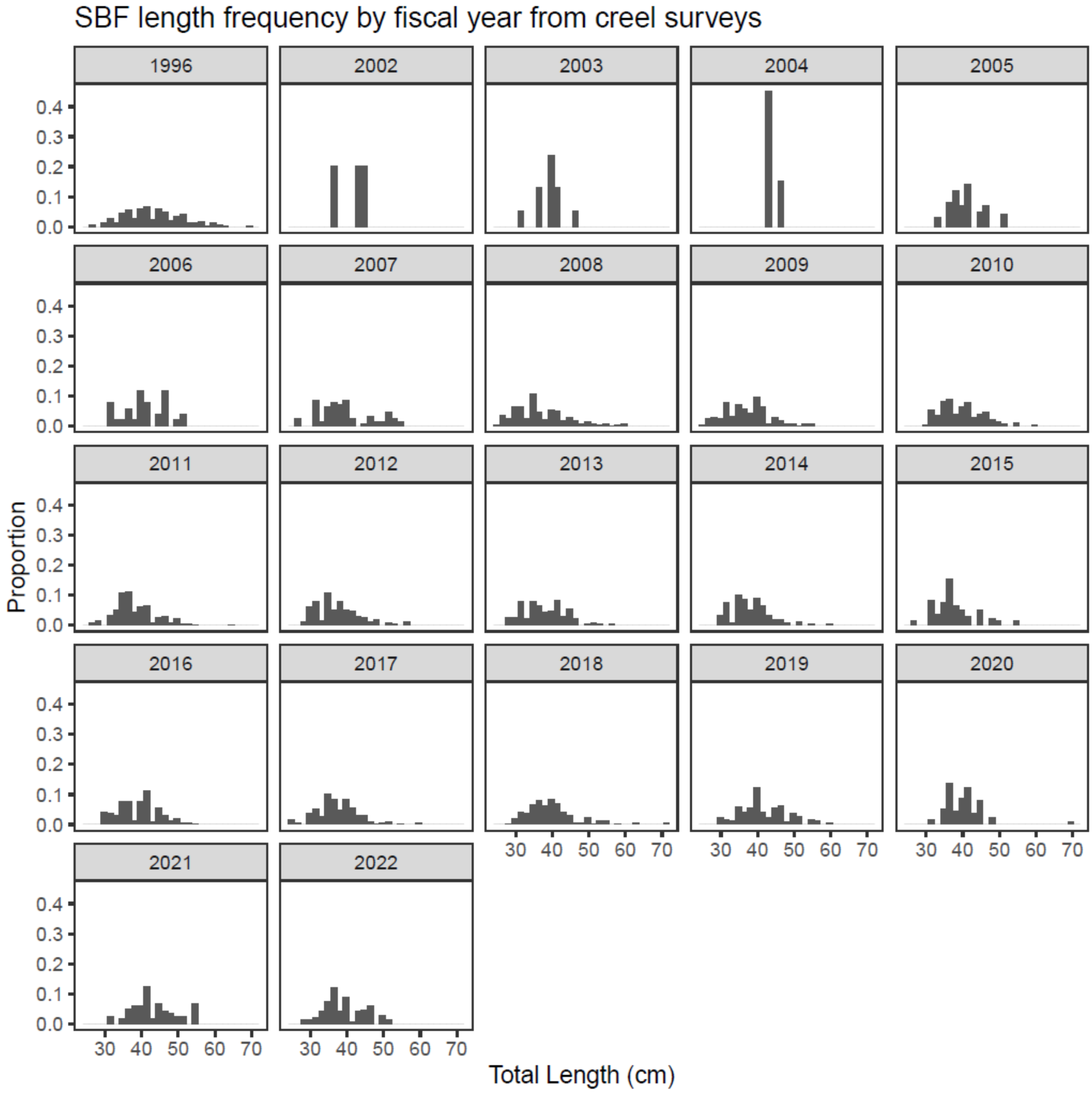

Figure 13 Length-frequency histograms of SBF landed by anglers interviewed during creel surveys in Port Phillip Bay by fiscal year (first year denotes fiscal year i.e., 2022 = 2022/23).

Bag and size limit modelling

Given the availability of the creel survey data representing what anglers catch in Port Phillip Bay, it is possible to estimate the effect of a change in legal minimum length (LML), bag limit, introduction of a slot limit with various numbers of SBF able to be retained above this limit, or any combination of these, will likely have on recreational landings (see Hamer et al. 2019 for model specification). The modelling used the observed number of SBF, and size composition of landings, to estimate how many fish would have had to be released by anglers should differing regulations have been in place, thereby providing a comparison of what would have occurred relative to current management arrangements. In this case, the percent by number of SBF that would have been released.

Input data from 2019/20 to 2022/23 fiscal years were used in the model as the relative rarity of SBF in anglers' landings meant insufficient data were available from the most recent year alone. The model was implemented using a standardised reduction in the bag limit to five fish, as higher bag limits had little to no effect – in >20,000 interviews we have never observed an angler landing the current bag limit of 20 SBF per person (the highest recorded was six). The LML was varied between the current 27cm size to 35 and 40cm and an upper size limit (termed slot limit herein), was implemented with the number of fish allowed to be landed above this size varied between zero and two fish. Multiple feasible variations of these limits were subsequently applied to explore how potential management changes would influence SBF landings, should they be applied in future.

Given that SBF generally comprise a small proportion of anglers' landings (Figure 14), and few very large individuals are landed, few of the possible alternative management scenarios reduced landings by much despite a reduction in the overall bag limit to five fish per person for all scenarios (Table 4). Replicating the management arrangements in place in Tasmania (i.e., LML of 40cm, bag limit of five fish, including no more than one fish >60cm) was estimated to reduce landings by 44%, which was effectively the same as all scenarios with a LML of 40cm. This is because a relatively large proportion of SBF landed are below 40cm, meaning this change alone had a large influence on retention rates and all scenarios retaining the current LML of 27cm had minimal influence on retention rates. As few fish landed are >50cm, the upper limit in all scenarios had little effect on landings. Thus, if there is a compelling desire to greatly reduce mortality of SBF from recreational fishing, the greatest reduction would be through a large increase in LML, which is further fortified by a relatively narrow slot limit, such as 50cm.

It must be noted, however, that most of the restrictions that would result in reduced mortality also impose relatively large restrictions on anglers, which may be acceptable to those targeting SBF, but could impose a considerable burden on those who happen to encounter a reasonable number on a given day by chance, especially if their landings of other species were low on a particular day. However, given the relative rarity that SBF are captured by most anglers (Figure 14) they contribute very little to anglers' landings in any given trip, generally 0% (Figure 15), with the largest number landed by any angler interviewed during creel surveys being six individuals.

There are, however, several credible anecdotal reports of a small number of anglers who actively target SBF catching numbers greater than has been observed during VFA's creel survey program, meaning there will be instances where the above bag and size limit modelling has a greater influence on the number of SBF that are able to be retained. While this is unlikely to have a meaningful influence on the modelling undertaken above, given it is representative of a majority of anglers, it will potentially have an impact on this minority of individual fishers.

Table 4 Estimated changes to anglers' SBF landings, in terms of numbers (%) landed under various bag, legal minimum length, and slot limit scenarios based on observed landings from creel surveys.

Bag limit	LML	Slot	Number above slot	Reduction in numbers (%)
5	27	40	0	55.9
5	27	50	0	9.3
5	27	60	0	0.8
5	35	50	0	16.1
5	35	60	0	8.5
5	40	60	0	44.9
5	27	40	1	5.9
5	27	50	1	0
5	27	60	1	0
5	35	50	1	7.6
5	35	60	1	7.6
5	40	60	1	44.1
5	27	40	2	0.8

5	27	50	2	0
5	27	60	2	0
5	35	50	2	7.6
5	35	60	2	7.6
5	40	50	2	44.1
5	40	60	2	44.1

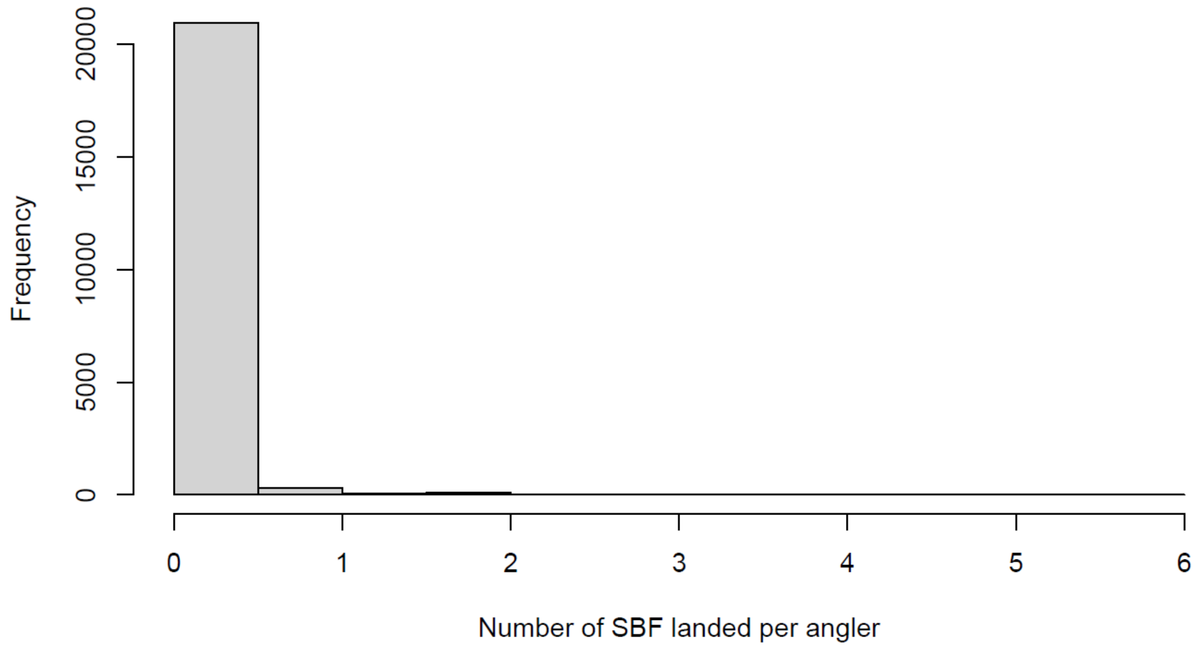

Figure 14 Contribution of SBF to anglers' landings (number per angler) observed from each trip during creel surveys in Port Phillip Bay

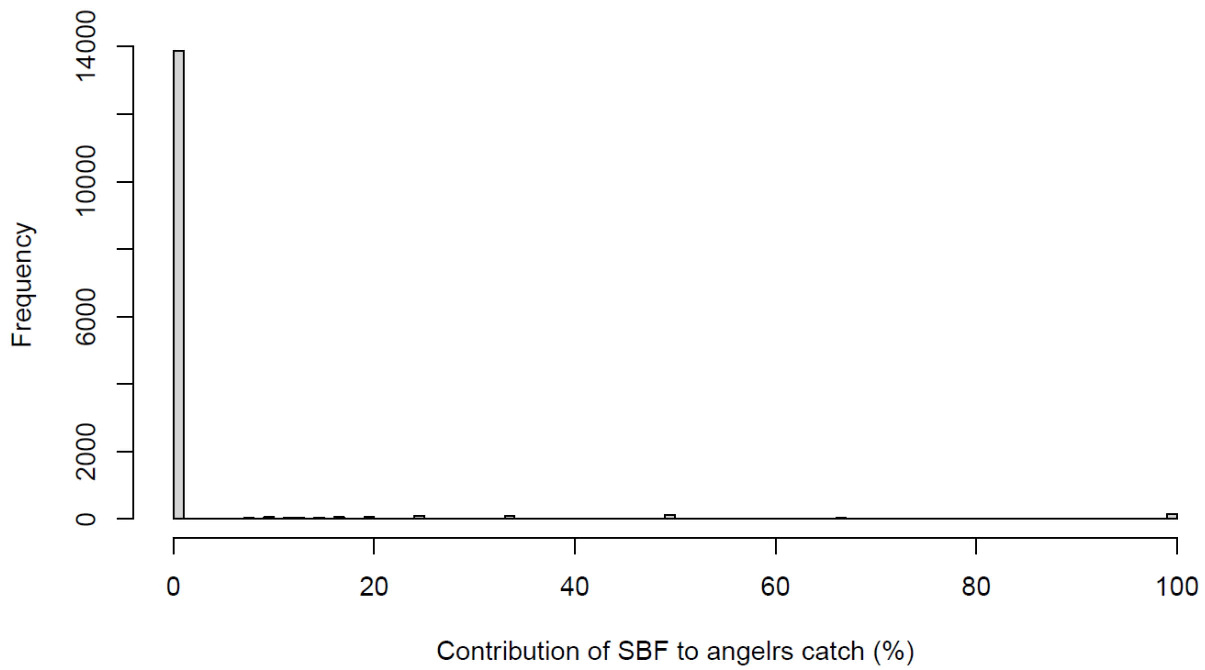

Figure 15 Contribution of SBF to anglers' landings (% of landings per fisher) observed from each trip during creel surveys in Port Phillip Bay. Histogram is in 1% increments.

Management Implications

Given that the Port Phillip Bay SBF stock is currently lightly exploited, few anglers target SBF and therefore few anglers catch large numbers of SBF, there appears to be little benefit in altering current management arrangements, both in terms of the sustainability of the species and potential improvements to the fishery by reducing fishing mortality. Further, the buyout of commercial net fishing in Port Phillip Bay is expected to have produced an ongoing reduction in F, with about 25,000–37,500 individuals no longer being captured by this sector.

In this context, there appears to be negligeable benefit to SBF stocks, and fishery performance, if current management arrangements were modified, and if they were, then there would be considerable complexity in implementing species-specific flathead management arrangements as for a majority of anglers SBF are virtually indistinguishable from sand flathead. This should not in itself represent a barrier to effective fisheries management if there is a compelling biological or resource sustainability need supported by sound scientific evidence, however this does not appear to be the case at present as it would provide little benefit from any perspective, yet could result in considerable inconvenience and confusion for many anglers.

The changes to SBF management arrangements in Tasmania were implemented because of increasing numbers of anglers targeting SBF in a small number of relatively small estuaries in northwestern Tasmania where there was potential to deplete stocks, or at least influence the population dynamics within these systems. This appears to have arisen with total mortality estimates from northwest Tasmania being considerably higher than those observed in the present study. In contrast, there is no evidence that this is the case in Port Phillip Bay – even though the species is landed often as a byproduct of targeting other species, and a niche fishery exists in which a minority of anglers' target SBF, the species is nevertheless widespread, and fishing practices operating under current management arrangements are highly unlikely to deplete stocks. Indeed, any feasible changes to current management arrangements are unlikely to have a meaningful impact on stocks, which are expected to increase in abundance as a result of reduced commercial landings and commensurately lower F.

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