The decline of sand flathead stocks in Port Phillip Bay: magnitude, causes and future prospects.

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Recreational Fishing Grants Program Research Report

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The decline of sand flathead stocks in Port Phillip Bay: magnitude, causes and future prospects

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Executive summary

Sand flathead (*Platycephalus bassensis*) was once both a significant commercial fishery and the largest recreational fishery in Port Phillip Bay (PPB). Since 2000 stocks have declined substantially in PPB. The cause/s of this decline are unknown; and attempts to rebuild stocks are unlikely to be successful without identifying and addressing the cause/s as part of any management response. This report draws on a range of data sources to summarize what is known about the current status of the fishery in PPB, the probable causes of the decline and the prospects for recovery. Finally we review the adequacy of the current management settings for sand flathead in PPB as part of ongoing efforts to assist the recovery of this stock.

Sand flathead stocks in Port Phillip Bay declined by 80–90% between 2000 and 2010, but had recovered to 30% of 1990s levels, and 50% of 1980s levels, by 2012/13. There was no evidence that fishing pressure exacerbated this decline. Stock exploitation remained stable between 2000/01 and 2006/07 at 15–30% of the stock biomass, despite the decline, due to a three-fold reduction in the total fisheries catch over this period (from 338 tonnes in 2000/01 to 115 tonnes in 2006/07).

A comprehensive review of the available evidence overwhelmingly supports the conclusion that declining recruitment (i.e. the introduction of new 'baby' fish to a population) from the mid-1990s onwards led to the decline of sand flathead stocks from 2000. In comparison, there is little evidence that sand flathead growth (and hence mortality) was affected by either the introduction of the exotic seastar *Asterias amurensis* in the late 1990s or the drought from 1997–2009.

The decline in sand flathead recruitment coincided with a period of prolonged drought in Victoria from 1997–2009; characterised by substantially lower rainfall and river flows. Sand flathead recruitment in Port Phillip Bay from 1988–2013 was significantly correlated with Yarra River flows during November and December when the majority of sand flathead larvae occur in the water column. The relationship between flow and recruitment was positive up to 3000 ML/day, but negative for flows in excess of 3000 ML/day. This means that recruitment was lowest in years when flows were either very low or very high and highest in years with intermediate flows between 1000 and 3000 ML/day. Almost all low flow years during the drought corresponded with low recruitment.

This analysis suggests that sand flathead recruitment in Port Phillip Bay is heavily influenced by climatic conditions and this conclusion is consistent with our understanding of the forces that drive cycles of productivity for other fisheries in Port Phillip Bay (e.g. snapper and King George whiting). However, the magnitude of this decline is unprecedented since catch and effort records began in 1978, and there is little evidence of declines of a similar scale amongst commercial catches recorded since 1914. We directly link the magnitude of this decline to the prolonged, severity of the most recent drought in Victoria.

The future prospects for the recreational sand flathead fishery in Port Phillip Bay are mixed. In the short to medium term, prospects are a more positive. Sand flathead stocks have transitioned from steady decline to slow recovery. The drought is over and the future outlook for Victoria's climate in the short-term (based on the Bureau of Meteorology's POAMA climate model) is for average rainfall. This should lead to enhanced river flows, particularly in spring, and if the relationship between river flows and recruitment holds, overall better recruitment.

Over the longer term, the prospects for this fishery are less positive. This is because south-eastern Australia's future climate is expected to become drier on average as a consequence of global warming. Projected decreases in rainfall and run-off, coupled with increasing frequency and intensity of El Nino events are expected to result in higher incidence of drought in south-eastern Australia. If the relationship between river flows and recruitment holds for sand flathead in PPB, then a drier climate is likely to result in less optimal conditions for sand flathead recruitment over the longer-term and overall lower stock biomass.

This future outlook poses a number of challenges for fisheries managers over both the short and longer term. In contrast to other major fisheries in PPB, the sand flathead fishery is dominated by a single sector: the recreational fishery. The recreational fishery accounts for >95% of the total catch and this potentially simplifies the overall management of this stock in comparison to other multi-sector fisheries in PPB. In the short term the management focus should be on how best to assist recovery. Given the fishery is now showing evidence of slow recovery, we propose a monitor and review approach. This approach would be based on monitoring of commercial and recreational CPUE and sand flathead recruitment surveyed as part of the snapper pre-recruit survey operated by Fisheries Victoria. This review should be used as the basis to consider further management options.

The management options for this species are limited and comprise essentially changes to size and bag limits. Increasing the minimum size limit is likely to increase the sex bias of catches (females are larger than males and estimated to be currently caught at twice the rate of males). Although the effect of this is unknown, this is considered to be an undesirable outcome for the sustainability of the stock. Consequently, reductions to current bag limits are likely to be the only effective tool available to managers to assist the recovery of this fishery in PPB. Bag-limit scenario modelling demonstrates that significant cuts to current bag limit settings for flathead are required to have any meaningful impact on reductions to total catch. A reduction in the maximum bag-limit from its current level of 20 to 5 flathead would be required to reduce the total recreational catch by 16% and the exploitation of the stock by between 2.1–4.4%.

Introduction

Sand flathead (*Platycephalus bassensis*) was once the largest recreational fishery in Port Phillip Bay (PPB), despite its status primarily as a by-catch species (Ryan et al. 2009). Since 2000 sand flathead stocks in Port Phillip Bay have declined by approximately 90% (Hirst et al. 2011). However, the cause/s of the decline are not well understood; and attempts to rebuild stocks are unlikely to be successful without identifying and addressing the cause/s of the decline as part of any management response.

The sand flathead fishery has a long history in PPB. Historically, sand flathead was once one of the most important commercial fisheries in PPB, second only to Barracouta in terms of total catch (Hall and McDonald 1986). Between 1914 and 1950 approximately 200 tonnes of flathead per year was caught in PPB by commercial fishers - most of this using mesh or gill nets (Figure 1). From the early 1960s onwards commercial catches of sand flathead began to decline in response to large reductions in fishing effort that accompanied the expansion of more economically viable fisheries in Bass Strait and the availability of higher quality table fish from other markets (Hall and McDonald 1986), adverse interactions between gill net fishers and scallop dredgers (Parry et al. 2009) and economic and social change that gave rise to other economic opportunities for fishers. Since the 1970s, sand flathead has largely been caught as by-catch as part of more valuable commercial fisheries such as snapper.

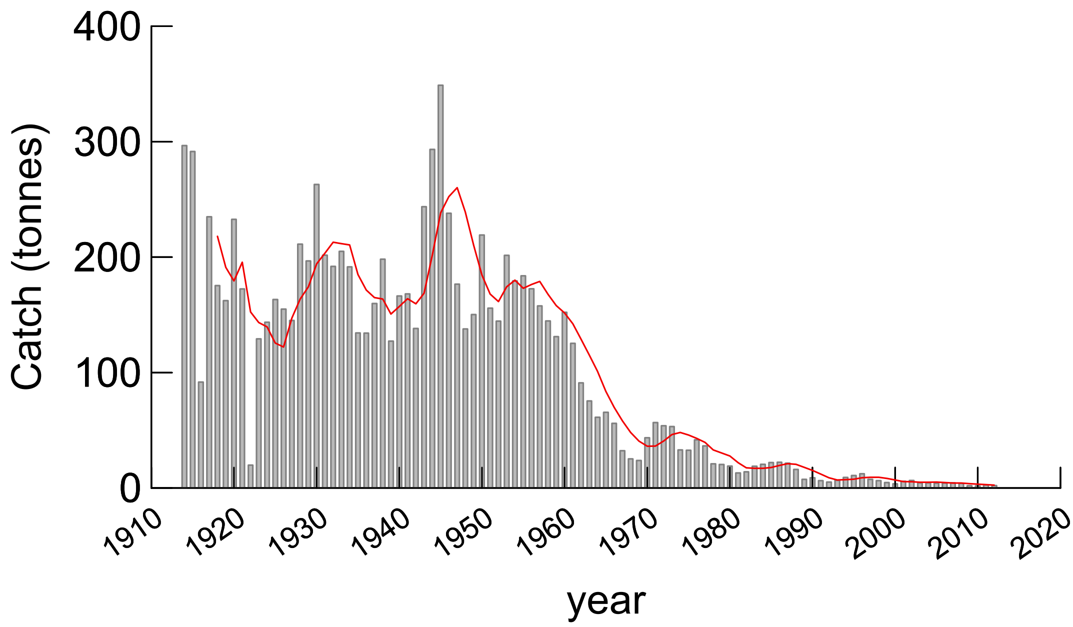

Figure 1 Commercial flathead catch (tonnes) in Port Phillip Bay 1914–2012. Red line = 5 year moving average. Source: Hall and MacDonald (1986) 1914–1986; Catch & Effort, Fisheries Victoria 1986–2012

Whilst the importance of sand flathead as a commercial fishery has waned considerably over the past 5 decades, its importance as a recreational fishery has increased in recent decades. Sand flathead is widely acknowledged as a staple catch for recreational fishers of all ages and experience because it is relatively easy to catch and the flesh is of excellent quality. Coutin (2000) estimated that about 40% of the total recreational catch in 1994/95 was sand flathead. Although information on total recreational catch is more difficult to obtain, a national phone survey in 2000/01 estimated that 322 tonnes of sand flathead were caught in PPB during this year (Henry and Lyle 2003). This catch was comparable to the commercial catches recorded earlier in the last century (Figure 1). The sand flathead fishery is now predominantly recreational in nature and during 2012/13 only 2 tonnes was caught by the commercial fishery (Fisheries Victoria, commercial catch and effort data).

Sand flathead are a conspicuous component of the fish fauna of southern Australia. They occur in coastal waters from the SW coast of Western Australia to the mid coast of NSW including the coasts of South Australia, Victoria and Tasmania (Gomon et al. 2008). Sand flathead are bottom dwellers living on sandy, shelly or muddy bottoms to 100 m depth. In Port Phillip Bay they are most abundant in deeper habitats >15 m living on silty and muddy bottoms (Hirst et al. 2011).

Sand flathead are ambush predators (Figure 2) that conceal themselves in fine sediments. They are able to change their skin colour by altering the arrangement of pigment within chromatophores (pigment containing and light reflecting organelles in skin cells) in response to specific environmental stimuli (Douglas and Lanzing 1981). This allows sand flathead to adopt a colour pattern that blends visually with the surrounding substrate. The diet of sand flathead in PPB is dominated by crabs, particularly *Philyra undecimspinosa* and *Nectocarcinus integrifrons*, and small fish such a gobies and anchovy (Parry et al. 1995).

Figure 2 Image of sand flathead partially concealed by sediments. Photo credit P. Hamer

Sand flathead are relatively long lived, reaching a maximum age of 23 years. Females are typically larger than males. Male and female sand flathead reach sexual maturity at between 2 and 4 (mean length = 22 cm length) and 3 and 5 years (25 cm) (Bani and Moltschaniwskyj 2008). Female sand flathead spawn eggs into the water column over a protracted period from September to January (Jordan 2001, Koopman et al. 2004, Bani and Moltschaniwskyj 2008). Eggs are fertilized and develop into larvae that live in the water column from October – April (Jenkins 1986, Neira and Sporcic 2002), with a peak in density in November (Jenkins 1986). Larval duration for this species is unknown, but based on individual ageing of larvae is known to be at least 25 days (Hamer et al. 2010). Larvae settle out of the plankton and are recorded in beam trawls once they reach 3–6 cm length from December through to February (Hamer et al. 1998, Jordan 2001).

Sand flathead are not strong swimmers and are considered to be relatively immobile in comparison to other migratory fish. The evidence for this comes from a range of studies that have used sand flathead as indicators of pollution in marine environments, and that have demonstrated localised accumulation of pollutants (Walker 1982, Holdway et al. 1994, Nicholson et al. 1994, Gagnon and Holdway 2002). There is thought to be little movement of adult fish in and out of PPB. By comparison, little is known regarding the movement of larval sand flathead in and out of PPB and the origin of spawned fish that recruit within PPB (Hamer et al. 2010).

Sand flathead have been regularly used as indicators of marine pollution in PPB (Walker 1982, Holdway et al. 1994, Nicholson et al. 1994, Gagnon and Holdway 2002). Past poor industrial practices led to heavy metal and other toxicant contamination of PPB. Walker (1982) found that mercury levels in the tissues of sand flathead collected between 1975 and 1978 in PPB were significantly higher than fish collected from outside PPB, and this was of considerable concern to health authorities because sand flathead was a popular recreational catch consumed by anglers. By the 1990s, following the implementation of appropriate abatement programs for toxicants, mercury levels in sand flathead were found to have returned to background levels (Fabris et al. 1992). The most recent study found that sand flathead collected from historically highly polluted areas such as Hobsons Bay and Corio Bay had heavy metal concentrations well below the maximum concentrations specified by the Food Standards Australia code (Fabris et al. 2006).

There is evidence that pollution has affected the health of sand flathead living in close proximity to sources of toxicants in PPB (Holdway et al. 1994, Gagnon and Holdway 2002). Holdway et al. (1994) found enzyme dysfunction in the livers of fish collected in regions closest to highly industrial and urbanised areas; whereas Gagnon and Holdway (2002) concluded that high concentrations of specific biliary metabolites in the blood of sand flathead collected from Corio Bay and Hobsons Bay was indicative of high exposure to petroleum hydrocarbons. Pesticides and petroleum hydrocarbons were found in the tissues of sand flathead throughout PPB, but occurred at levels considered safe for human consumption (Nicholson et al. 1994).

Concerns regarding the health of sand flathead stocks in PPB have been raised in a number of previous stock assessments (Winstanley 2008). Sand flathead stocks first began to decline following the arrival of the introduced northern Pacific seastar (*Asterias amurensis)* in the late 1990s and there is a popular perception that the two events are linked. The Baywide Fish Stock and Recruitment Monitoring Program undertaken as part of the Channel Deepening Monitoring Program detected a significant decline in the biomass and abundance of sand flathead between 2004–2007 and 2008–2011 (Hirst et al. 2011). A management review concluded that the decrease in flathead biomass was considered to be the continuation of a decline that could be traced to 2000 and unrelated to channel dredging activities from 2008–2010 (Office of Environmental Monitor 2012). This finding was referred to the Department of Primary Industries and Department for Sustainability and Environment for further action.

There is currently little information on whether the decline in PPB is part of a broader pattern across its geographic range. If the decline is more widespread, then the causes of the decline are unlikely to be restricted to PPB and this may have broader implications for the management of this species across its geographic range.

Aims

This report:

1 Quantifies the magnitude of the decline and provides an assessment of the current status of sand flathead stocks in PPB.

2 Considers whether the decline observed in PPB is more widespread (i.e. not just restricted to PPB).

3 Examines and identifies the cause/s of the decline by examining the evidence that a) fishing pressure (recreational and commercial) and/or b) environmental factors explain, or contributed to, the decline in PPB.

4 Examines the best strategies for rebuilding sand flathead stocks in PPB, including recommendations on what are the best methods for anglers to use to catch sand flathead sustainably?

5 Examine the prospects for recovery of this stock in the short-to-medium term and the viability of the fishery over the longer term.

Methods

This report draws upon a number of independent data sources that provide information on the status of sand flathead in Port Phillip Bay (PPB). The primary source used in this study was the PPB annual demersal trawl, which provides information on catch trends for fish > 1 year of age, size and age structure, and diets from 1990 to 2011. Direct information on the number of first year (0+ age) sand flathead recruited to the population every year from 2000 to 2013 was provided by the snapper pre-recruit survey using methods described in Hamer et al. (1998).

This report also used three independent sources of information on fisheries trends for both the commercial and recreational sectors: 1) commercial catch and effort data (i.e. catch rates and total catch), 2) recreational creel and angler diary surveys that provide data on recreational catch rates, and 3) phone surveys of recreational fisher behaviour/activity that provide estimates of total catch for this sector.

In combination this information enabled us to examine past trends in size of the stock, recruitment trends and changes to size and age structure.

Data sources

Port Phillip Bay annual trawl

Demersal fish populations were sampled using a demersal trawl net (13 m wide at the mouth) at 22 depth-stratified sites within PPB (Figure 3). Sites were sampled annually in March between 1990 and 2011, with the exception of 1998 and 2001. Sampling sites were located along six transects positioned perpendicular to the coastline at depths of 7, 12, 17, and 22 m, except for transect in the Geelong Arm, where depths permitted trawling only at 7 and 12 m (Figure 3). At each site, two trawl tows were undertaken, such that 44 tows were completed annually.

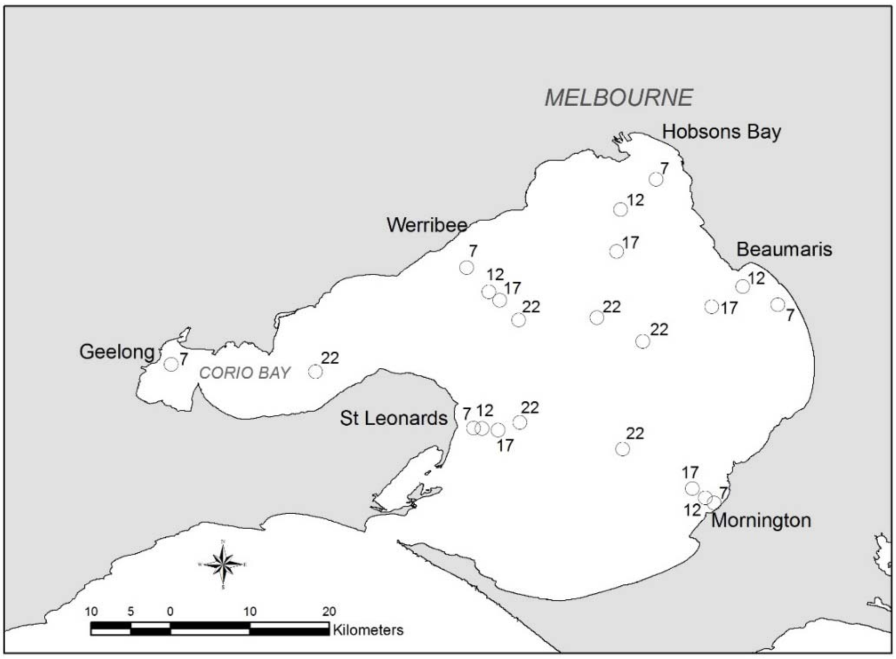

Figure 3 Location of annual trawl survey sites in Port Phillip Bay displaying transects off Beaumaris, Geelong, Hobsons Bay, Mornington, St Leonards and Werribee

The duration of each trawl shot was nominally five minutes. Differential Global Positioning System (DGPS) software was used to record the start and finish of each tow. The speed of the net across the benthos was estimated from the duration and latitude and longitude at the start and finish of each tow.

Fish were sorted on deck and the number and total weight of each species recorded. The lengths of a sub-sample of sand flathead were measured from each site for 100 haphazardly chosen individuals, except where less than 100 individuals were caught at a site, then all fish were measured. A sub-set of these fish were retained for ageing and stomach content analysis. Further detail on PPB annual trawl methods can be found in Parry et al. (2009) and Hirst et al. (2011).

Pre-recruit annual survey

Zero year (<12 months) aged sand flathead were surveyed at night using a small purpose- built beam trawl net (2.5 m wide mouth; 8 mm^2 aperture mesh net) at nine locations within PPB (Figure 4). Five 10 minute trawls were undertaken within each location. Sampling was undertaken in late March/early April from 2000 to 2013 and was designed principally to survey trends in 0+ aged snapper (*Chrysophrys auratus*) abundance, but also records information on sand flathead abundance and length frequency. Sand flathead collected during this program were also used to daily age 0+ age fish.

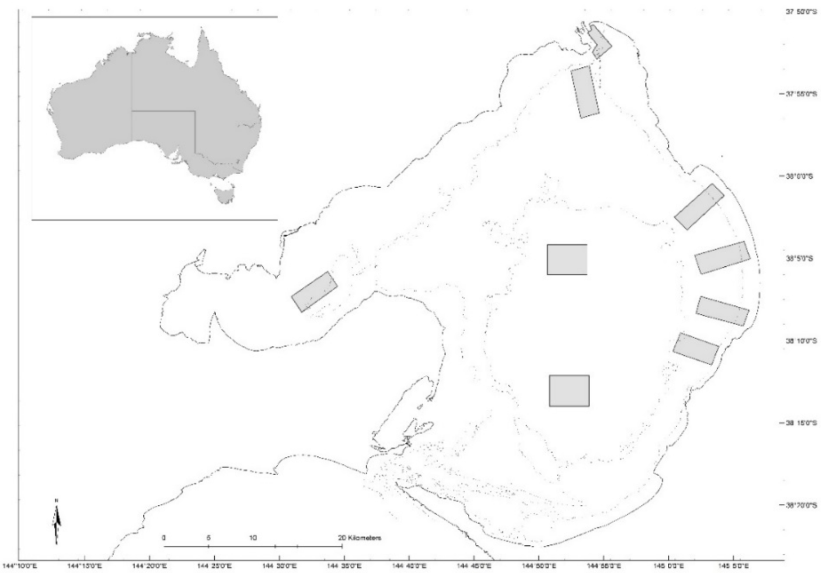

Figure 4. Map of Port Phillip Bay showing the regions (grey boxes) sampled by the pre-recruit survey

Further details on the methods used in this program can be sourced from Hamer et al. (1998).

Recreational fishery surveys

Information on recreational fishery trends was sourced from on-site boat ramp (Creel) and angler based surveys conducted by FV.

Boat ramp surveys of angler activity were undertaken during January-April each year at selected boat ramps across PPB (Figure 5). Boat ramps were grouped into three key regions: Melbourne, Mornington and Bellarine. Anglers were asked to provide information on the species targeted, the number of fish species retained and released, time spent fishing and the location fished. A sample of important recreational species retained in the catch were inspected, identified and individuals measured. Total length was recorded for species with truncate or rounded caudal fins (including flathead). Annual catch rates (measured in fish per angler hour) were used as an indicator of flathead stock abundance from 1995–2012. Further details can be sourced from Bruce et al. (2012).

Time series of recreational catch rates for flathead were supplemented by information collected by angler-based assessments (also referred to as the ‘Research Angler Diary Program’ or RADP), designed to monitor the length/age composition of key species based on the catch of the participating ‘research anglers’ (Conron et al. 2012). Research anglers are skilled fishers, who adjust their fishing techniques (hook sizes, baits and fishing locations) to target fish species both above and below the minimum size limit.

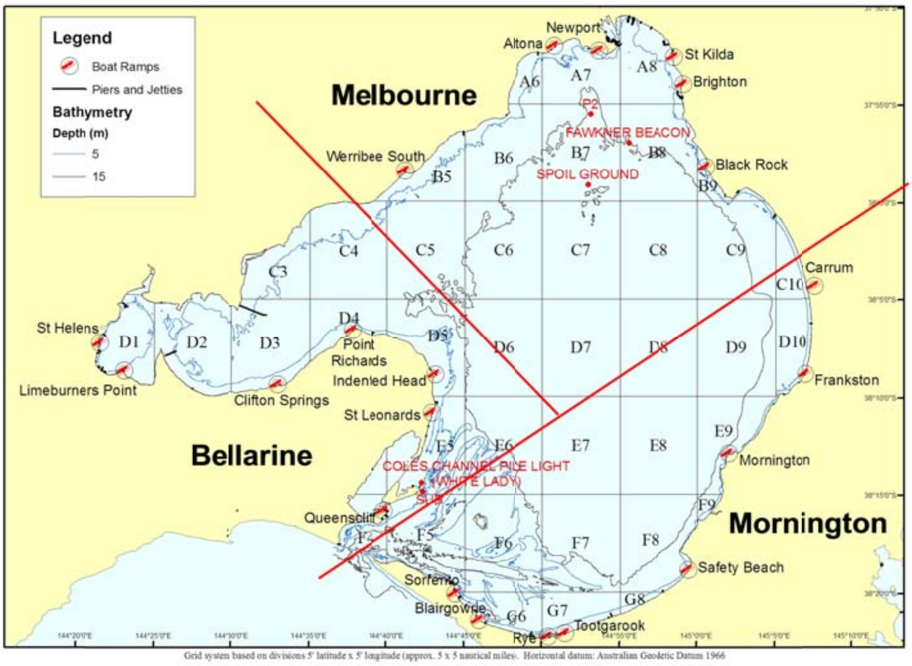

Figure 5 Boat ramps in key regions of PPB selected for on-site boat ramp surveys

Data analysis

Estimation of stock biomass in Port Phillip Bay

Sand flathead catch data collected by the PPB trawl program from 1990–2011 forms the basis of calculations of stock biomass and fisheries exploitation for the sand flathead population in PPB. Stock biomass was extrapolated from estimates of sand flathead density (i.e. catch per unit area) at each depth trawled (7, 12, 17 and 22 m) using a depth-stratified GIS model of bathymetry in PPB.

Sand flathead density at each depth was calculated by dividing the weight (kg) of fish caught by the area swept (m^2 area swept) during each 5 minute tow. Swept area can be broadly divided into two components: A) the area swept directly in the path of the net (net area), and B) the area adjacent to the net path swept by the ‘bridles’ (bridle area) (Figure 6). The bridles connect the doors to the net and ‘sweep’ the bottom during trawling, in the process, herding fish into the path of the net. The width of the net area/path was estimated from the dimensions of the net (approximately 13 m wide); whereas the width of the adjacent bridle areas was calculated by subtracting the width of the net path from the width of the spread between the trawl doors at each depth (see Figure 6). Door spreads were calculated at each site using simple geometry, and are typically wider at greater depth due to the longer tow cable (warps) used.

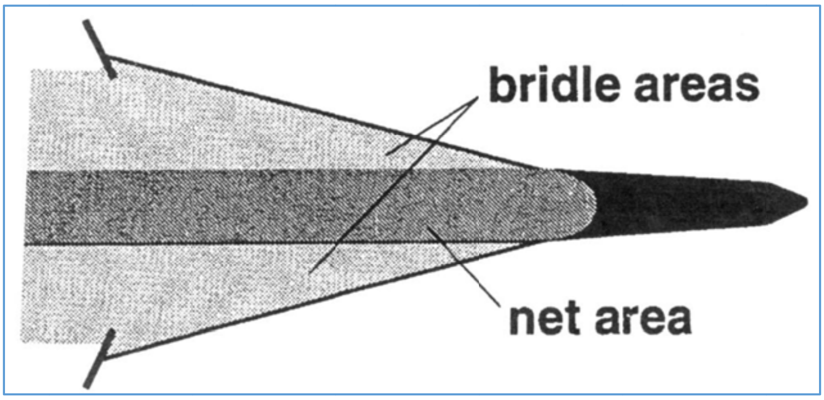

Figure 6 Diagram showing path of net (net area) and the adjacent area in which herding by bridles/sweeps occurs (bridle areas) (Parry 2011).

Swept area measurements were corrected for differences in fishing duration by measuring the time the net was in contact with the bottom during each tow. This is an issue because there is a small discrepancy between the point at which the trawling finishes (nominally 5 minutes) and the point at which the winch actually lifts the net off the bottom (the point at which trawling actually ceases). Actual fishing duration for each depth and site was calculated during the 2011 trawl using an underwater digital video camera mounted directly inside the mouth of the net so that the behaviour of the footline could be directly observed whilst trawling. Fishing duration was calculated by measuring the time the net was in contact with the benthos. The mean fishing duration at each depth is shown in Table 1. Fishing duration was longest at the 7 m site and shortest at the 22 m depth site.

Calculations of sand flathead density were then adjusted to account for variation in the efficiency of the net. Net efficiency is the proportion of fish in the path of the net and the bridles that are actually captured. The assumption that all fish encountered in the path of the net are captured is unlikely to be true; moreover, the efficiency of the net in the regions directly fished by the net and the area adjacent to the net path (bridle area) also varies considerably. We had no way of directly measuring the efficiency of the nets used in this program, however, a number of other studies have measured the efficiency of trawl nets for a variety of demersal fish species using a range of experimental approaches. Net efficiency in this study was estimated from a comprehensive review of the literature (see Parry 2011).

Table 1 Fishing duration in decimal minutes at 7, 12, 17 and 22 m depth sites.

Depth (m)	Fishing duration (mins)*	Length of tow cable (m)	Warp:depth ratio
7	6.2	50	7.14
12	5.9	50	4.17
17	5.5	75	4.41
22	5.4	100	4.55

*duration that trawl net is in contact with bottom

The literature review indicated that efficiency was higher in the region directly fished by the net compared to the region swept by the bridles to the side. This is because there is greater scope for fish ‘herded’ by the bridles to escape over the bridle cables during trawling. To calculate sand flathead density we used net efficiency estimates based on a small number of studies that had directly examined net efficiency for flathead species. In general net efficiency was found to be relatively high for flathead species because fish from this group are incapable of prolonged, sustained swimming required to evade the net (Parry 2011). We used three net efficiency scenarios to reflect the level of uncertainty present in estimating the actual fishing efficiency of the nets used in this study. These scenarios reflect the minimum, median and maximum net efficiencies possible. For sand flathead we have assumed a median fishing efficiency in the path swept by the net of 85 ± 10% and 40 ± 20% efficiency for the adjacent region swept by the bridles (Table 2).

Table 2 Percentage capture of sand flathead in the path directly swept by the net and the region swept by the bridles (wings) using minimum, median and maximum net efficiency scenarios

Scenario*	Net path (A)	Wings (B)
min	75	20
median	85	40
max	95	60

* based on high, median and low fishing efficiency for sand flathead

The swept area of the net at each depth was calculated by multiplying the width of the door spread by the distance covered by the tow in 5 minutes; and then correcting for variation in fishing duration at each depth (Table 3). Distance covered was calculated using GPS in the field.

Table 3. Calculations of swept area (m^2) at each depth using measurements of door spread and distance covered and corrected for variation in actual fishing duration

Depth (m)	Fishing duration (mins)*	Door spread (m)	Distance (m) covered in 5 min (B)***	Correction for actual fishing time (C).	Swept area (m^2) = A*B*C
7	6.2	33.3	481	1.24	19,838
12	5.9	30.6	481	1.19	17,461
17	5.5	40.8	481	1.10	21,625
22	5.4	48.6	481	1.08	25,294

*based on video analysis of net behaviour in 2011; **based on door spread measurements 2009–2011; ***mean trawl distance calculated using GPS

Total swept area was corrected for variation in net efficiency (A) and losses due to leakage over the bridles in the wings (B). This was accomplished by partitioning the swept area into the proportion swept by the net and the bridles and multiplying each area by the efficiency of the region. In general the proportion of the total swept area directly swept in the path of the net declines at greater depth due to the increasing width of the door spread. At 7 m 39% of total swept area is swept by the net, whereas at 22 m only 26.7% of the area is swept directly by the net (**Error! Reference source not found.**). Although the greatest proportion of the total swept area is swept by the wings, this component of the trawl is believed to capture fish with much less efficiency than the net and this has a major implications for the calculation of sand flathead density for the area trawled.

Table 4. Proportion of swept area directly swept by the net and by the bridles in the wing path

Depth (m)	Spread of doors (m)	Swept area (m^2)	% net path*	% wings path**
7	33.3	19838	39.0	61.0
12	30.6	17461	42.5	57.5
17	40.8	21625	31.9	68.1
22	48.6	25294	26.7	73.3

*% area swept by net based on net width = 13 m; **% area swept by bridles (area varies with depth and warp length)

Sand flathead density (kg/m^2) at each depth was calculated by dividing the mean catch (kg) by the corrected swept area of the net (i.e. area of net path + wing path corrected for differences in capture efficiency) (m^2).

Total fish biomass (tonnes) for PPB was extrapolated from density estimates. This method assumes that the density estimates calculated at the 7, 12, 17 and 22 m trawl depths are representative of the bay. The density measurements are based on the mean of 5–6 trawls at each depth located in the central, northern and western part of PPB. The trawl survey did not survey the shallow 'Great Sands' region in the southern part of PPB; and accordingly, the biomass estimates provided here do not apply to this region.

To estimate total sand flathead biomass in PPB we divided the area of the bay into four depth intervals: 0-10, 10-15, 15-20 and >20 m indicative of sand flathead abundance trends at 7, 12, 17 and 22 m depths, respectively (Table 5). The area of each zone was derived from a digital elevation model (DEM) for Port Phillip Bay using GIS (Ball et al. 2004). Total sand flathead biomass was extrapolated from density estimates by multiplying the density of fish (kg/m^2) at each depth by the area of the corresponding depth zone. This process was undertaken for all of PPB except the shallow Great Sands region in the southern part of PPB. This region was not trawled as part of the PPB annual trawl and catch statistics presented in this report are unlikely to representative of this region. Consequently, this process may underestimate sand flathead biomass in PPB slightly due to this omission. Extrapolations for each depth zone were combined to produce a total stock biomass (tonnes) for PPB.

Table 5 Total area of depth zones used to estimate total fish biomass for PPB. Areas derived from digital elevation models (DEMs) for Port Phillip Bay (Ball et al. 2004)

Depth (m)	Depth zone	Area (m^2)	Area (km^2)	% area
7	0-10 m	515,016,198.7	515.0	31.1
12	10-15 m	291,038,745.6	291.0	17.6
17	15-20 m	393,868,344.2	393.9	23.8
22	>20 m	457,511,244.4	457.5	27.6
	Total*	1,657,434,532.9	1,657.4	100

*excluding 'Great Sands' region (approximately 319 km^2)

Commercial and recreational CPUE trends

Commercial catch per unit effort (CPUE) trends for sand flathead in PPB were obtained from commercial snapper long line fishery catch returns for the period August 1978 to June 2013. Sand flathead is caught as by-catch for a range of commercial fisheries in PPB including the snapper long line, gill net, haul and beach seine fisheries. By-catch records for the snapper long line fishery comprise the largest and most complete data series for sand flathead by-catches in PPB, and hence the analyses presented in this report are based on this fishery. Sand flathead are not targeted as part of this fishery and catches are largely incidental; consequently, catch rates for this species are largely unbiased by a range of issues (i.e. changes to effort, gear or methods in order to maximize catches) that may confound interpretation of catch rates for targeted species (Harley et al. 2001). Catch rates were expressed as catch per unit effort (kg fish caught per 1000 hook lifts) using the total effort for the snapper long line fishery over this period.

Recreational catch per unit effort (CPUE) trends for flathead in PPB were obtained from creel (boat ramp) surveys undertaken by Fisheries Victoria. The creel surveys do not distinguish between flathead species caught by fishers, however, we know from the angler diary (boat based) surveys that about 80% of the recreational flathead catch is sand flathead. Creel survey catch rates for the period 1995–2012 were presented for both nominal and standardized CPUE. CPUEs were standardized using a general linear model (GLM) which adjusted for variation in CPUEs between years, seasons, regions, angler type and whether flathead was targeted by the angler. The majority of variation in CPUE was explained by the type of angler and whether flathead were targeted. The trend is similar regardless of the standardization applied.

Age and growth analysis

Sand flathead ages were determined from counting annual growth increments (rings) in their otoliths (ear bones). The age structure of the sand flathead stock in PPB was examined using data on the age of fish randomly sampled from PPB trawl catches from 1990–2011 (except 1998 and 2001). The program aged between 160 and 600 fish in each year using standardized ageing protocols developed by Fishing Ageing Services (FAS 2011) (formerly central ageing facility, DPI Queenscliff). Regional comparisons were achieved by collecting sand flathead otoliths from fish caught in Western Port, Corner Inlet, across Bass Strait and south-eastern Tasmania. Data from the latter was provided by IMAS, University of Tasmania.

Regional and temporal variation in growth patterns for sand flathead populations were analysed using von Bertalanffy growth curves fitted to the age-length data using the ‘growth’ routine in the R package *fishmethods* (Nelson 2013).

Fishing impacts: calculation of fishery exploitation

The contribution of fishing to the observed decline was examined by calculating the fishery exploitation rate for two periods in time for which total recreational catch information for sand flathead was available. The exploitation rate is a measure of the proportion of the total stock caught and retained (and hence exploited) and in conjunction with catch rates can be used as an indicator of changes to fishing pressure.

Exploitation rates for sand flathead population in PPB were calculated by combining the total recreational and commercial catches for the periods 2000/01 and 2006/07. Total recreational catch was estimated from two separate phone surveys undertaken in 2000/01 and 2006/07 (Henry and Lyle 2003, Ryan et al. 2009). These surveys provided an estimate of the number of flathead retained and discarded by recreational anglers, but did not distinguish between different species of flathead caught (principally sand flathead and yank flathead *Platycephalus speculator*).

In order to calculate the biomass of sand flathead caught by the fishery in PPB a number of assumptions have been used. These assumptions relate to the proportion of the total recreational catch that is sand flathead, the size and hence weight of retained and discarded fish and the mortality of discarded fish. The latter is important because the death of discarded fish is also a source of fisheries exploitation/mortality in this population.

First, we assumed that 80% of the flathead caught by recreational anglers were sand flathead. This figure is based on the catches of angler diarists used by Fisheries Victoria to monitor patterns in recreational catch rates for key recreational species in PPB. Secondly, we used a mean length of 30 cm for retained fish and 23.5 cm for discarded fish. Again these figures are based on the catches of angler diarists for the period 1995–2011. The biomass of retained and discarded fish was calculated using the weight-length relationship (weight (g) = $0.0032*\text{length}^{3.22}$, Koopman et al. 2004) for sand flathead (Figure 7). A 30 cm length fish was estimated to be approximately 184 g, whereas a 23.5 cm discarded fish was estimated to be approximately 84 g.

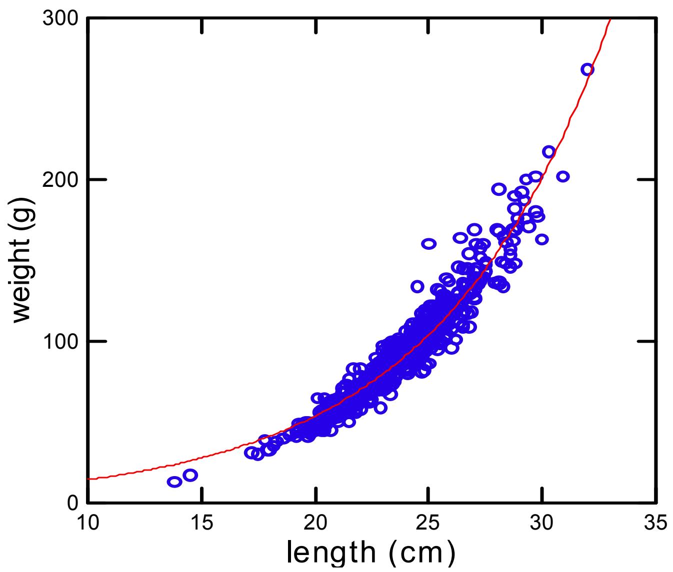

Figure 7 Length-weight relationship for sand flathead caught in PPB (weight (g) = 0.0032*length (cm) $^{3.22}$). Sexes combined.

Finally, the mortality of discarded fish was obtained from a study on sand flathead discard mortality (Lyle et al. 2006). This study estimated that 9% of all fish discarded by fishers in Tasmania died (i.e. 91% survived). This indicated that the mortality of discarded fish was relatively low for the recreational sand flathead fishery.

Total commercial catch for sand flathead was obtained from catch and effort information collected by Fisheries Victoria for the financial years 2000/01 and 2006/07. The total catch (fisheries mortality) was calculated by combining the biomass (kg) of the total recreational and commercial catches for sand flathead, plus the weight of fish discarded that were estimated to have died.

Recruitment trends

Recruitment variability for sand flathead in PPB was examined using two independent measures:

- The abundance of 2+ year old sand flathead caught by the PPB trawl survey in each year from 1990-2011. The number of 2+ fish caught was estimated by multiplying the proportion of 2+ fish that were aged at each site by the total number of fish caught. This value was then lagged by 2 years to provide a measure of sand flathead recruitment in each year over the period 1988–2009, and
- The abundance of 0+ aged sand flathead caught by the pre-recruit survey in each year from 2000–2013.

A single measure of recruitment variation for sand flathead for the period 1988–2013 was developed by combining the PPB trawl (1988–2000) and pre-recruit (2001–2013) estimates of recruitment variability. The PPB trawl recruitment index was standardised using the linear regression between the pre-recruit and PPB annual trawl recruitment indices. This enabled the measure of recruitment variability derived from the PPB trawl and pre-recruit surveys to be represented on a similar scale.

Past trends in recruitment variability, prior to 1988, were estimated from sand flathead age structure using the catch curve residual methods outlined in Jenkins et al (2010). The basis of this approach is that strong year classes can be consistently identified through time within the population age structure providing a relative measure of recruitment in each year.

Past recruitment variability was estimated from the age structure of sand flathead caught by the PPB trawl from 1990–2011. Zero+ and 1+ aged fish were excluded from the analysis because these age classes are under-represented by the PPB trawl. Catch curve regression residuals were calculated by regressing $\log_e$ number of fish in each age class against age following the methods of Maciena (1997). Catch curve residuals were assumed to reflect recruitment variation, with large positive and negative studentised residuals representing strong and weak year classes respectively. The mean and standard error of the mean for each year class was calculated by combining the catch-curve residuals for all years. Year classes at the beginning (1967–1969) and end (2007–2009) of the time series were excluded because these mean residual scores were generated using less than three years of age data and believed to be less reliable.

Environmental-recruitment relationships

Knowledge of the early life-history of sand flathead in PPB is critical to understanding the potential relationships between recruitment and environmental factors. A summary of what is known about the early life-history of sand flathead is presented in Table 6. Female sand flathead spawn eggs into the water column over a protracted period from September to January (Jordan 2001, Koopman et al. 2004, Bani and Moltschaniwskyj 2008). Eggs are fertilized and develop into larvae that occur in the water column from October – April (Jenkins 1986, Neira and Sporcic 2002). Jenkins (1986) recorded the highest larval densities in November. Larval duration for this species is unknown, but is at least 25 days (Hammer et al. 2010). Larvae settle out of the plankton and are recorded in beam trawls once they reach 3-6 cm length from December through to February (Hamer et al. 1998, Jordan 2001).

Table 6 Summary of knowledge about the early life-history of sand flathead

Life-history parameter	Summary information
Spawning (Gonadal Somatic Index)	
Koopman et al. (2004) - PPB	Peak GSI in September, followed by a smaller peak in January
Jordan (2001) - SE Tasmania	GSI peak October-December
Bani and Moltschaniwskyj (2008) - Tasmania	Protracted spawning phase October - March
Larval phase	
Jenkins (1986) - PPB	Peak larval density in November (and to a lesser extent December)
Neira and Sporcic (2002) - PPB	Larvae recorded December - March
Larval duration	
Hamer (2010) - PPB	at least 25 days at 11.8 mm length
Settlement	
Hamer et al. (1998) - PPB	cohorts recorded in December and January at 3-6 cm length
Jordan (2001) - SE Tasmania	cohorts recorded in January-February at 3-7 cm length suggesting earlier settlement (i.e. December)

It is this larval phase, and to a lesser extent, the post-settlement phase that follows, which is critical to the recruitment success of fish. This is a period in the life-history where mortality is highest. The most common causes of mortality for larval fish are predation and starvation. Without sufficient food larvae are unable to grow and survive. Environmental factors particularly influence the latter by affecting the productivity of PPB and the level of food available for larval fish. If mortality is higher than average, then recruitment will be low (because few larvae settle-out of the plankton), conversely if survival is higher than average then recruitment may be stronger in these years.

In contrast to information on recruitment, there are no continuous time-series on larval abundance for sand flathead in PPB other than limited snapshots in time (e.g. Jenkins 1986, Neira and Sporcic 2002). Hence there is no direct way to assess whether failures in recruitment are linked to a scarcity of larvae in the water column.

We considered a number of environmental variables known to influence recruitment and for which there were time-series spanning the period for which recruitment data were available (1988-2013). A rationale for the inclusion of each variable is provided in Table 7. As spawning in sand flathead is protracted, it was difficult to isolate periods in each year in which these environmental variables might directly influence recruitment success. Peak larval phase was identified using back-calculation of hatching dates and larval duration (see below). Spawning phase includes the period of peak GSI and 2 months prior to this date (Table 7).

Table 7 Environmental variables selected to explore relationship between recruitment variation and environmental factors including the parameter and temporal scale examined and ecological link between recruitment and environment factor tested

Variable	Parameter	Temporal scale	Ecological link
Yarra River flows	mean flows (ML/day)	peak larval phase (Nov-Dec)	River flows affect planktonic productivity which influences larval growth and survival; changes to salinity may influence productivity, larval growth and survival
	no. flow events (i.e. floods > 2500, 5000 ML/day)	peak larval phase (Nov-Dec)	Influence on post-settlement growth and survival unknown
Air/SST temperature	mean daily temp prior to peak spawning in Sept.	spawning phase (Jul - Oct)	Temperature influences gonad development in months prior to spawning
	mean daily temp during larval phase	peak larval phase (Nov - Dec)	Temperature influences larval growth, development and survival Influence of temperature on post-settlement growth and survival unknown
Wind speed	mean daily wind speed (mean km/h day)	larval phase (Sept - Jan), individual months within larval phase	wave turbulence can influence planktonic productivity (+ve effect) and larval feeding efficiency (-ve effect)

Estimation of peak larval phase using daily-ageing of 0+ aged fish

Peak larval phase – the period in which the majority of larvae occur in the water column - for sand flathead in PPB was determined using a three-step process: 1) hatching dates were back-calculated by daily-ageing 0+ fish recruited in 2012 and 2013, 2) peak hatching dates were determined using the length-frequency structure of the 0+ age cohort in 2012 and 2013, and 3) incorporation of information on larval duration for sand flathead. This period was used to model the influence of environmental variables on recruitment.

Hatching dates for sand flathead were calculated from daily ageing of 0^+ fish collected by the pre-recruit surveys in March 2012 and 2013. The age in days of 0+ age fish ranging in length from 8–16 cm was determined by counting daily growth increments (Fish Ageing Services 2011). A total of 50 0+ age fish were aged, 17 from 2012 and 33 from 2013. The relationship between length and age (days) was fitted using linear regression. Differences in growth rates between years were examined using a test for homogeneity of regression slopes. This test was done by fitting a model that related length (cm) to year, daily age (covariate) and the interaction between year and age using analysis of covariance (ANCOVA). The latter term tests for the H_0 of equal regression slopes between years.

Hatching dates for 0+ fish recruited in 2012 and 2013 were calculated via back-calculation using the relationship between length and age. Periods of peak hatching were estimated from the length-mode structure of the 0+ age-cohort in each year using length-frequency data collected by the pre-recruit surveys. Modes were identified by fitting a kernel density estimate function to the length-frequency data.

Larval duration for sand flathead was estimated at 30–40 days. This estimate was based on two studies: 1) sand flathead larvae (total length 11.8 mm) collected from PPB aged at 25 days (Hamer et al. 2010), and 2) post-larvae reared in an aquarium for a similar species *Platycephalus indicus* aged at 35 days (Hsiao-wei et al. 1980).

Environmental-recruitment model

The following environmental factors were examined:

1. Yarra River flows: Are a direct measure of freshwater flows from the catchment into PPB and account for 70% of all catchment inflows into PPB. Catchment inflows are closely correlated with modelled nitrogen loadings into PPB (Figure 8) and hence are a proxy for nitrogen input and to a lesser degree productivity in PPB.
2. Air temperature: Is a measure of water temperature in PPB. Air temperature was significantly correlated with satellite SST from 1994–2009 during the spawning phase (r^2=0.45; P=0.003) and peak larval phase (r^2=0.57; P<0.001).
3. Wind speed: Is a rough measure of wind-generated wave turbulence and mixing in PPB which may influence productivity
4. Stock biomass (tonnes) in the preceding year from 1990–2011

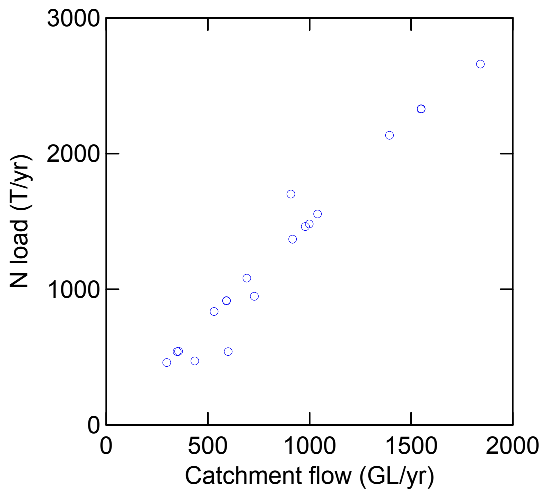

Figure 8 Relationship between N loads (tonnes/year) and catchment inflows (GL/year) into Port Phillip Bay. Source: Stewart et al. (2011)

Multiple linear regression was used to examine the influence of environmental variables on sand flathead recruitment in PPB over the period 1988–2013. We used the standardized index of recruitment for sand flathead developed by combining the trawl and pre-recruit indices (see Results). Assumptions of linearity, normality and homogeneity of variances were assessed for all variables through examination of residuals and normalised using a $\log_{10}$ transformations where applicable. Independent variables were evaluated for collinearity, by examining Pearson product-moment correlations between independent variables and the tolerance (1 – R^2 between an independent variable and other independent variables in the model) of each independent variable. Two variables, number of flood events > 5000 ML/day and mean temperature during the spawning phase, were discarded because these variables were highly correlated with mean flows and temperature during November and December. The optimum explanatory model was explored using likelihood-ratio tests by comparing all possible combination of environmental variables.

Dietary analysis

Temporal trends for sand flathead diet from 1996 to 2007 were analysed by examining sand flathead stomach contents for fish collected in 1996, 1997, 1999, 2000 and 2002-2007 at deep (22 m) and intermediate (12-17 m) depth locations. There was no stomach content data for sand flathead collected at shallow (7 m) locations. This approach was used to examine the impact of the introduced Northern Pacific seastar (*Asterias amurensis*) on the diets of sand flathead collected from deep and intermediate depth locations in PPB. *A. amurensis* abundance was initially highest at deeper depths in PPB following its introduction and subsequent expansion after 1995 (Parry et al. 2004). In March 2000, *A. amurensis* biomass was equivalent to 56% of total fish biomass in the deep region, 10% of total fish biomass in intermediate region and 5% of total fish biomass in the shallow region (Figure 9). It was predicted that impacts on sand flathead diets would be greatest in areas of PPB where *A. amurensis* biomass was highest due to either direct competition for food, or other indirect effects arising from the impact of *A. amurensis* feeding on the benthos.

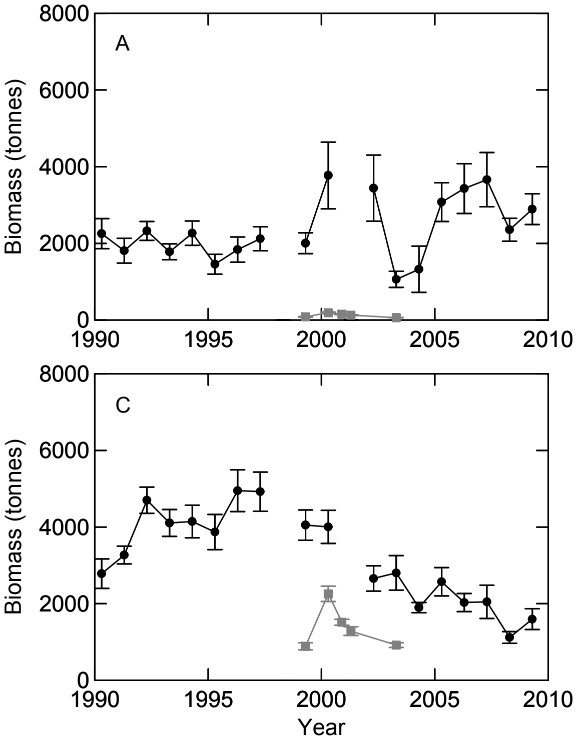

Figure 9 Mean (± se) total fish (black line) and *Asterias amurensis* (grey line) biomass (tonnes) in A) shallow (7 m), B) intermediate (12-17 m) and C) deep (22 m) regions of Port Phillip Bay. *Asterias amurensis* biomass was estimated using a modified scallop dredge between November 1999 and April 2003. Source: Parry et al. (2004) and Hirst (in prep.)

Changes in the diet of sand flathead collected at intermediate (12–17 m) and deep depths (>22 m) were analysed using similarity based multivariate statistical techniques (Clarke and Warwick 2001). Shifts in the dietary composition of sand flathead gut contents were analysed using non-metric multidimensional scaling (nMDS) in the PRIMER 6.0 software package. The contribution of different prey items to observed shifts in sand flathead diets was examined using the similarity percentage analysis (SIMPER) routine in PRIMER 6.0.

Growth chronology (trends)

A growth chronology for sand flathead was constructed using otoliths collected during 1970 and from 1990 to 2011. Otoliths were sourced from two studies a) a PhD undertaken by Brown (1977) and b) the PPB annual trawl survey (1990-2011). Otoliths were only sourced from a single location: the Beaumaris site at 22 m (38.04^0 S 144.55^0 E). This site was chosen because: a) otoliths were available for most years (in contrast to other sites considered), and b) the station is located within the central PPB basin and occurs in a region directly influenced by Yarra River flows. It was beyond the resources of this study to consider otolith time-series from a greater range of stations. This station was also located in a region where the heaviest infestations of *A. amurensis* occurred during its initial invasion (Parry et al. 2004).

Otoliths were prepared, aged and increments measured using standard techniques. Further details are provided in Rees (2013). The growth chronology was generated using a minimum of 15 otoliths for each year with the exception of 1995 (otoliths missing), and 1998 and 2001 (no PPB trawl completed in these years). The final data set comprised 2883 increment at age measurements for a total of 338 individual fish collected from 1970 to 2011.

A growth chronology was developed from the otolith increment measurements using a linear mixed-effects model (Weisberg et al. 2010). This statistical technique is used because the increment data are hierarchical, i.e. comprising repeated measurements taken from each of many individuals that are in turn nested within year classes and years. Traditional statistical techniques do not easily deal with this data structure. Mixed models are very flexible and adequately capture the increment data's underlying hierarchical structure.

Mixed effects models incorporate both fixed-effects and random-effects parameters. Fixed effects are when the levels of an effect constitute the entire population of interest and include the variables *Age*, *Sex*, and *Age at Capture.* These variables directly affect growth and account for the intrinsic sources of growth in the model. Random effects are when inferences are made on an entire population from a sub-sample of the population and include the terms *FishID* (a unique identifier for each individual fish), *YearClass* (the year the fish was spawned in - calculated from the year of capture and the age at capture) and *Year*.

Growth chronologies are based on the assumption that the distance between increments is a measure of annual somatic growth (Weisberg et al. 2010). This growth can be compartmentalized into two components: intrinsic and extrinsic factors. The intrinsic component operates on internal processes and includes age, sex, genetics or size (Weisberg et al. 2010), whereas extrinsic factors are operating from the outside (e.g., environmental conditions or fishing pressure) (Weisberg et al. 2010). These different sources of growth variation are accounted for in the mixed effects model.

The increment measurement data for the first year was discarded due to ambiguity in locating the first annulus (i.e. growth data ranged from 2–23 years of age). Increments on the outer edge were also not used in the analysis as they are incomplete annuli. The final two years of increment data for an older female fish were discarded so the *age**sex* interaction could be fitted (i.e. there were not any male fish of similar age in the data set). The data spanned the fish years (i.e. from 1st Oct – 30th Sept and comprising spawning, larval development, settlement and the first annual growth increment) 1953-2009 (i.e. ending in Sept 2010).

The model was fitted with the statistical software package lme4 for R. Model selection was a two stage process. First the optimal random effect structure was determined with all the intrinsic fixed terms fitted (e.g. *Age**Sex+Age at Capture*), and then this model was used to select the best fixed effects structure. Increment measures were log transformed to satisfy the assumptions of the model.

The variable *FishID* is treated as a random effect as it explains a component of growth variation (individual differences) that is not of primary interest; but accounts for correlations between increments within individual fish. *YearClass* accounts for correlations between individual fish of the same cohort and explains cohort-specific environmental induced variation (e.g. conditions at birth).*Year* accounts for all remaining extrinsic sources of growth variation. Three models of increasing complexity of random effect structures were fitted to the data using restricted maximum likelihood (REML), and the relative support for each model was assessed using likelihood ratio tests. The optimum random effect structure included the random intercept terms for *FishID*, *Year* and *YearClass* (log likelihood test F-ratio = 11.20, P = 0.001).

The fixed effect structures were examined with 6 models of increasing fixed effects complexity using the random effect structure for *FishID*, *Year* and *YearClass*. The models were fitted using maximum likelihood (ML) and compared with Akaike Information Criterion (AIC) and with delta AIC (∆AIC) – the difference between a given model and the model with the lowest AIC.

Age-at-capture tested for the possibility that the underlying growth chronology was biased by fish of different ages contributing to different years (e.g. all the early years come from older fish, whereas recent years are from a mixture of young and old fish). *Age* was treated as a categorical factor as it could not be adequately treated as a continuous variable (violated the model assumption of homogeneously distributed errors). This allows each age to have a unique value and thus no assumption is required about the underlying growth relationship (e.g. not forced to be linear, quadratic etc.). The optimum fixed effects model contained only the additive effects of *Age and Sex*. There was no interaction term between age and sex, as female sand flathead grow faster than males consistently across all ages.

Parameter estimates for the random effects *Year* and *YearClass* were extracted from the final model. The year random effect was used a biochronology of growth with intrinsic effects removed. The biochronology represents annual growth for the average fish (with age, sex and cohort to cohort variation effects removed) from 1953–2009. The year class random effect partitions extrinsic sources of growth variation into those that can be attributed to the year in which fish were spawned and averaged across the entire life span of the fish until it was caught.

Relationships between these year estimates of growth and environmental variables were explored using simple linear regression. One of the major difficulties when attempting to fit environmental relationships to such a long growth series is the absence of environmental time-series of a similar length. Air temperature and rainfall records are available from 1855, however, flow data is only available for the Yarra River from 1959 and satellite measured sea surface temperature (SST) in PPB from 1993. Chemical measurements of salinity and chlorophyll *a* are extremely patchy and cannot be used to generate reliable time-series of change in these variables. Consequently, we were only able to examine environmental correlations for the entire growth chronology using air temperature and rainfall, and for subsets of the growth time-series for river flows (1959-2009) and SST (1993-2007) data.

Management options scenarios

Changes to size limits

Limiting the size of individuals retained is one of the basic regulations utilised by fisheries managers. This regulation involves returning captured individuals smaller than a prescribed minimum size. It performs a number of functions: 1) it allows individual fish to reach maturity and spawn at least once prior to capture, and 2) it can operate, in conjunction with other management regulations (e.g. bag limits) to reduce total catch by limiting the catch to a smaller sub-set of the population. Size limits are popular with fisheries managers because there is general public sympathy for such regulations (King 1995). From a management and enforcement perspective, well publicised and enforced size limits are a constant reminder to the public of the need for conservation.

Currently, at a legal size limit of 27 cm, 2.1 females of legal size are encountered for every male (see results). How might changing the size limit affect catches of males versus females?

To examine this question we ran a scenario where the minimum size limit was varied from 24 to 29 cm. For each size limit we calculated the proportion of male and female fish that exceeded this limit. This analysis was undertaken using the length-frequency data for male and female sand flathead collected during the last year of the PPB annual trawl (i.e. 2011).

Bag limits

Bag limits are output controls that seek to limit total catch by placing a ceiling on the catches of individual anglers. Fisheries managers can potentially reduce the total recreational catch for a fishery by lowering bag limits. However, the extent to which reductions in bag limits may work will depend on how effectively bag limits are currently utilised by anglers. Where few anglers catch the maximum bag allowable, or many catch a much smaller number of fish, the effectiveness of any reduction in bag limits may be limited. The current personal/possession limit is 20 flathead for Victorian coastal waters. This analysis considers what reduction in sand flathead recreational catch could be achieved by reducing the maximum bag limit from the current limit of 20 fish.

This exercise was undertaken using creel survey data collected over a five year period from 2009–2013 in Port Phillip Bay: a period in which sand flathead stocks have stabilised in Port Phillip Bay (see results). This analysis combines interview data across all five years. The impact of reducing bag limits on total sand flathead catch was modelled by simulating a range of maximum bag limits. This was undertaken using information on the frequency of bags of varying sizes caught by anglers using the methods contained within Attwood and Bennet (1995). This method assumes fisheries mortality (F) is proportional to total fisheries catch (C) where effort remains constant (Conron 2004).

This analysis involved a number of steps. First, sand flathead recorded during the creel surveys were allocated amongst the individual anglers surveyed (so that individual bags could be analysed). Next the total catch for each bag limit was calculated by multiplying the frequency of bags of various sizes by the size of the bag (i.e. 5 x bag size (5) = 25 fish and so on). A range of bag limits was simulated by maintaining the total number of angler trips, but reducing the total catch in line with the simulated maximum bag limit. This analyses assume that fishing effort will remain steady regardless of the bag limits imposed. Finally, proportional (%) reduction in fishing mortality (F) was calculated using the following equation:

$$F_k = (F-F_r)/F$$

where Fr is restricted mortality rate at bag limit of k fish and F is proportional to catch rate (Attwood and Bennett 1995).

Results

Status of fishery in PPB

Stock biomass trends 1990–2011

Catch rates for sand flathead declined across all depths between 1990 and 2011 (Figure 10). Sand flathead abundance was greatest at the 17 and 22 m sites, and the decline is most pronounced at these deeper sites. Catch rates declined appreciably at the 12, 17 and 22 m depth sites after 2000.

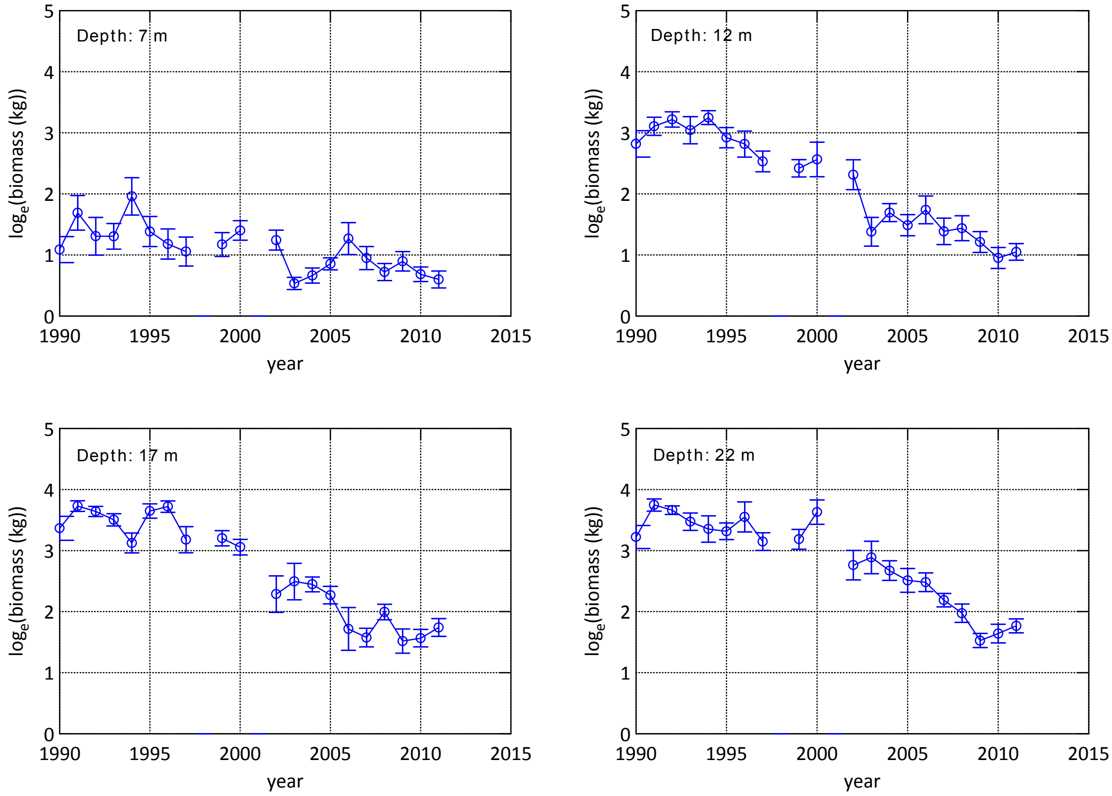

Figure 10 Mean (± se) catch rate trends for sand flathead $\log_e$ biomass (kg) caught by the PPB trawl for the period 1990–2011 at 7, 12, 17 and 22 m depth stations.

Sand flathead biomass declined by 87% between the period 1990–2000 and 2010 (Figure 11). The pattern and extent of the decline is clear regardless of the fishing efficiency scenario used. Using the median net efficiency sand flathead stocks were estimated to have declined by 250 tonnes per year during this 10 year period from 2000 to 2010. Median stock biomass increased slightly from 400 to 464 tonnes between 2010 and 2011. This was the first recorded increased for sand flathead stock biomass in PPB since 2006. Peaks in biomass during the period 1990–2000 corresponded with the emergence of strong year classes entering the population (see also recruitment section below).

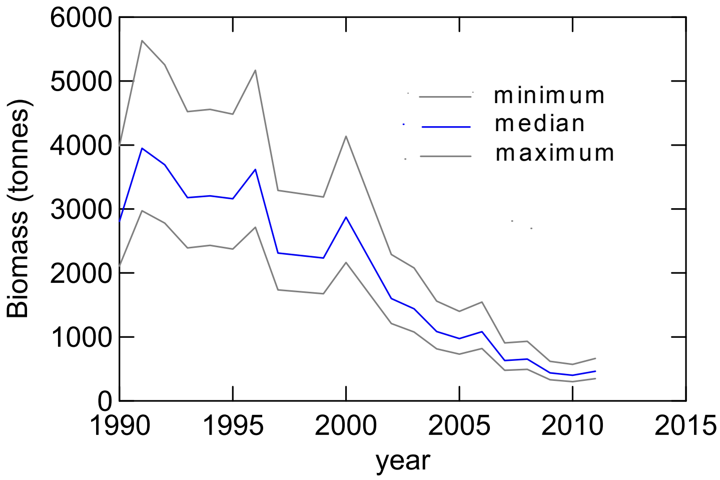

Figure 11 Trends in sand flathead biomass (tonnes) 1990–2011 for minimum, median and maximum trawl efficiency scenarios.

Commercial and recreational CPUE trends

The overall drop in the total catch for sand flathead during this period is mirrored by declines in both commercial and recreational fishery catch rates. Total commercial catch, effort and catch per unit effort (CPUE) for sand flathead caught as by-catch by the snapper long line fishery in PPB are shown in Figure 12. Total sand flathead catch declined in this fishery from 1978/79 to 2010/11 coincident with overall reductions in fishing effort (Figure 12 top). The number of fishers in this fishery declined from 57 in 1979/80 to 20 fishers in 2010/11. Catch rates remained steady from 1978/79 to 1993/94, were substantially higher from 1994/95 through to 2002/03 and then declined from 2003/04 to 2009/10. CPUE in 2009/10 was 87% lower than the mean catch rate recorded during the period 1994/95 to 2000/01, and was the lowest recorded since 1978/79. CPUE rates increased after 2009/10, but are still well below levels recorded from 1978/79 to 2003/04 (Figure 12 bottom).

Catch rates for the recreational flathead fishery in PPB declined by 82% between 1995 and 2011 (Figure 13). Creel surveys do not distinguish between different species of flathead, but approximately 80% of the recreational flathead catch is sand flathead (sourced from the angler diary surveys). Recreational catch trends for flathead is similar regardless of the season or the location surveyed (Figure 14).

All three data sources – PPB annual trawl, commercial and recreational catch rates – corroborate the magnitude of the decline in the range of 80–90% for sand flathead in PPB. Notably, all three survey methods detected increases in sand flathead catch rates following 2010.

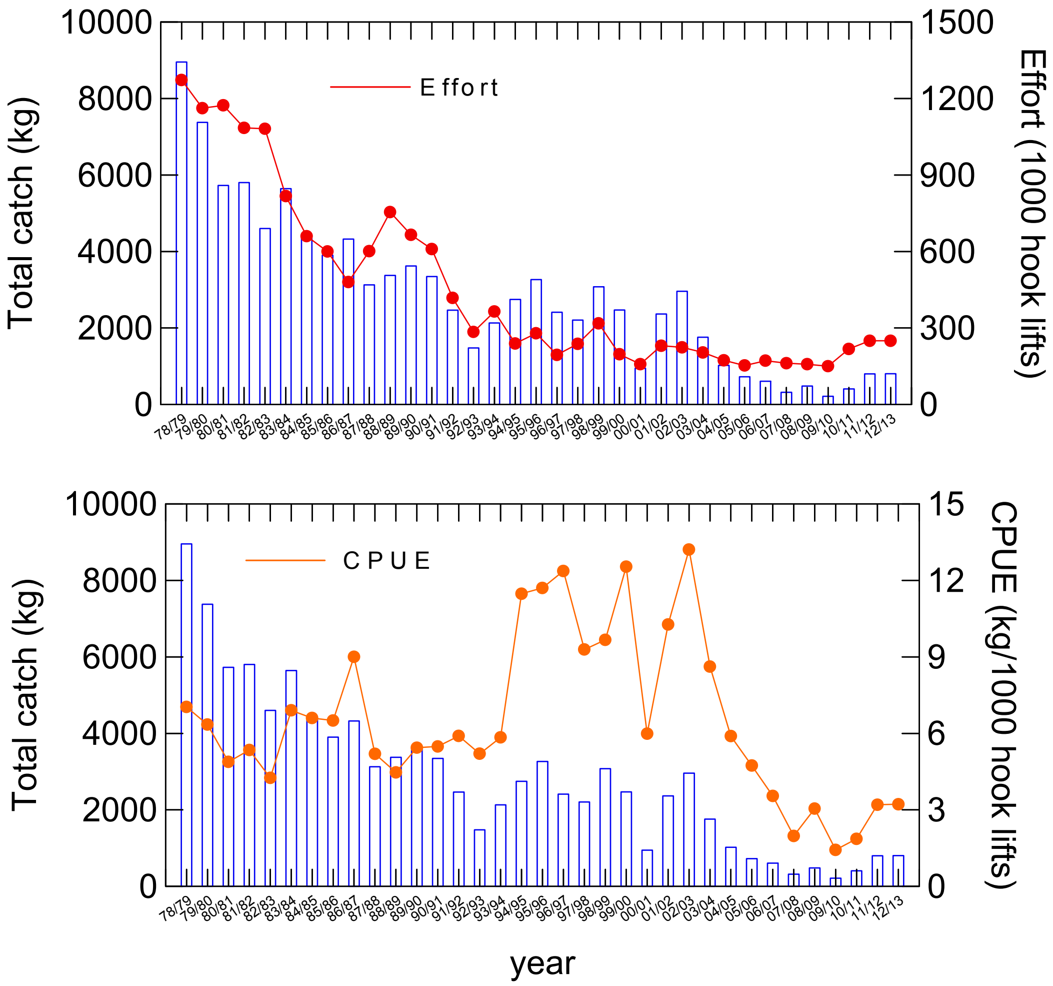

Figure 12 Total catch, effort (above) and CPUE (below) for sand flathead caught as by-catch by the commercial snapper long line fishery in PPB 1978/79 – 2011/13

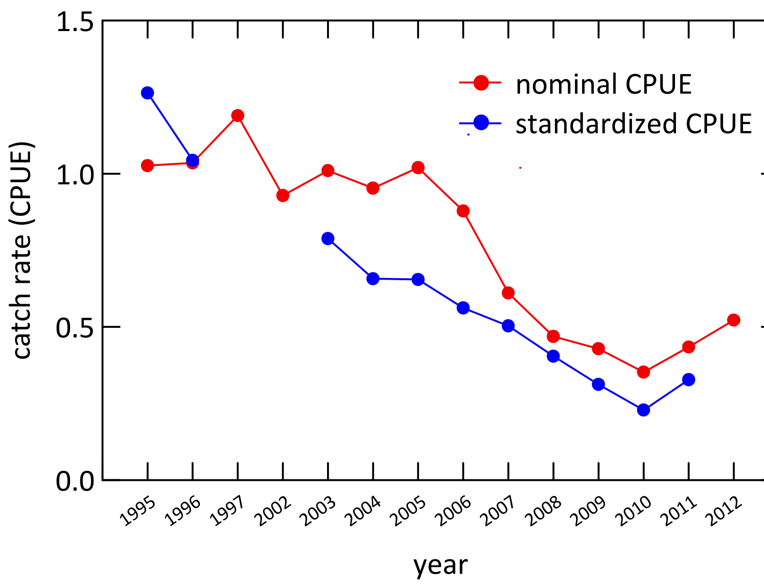

Figure 13 Nominal and standardized catch per unit effort (CPUE) for flathead in PPB from 1995–2012

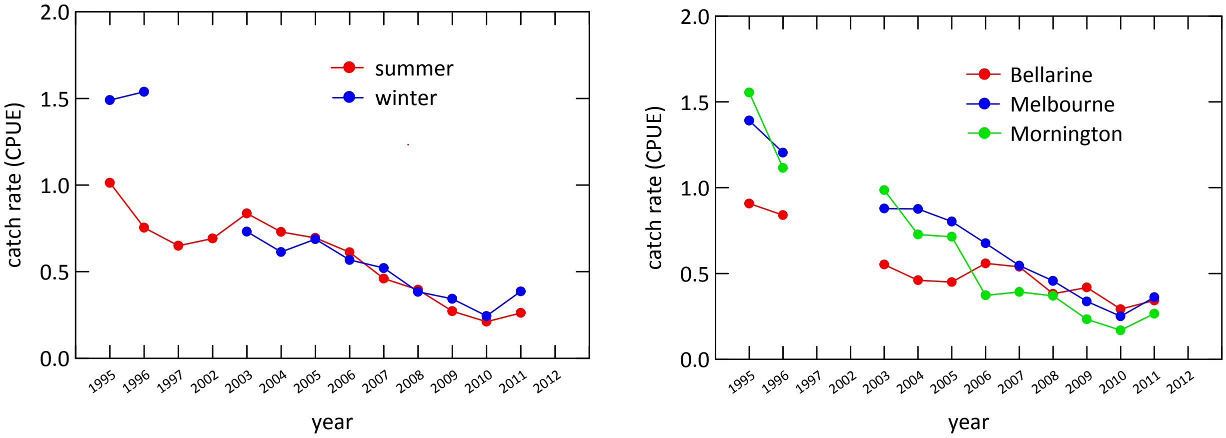

Figure 14 Standardized CPUE for seasons (left) and regions (right) for the period 1995–2011

Size and age structure

Time series of size structure for sand flathead for the period 1990–2011 are based on length-frequency data collected as part of the annual trawl survey of demersal fish populations in PPB. Smaller (<15 cm) and hence younger fish (0+ age class) are poorly sampled by the demersal trawl net and therefore the trawl does not provide direct information on the abundance of newly recruited 0+ aged fish. A more accurate measurement of the abundance of 0+ age fish in PPB is provided by the snapper pre-recruit survey (2000–2013) which uses a smaller net and mesh size.

The size structure of the sand flathead population remained relatively constant in PPB from 1990–2011, despite the large decline in the overall population (Figure 15 and 16). Median fish length was slightly lower in the 1990s (median=22.9 cm TL; Figure 15) compared with the 2000s (median=24.5 cm TL; Figure 16). The majority of fish in the population are below legal size (27 cm) and this pattern has remained consistent since 1990 when the trawl program began. The largest sand flathead recorded during the PPB trawl survey was 41 cm in length.

The proportion of fish caught by the trawl survey that exceed the minimum legal size limit (i.e. >=27 cm) varied from 1990 to 2011 (Figure 17). During the early part of the 1990s (1990–1995) <10% of fish caught by the trawl were legal size, however, from 2002 onwards this had increased to >20% of the fish caught. This trend in the proportion of fish that are legal size is most likely related to trends in recruitment (discussed in detail in later sections) and its effect on the age and size-structure of the population. This effect is illustrated by plotting the change in the mean age of fish caught in each year (Figure 17). During the early 1990s the population was dominated by younger fish which tend to be on average smaller in size. As the mean age increased into the early 2000s, the proportion of older, generally larger, and hence legal sized fish, increased. The mean age decreased in the later years of the time series and in 2011 was similar to the mean age in the early 1990s. The proportion of legal size fish caught in 2011, however, remained above 20%.

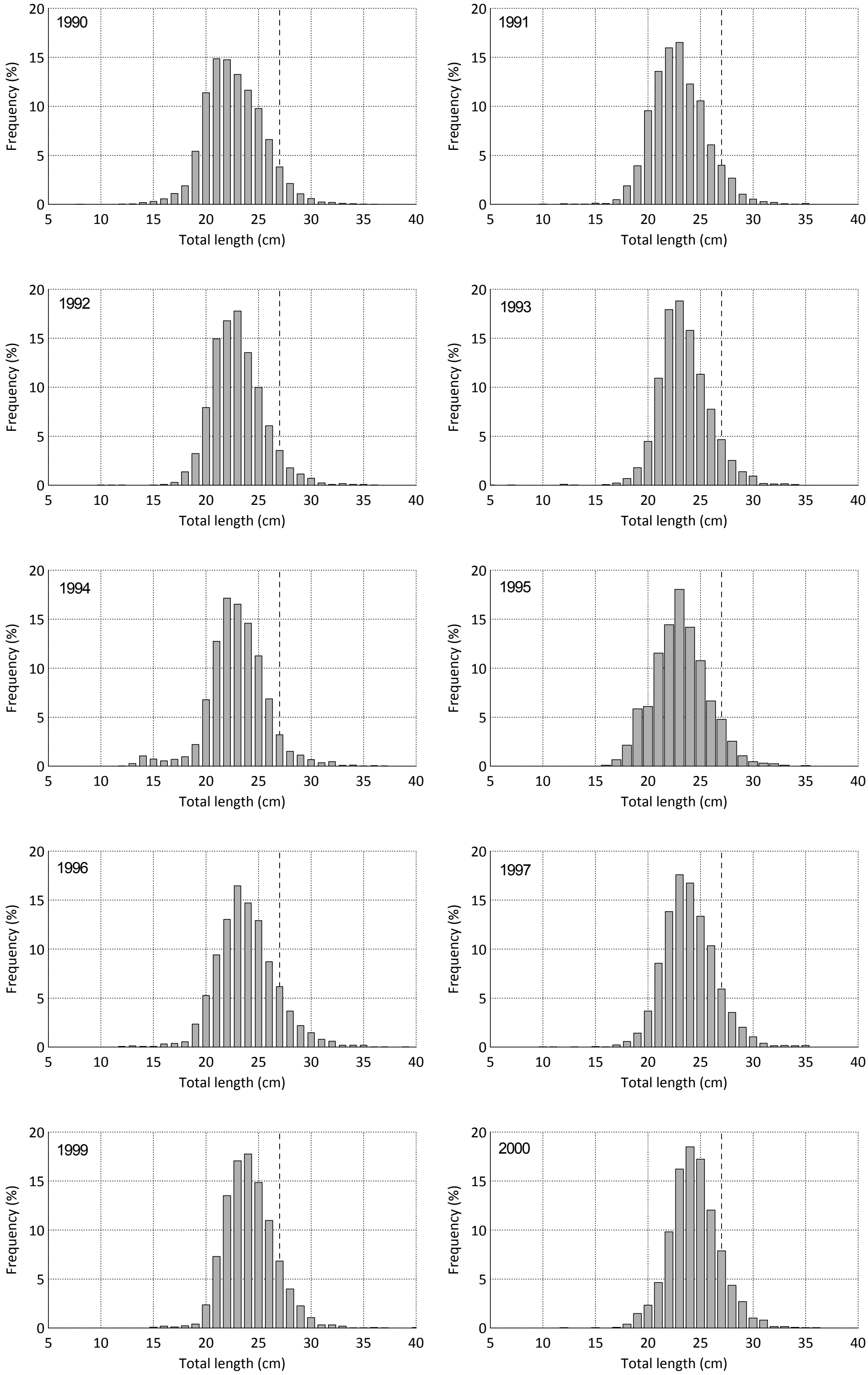

Figure 15 Length-frequency (%) distribution of sand flathead caught by the PPB annual trawl 1990–2000. Vertical dashed line = lower legal size limit (27 cm)

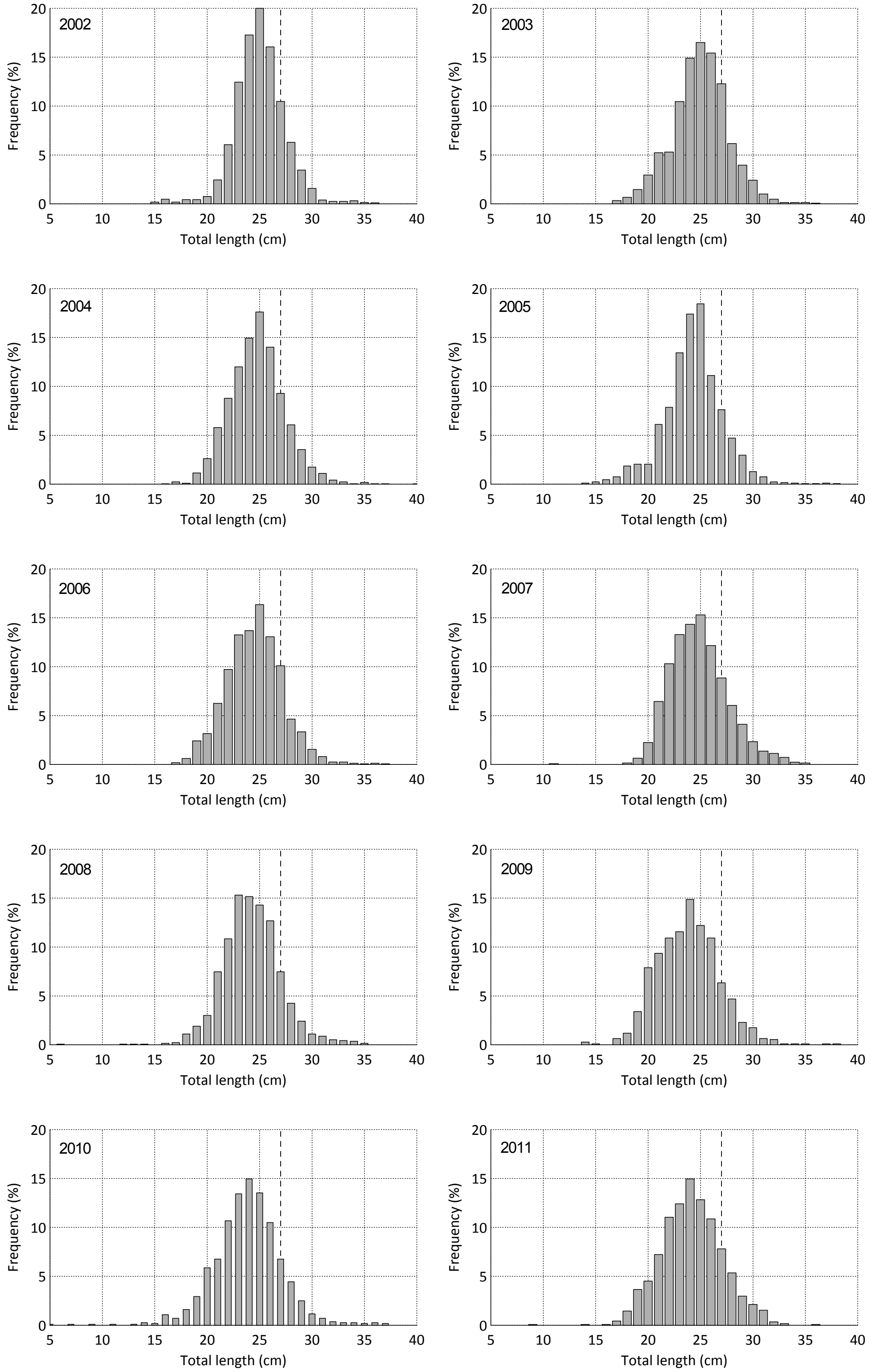

Figure 16 Length-frequency (%) distribution 2002–2011. Vertical line = lower legal size limit (27 cm)

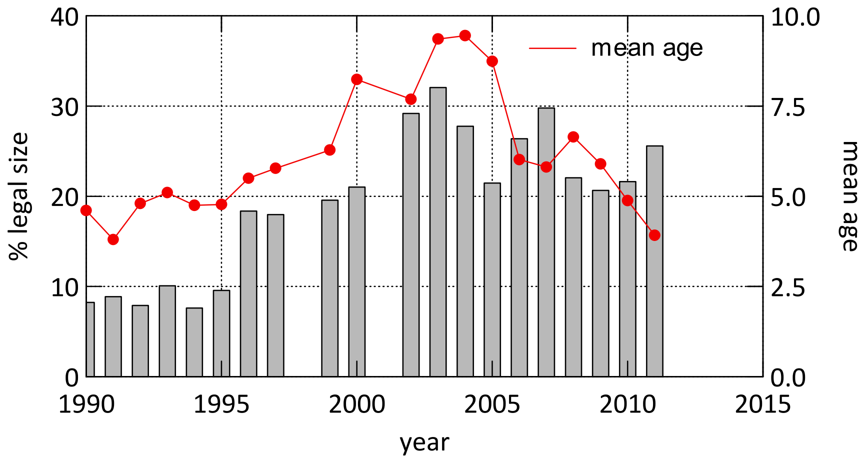

Figure 17 Mean age of sand flathead caught by PPB annual trawl superimposed onto proportion (%) of fish legal size from 1990–2011

The relationship between age and length for sand flathead collected from PPB from 1990-2011 is shown in Figure 18. The fitted von Bertalanffy growth curve depicting the relationship between age and length indicates there is minimal growth (in length) beyond 5 years of age. Consequently, length is not a useful predictor of age amongst older age classes. Age-length relationships also differed for males and females (**Error! Reference source not found.**). Female sand flathead reach a greater mean and maximum length and grow at a faster rate during the early years of life (0–5 years). This is the period in which the majority of growth occurs in sand flathead (see also increment analysis section).

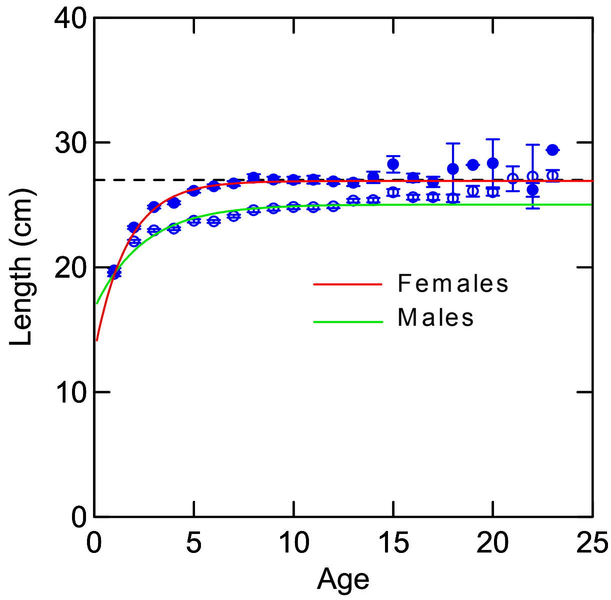

Figure 18 Age-length relationships for male and female sand flathead caught by PPB demersal trawl 1990-2011. VB growth curves for males and females are plotted against mean (± SE) length of each age class. Horizontal dashed line = minimum legal size limit (27 cm)

Table 8 von Bertalanffy growth curve parameters for all, male and female sand flathead collected from PPB 1990–2011

Variable	L_∞	K	t_0	n
All	25.62	0.582	-1.49	6532
Males	25.03	0.407	-2.73	3397
Females	26.92	0.603	-1.11	3051

L_∞: L infinity is the asymptotic length at which growth is zero

K: growth coefficient (rate)

t_0: intercept estimate of (age) at 0 length

n: no. aged fish used in analysis

The propensity of female sand flathead to grow faster and on average larger may result in a higher proportion of female fish being caught and retained by recreational anglers. This is because a greater proportion of females exceed the minimum legal size limits (Figure 19). Size-frequency records for age and sexed fish collected during the PPB trawl program from 1990–2011 demonstrate that approximately twice as many females exceeded the minimum legal size limit from 1990 to 2011. On average 39% of females caught by the PPB trawl from 1990–2011 were legal size compared to only 15% of males over this period.

In contrast to size, age structure varied significantly from 1990–2011 (Figure 20 and 21). The oldest sand flathead recorded in PPB were 23 years old, although few fish survive beyond 16 years. During the 1990s the majority of fish caught during the trawl were <10 years old, however, the proportion of fish >10 years old steadily increased after 2000 due to the absence of strong year classes of young fish entering the population from the late 1990s onwards. Years with high recruitment are signified by the presence of strong 2+ age cohorts (e.g. 2 year old fish in 1991 recruited two years earlier in 1989), and often these strong year classes can be clearly discerned in subsequent years. The importance of the year class recruited in 1989 to the sand flathead population, for example, is still visible 16 years later in 2005 (Figure 20). The age structure of sand flathead in the 1990s is dominated by fish recruited in 1988, 1989, 1993 and 1997, and these cohorts comprise a high proportion of the population through to about 2005. By comparison, the 2000s are characterised by the absence of similarly strong year classes (Figure 21).

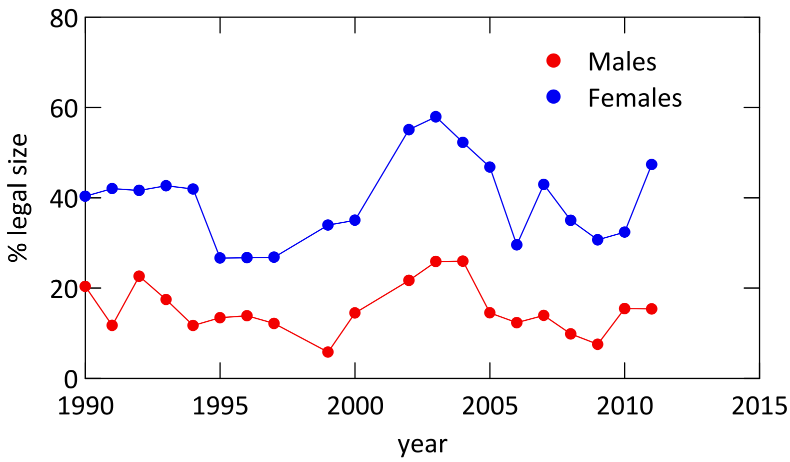

Figure 19 Proportion of male and female sand flathead that exceeded 27 cm in each year of the trawl 1990-2011. Note the minimum legal size limit for flathead in Victorian waters was changed from 25 cm to 27 cm in 2007

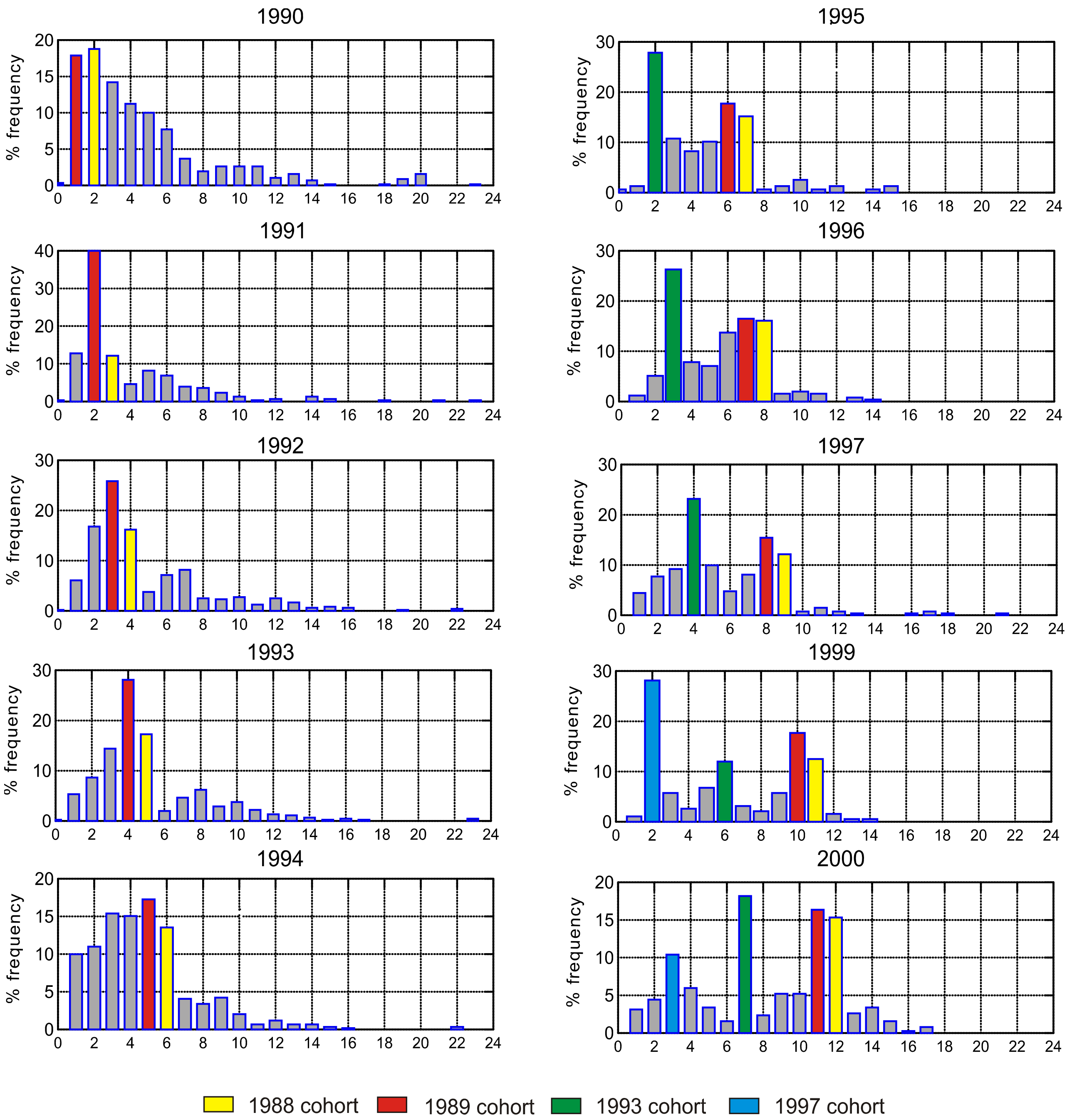

Figure 20 Age frequency (%) histograms for sand flathead in PPB collected by annual trawl from 1990–2000. Cohorts for high recruitment years are displayed using coloured bars

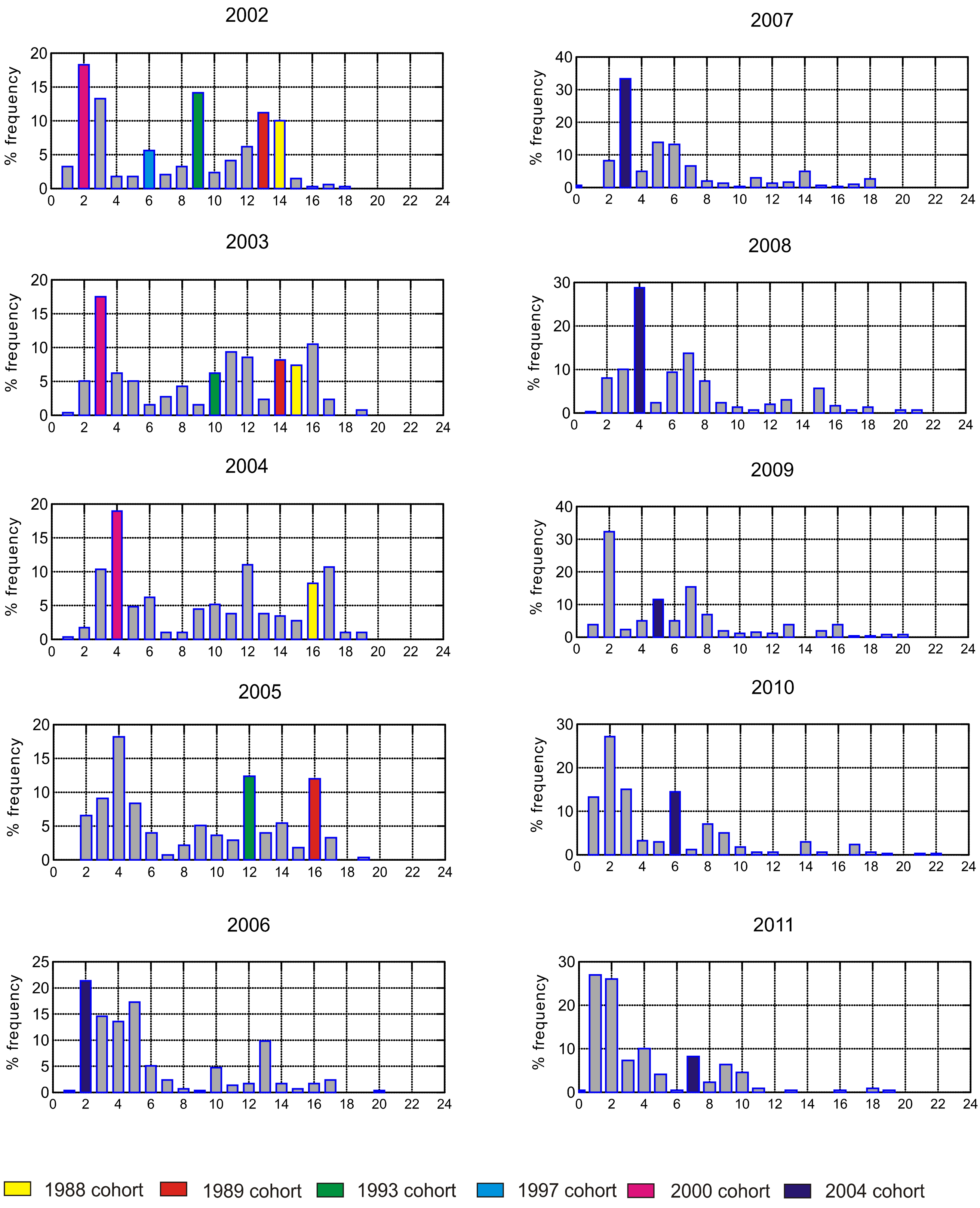

Figure 21 Age frequency (%) histograms for sand flathead in PPB collected by annual trawl from 2002–2011. Cohorts for high recruitment years are displayed using coloured bars

Regional status: geographic extent of decline

Sand flathead occurs in coastal waters from the SW coast of Western Australia to the mid coast of NSW including the coasts of South Australia, Victoria and Tasmania (Gomon et al. 2008). This species is caught recreationally and as by-catch for a number of commercial fisheries across its range. A summary of fisheries trends for sand flathead across its geographic range is shown in Table 9.

Port Phillip Bay

Catch rate trends for sand flathead in PPB were similar regardless of the indicator used. Each index of abundance declined by >80% over the period 2000–2010. Consequently, the decline is not an artefact of any single method and there is high confidence in the magnitude of the decline measured.

Western Port

Recreational CPUE rates for Western Port displayed a slight, yet significant negative trend (linear regression slope = -0.015; $F_{1,12}$=11.05; P=0.006) for flathead catch rates from 1998 to 2010 (Figure 22). Although significant, the trend is not as steep as the decline observed for recreational catch rates in PPB over the same period (slope=-0.06; $F_{1,9}$=261.6; P<0.001). Catch rates declined by on average 0.06 fish/angler day per year in PPB compared with 0.015 fish/ angler day per year in Western Port. However, if the regression is limited to the period in which the greatest decline occurred in PPB (i.e. from 2000–2010) then the negative trend for standardized CPUE for Western Port was not significant (slope=-0.011; $F_{1,10}$=4.1; P=0.07). Catch rates were higher in PPB than Western Port.

There are no other indicators of sand flathead abundance in Western Port (e.g. commercial fisheries catch and effort data) with which to corroborate the significance of this decline (see **Error! Reference source not found.**).

Bass Strait

There is insufficient data from which to draw conclusions about the status of sand flathead populations in Bass Strait. Sand flathead is caught as a by-catch in the Danish Seine fishery in Bass Strait which targets tiger flathead and school whiting. There have been major reductions in the total effort expended in the Danish seine fishery in Bass Strait from 1978 to the present and this has obscured attempts to analyse long-term trends in CPUE. The Bass Strait Danish Seine fishery was managed by Victoria between 1978 and 1998, and by the commonwealth from 2000.

South-east Tasmania

Several species of flathead are caught in Tasmanian waters, but commercial catches are dominated by tiger flathead (*Neoplatycephalus richardsoni*) taken by Danish seine. Sand flathead is taken to a lesser extent by line. Catches for the two species have not until recently been distinguished in catch returns and trends for sand flathead are inferred largely from the gear type (Hartmann and Lyle 2011). Commercial catch rates for sand flathead remained steady in south-eastern Tasmania between 1995/96 and 2009/10 (Hartman and Lyle 2011). Moreover, there has been little change in the estimated total recreational catch for the recreational fishery in south-eastern Tasmania. The recreational catch was estimated to be 361 tonnes in 2000/01 and 292 tonnes in 2007/08 (Ziegler and Lyle 2010).

There is no information from either Western Australia or South Australia where sand flathead is a very minor recreational fishery (K Ryan, A Fowler pers. comm.).

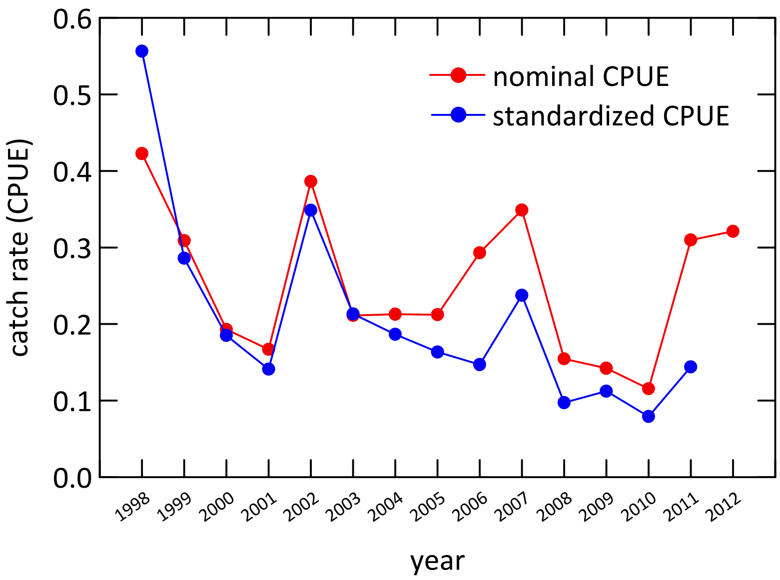

Figure 22 Nominal and standardized catch per unit effort (CPUE) for the recreational flathead fishery in Western Port from 1998–2012

Table 9 Summary of regional stock assessment for sand flathead

Region	Fishery (time-series)	Source	Trend/s
Port Phillip Bay	Fisheries independent (1990–2011)	PPB annual trawl survey	Stock biomass estimated to have declined by 87% between the period 1990-2000 and 2010.
	Commercial (1978–2013)	Catch and effort records for snapper long-line fishery	CPUE rate in 2009/10 was 87% lower than the mean catch rate recorded during the period from 1994/95 to 2000/01. Sand flathead caught as by-catch for a range of commercial fisheries including snapper long line (n=1138 records), gill mesh (n= 862) and haul (n=682) and beach seine (n= 542). Total commercial by-catch declined from 8.9 tonnes in 1979/80 to 804 kg in 2012/13, commensurate with a substantial reduction in commercial fishing effort in PPB. Total number of long-line fishers declined from 57 to 20 over this period.
	Recreational (1995–2012)	Fisheries Victoria creel surveys	CPUE declined by 82% between 1995 and 2010
Western Port	Commercial		No data. Shallow, seagrass dominated embayment that supports no significant commercial fishery for sand flathead. Commercial catches dominated by King George whiting, garfish and rock flathead.
	Recreational (1998–2012)	FV creel surveys	Slight, but significant decline in recreational catch rates between 1995 and 2011.However, no significant decline since 2000.
Bass Strait	Danish Seine (1978–1998)	Catch and effort records (Fisheries Victoria)	Sand flathead recorded as by-catch. Large reductions in total catch between 1978/79 and 1997/98 commensurate with large reductions in total fishing effort in Bass Strait Danish seine fishery. Number of fishers declined from 22-25 fishers in the 1980s to 2-4 fishers by 1997/98.
	Commonwealth Trawl (AFMA) (1999– 2012)	AFMA	Sand flathead recorded as by-catch. Large reductions in total catch (effort) following 2005 due to industry restructuring.
SE Tasmania	Commercial (1995– 2011)	Ziegler and Lyle 2010, Hartmann and Lyle 2011	Commercial catch of sand flathead <20 tonnes/year. CPUE rates relatively stable. Catch rates increased slightly between 1995/96 and 2008/09.
	Recreational	Ziegler and Lyle (2010), Hartmann and Lyle (2011)	Little change in the estimated total recreational catch. Recreational catch was estimated to be 361 t in 2000/01 and 292 t in 2007/08.
South Australia		Fowler et al. (2012)	No significant fishery in South Australia: no stock assessment.
Western Australia		K. Ryan (WA Fisheries) pers. comm.	No information.

Regional variation in growth patterns

Regional variation

Sand flathead in PPB grow more slowly and reach a smaller maximum size than sand flathead collected from Bass Strait and SE Tasmania (Figure 23). The L∞ asymptote (length at which growth is zero) is 11 cm greater in fish collected from Bass Strait than PPB, indicating than on average sand flathead in PPB are 30% smaller than those caught in Bass Strait (Table 10). Sand flathead in PPB also grow more slowly and reach a smaller maximum size than fish collected from SE Tasmania. On average fish from PPB were 20% smaller than fish from SE Tasmania.

It was not possible to construct growth curves for sand flathead obtained from Western Port and Corner Inlet because these samples contained no fish >5 years of age. Instead the early growth rates of sand flathead from PPB, Bass Strait, Western Port and Corner Inlet were compared by plotting otolith weight (an overall measure of somatic growth) against age (Figure 24). Analysis indicates that growth trends for Western Port and Corner Inlet individuals <5 years was more similar to Bass Strait than PPB (ANCOVA; $F(region)_{3,662}$=123.1, P<0.001; $F(Age)_{1,662}$=770, P<0.001). PPB fish <5 years displayed the lowest growth rates of all four regions considered in this analysis (Figure 24).

Growth curves for sand flathead collected in PPB aged in 1990, 1995, 2000, 2005 and 2010 were unchanged over this 20 year period (Figure 25). This indicates that lower growth rates experienced by sand flathead in PPB are not associated with the decline in the population that has occurred since 2000.

Females grow faster and reach greater L∞ than males for all regions (Table 11). The differences are most pronounced for fish collected from Bass Strait where the difference between males and females for L∞ is >10 cm (Figure 26). The von Bertalanffy growth curve for female sand flathead collected from Bass Strait appears not to have reached an asymptote due to the paucity of length at older age classes. Consequently, the growth parameters for females from Bass Strait may not be entirely reliable.

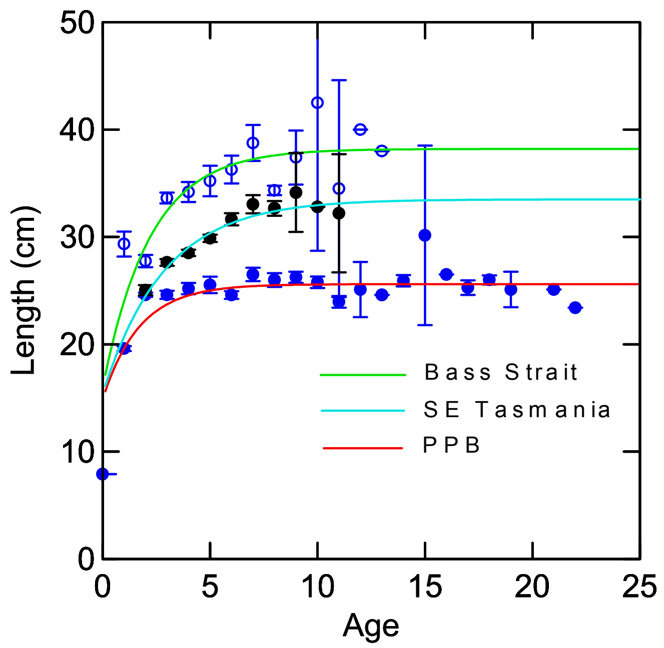

Figure 23 Age-length relationships for sand flathead collected from PPB, Bass Strait and SE Tasmania in 2011/12. Von Bertalanffy growth curves plotted against mean (± SE) length of each age class

Table 10 von Bertalanffy growth curve parameters for sand flathead collected from PPB, Bass Strait and SE Tasmania from 2011-2012

Region	L∞	K	t_0	n
PPB (2011)	27.08	1.155	-0.14	256
Bass Strait (2012)	38.26	0.446	-1.21	175
SE Tasmania (2012)	33.50	1.75	-0.35	307

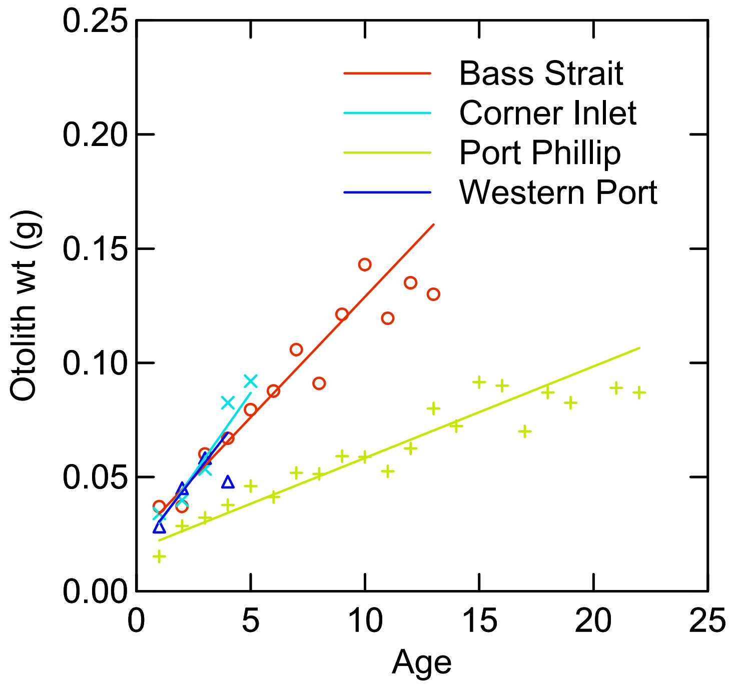

Figure 24 Age-otolith weight relationships for sand flathead collected from PPB, Bass Strait, Western Port and Corner Inlet in 2011-12. Lines are linear regression trends. Note, all sand flathead collected from Western Port and Corner Inlet were < 5 years

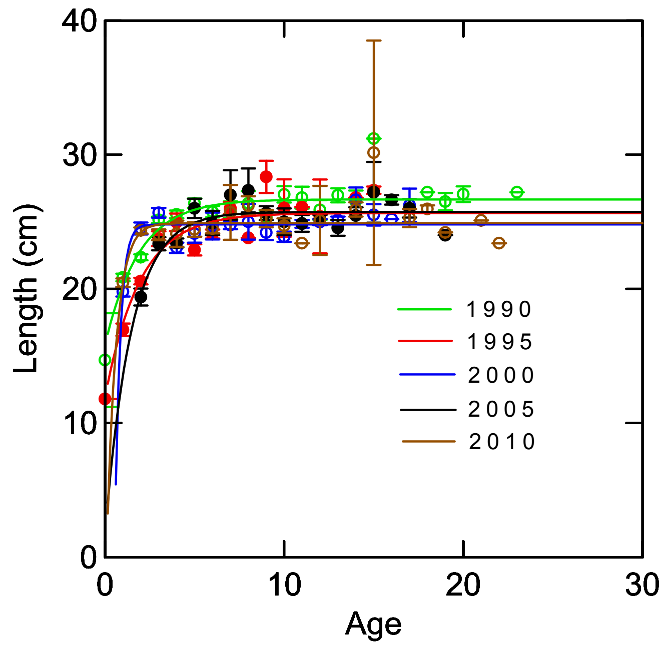

Figure 25 Age-length relationships for sand flathead collected from PPB at 5 year intervals in 1990, 1995, 2000, 2005 and 2010. Von Bertalanffy growth curves plotted against mean (± SE) length of each age class

Table 11 von Bertalanffy growth curve parameters for male and female sand flathead collected from PPB, Bass Strait and SE Tasmania

Region/Sex	L∞	K	t_0	n
PPB (1990-2011)				
Males	25.03	0.407	-2.73	3397
Females	26.92	0.603	-1.11	3051
Bass Strait (2012)				
Males	38.36	0.184	-5.53	47
Females	54.24	0.137	-3.72	107
SE Tasmania (2012)				
Males	32.30	1.720	-0.35	96
Females	34.40	1.420	-0.36	211

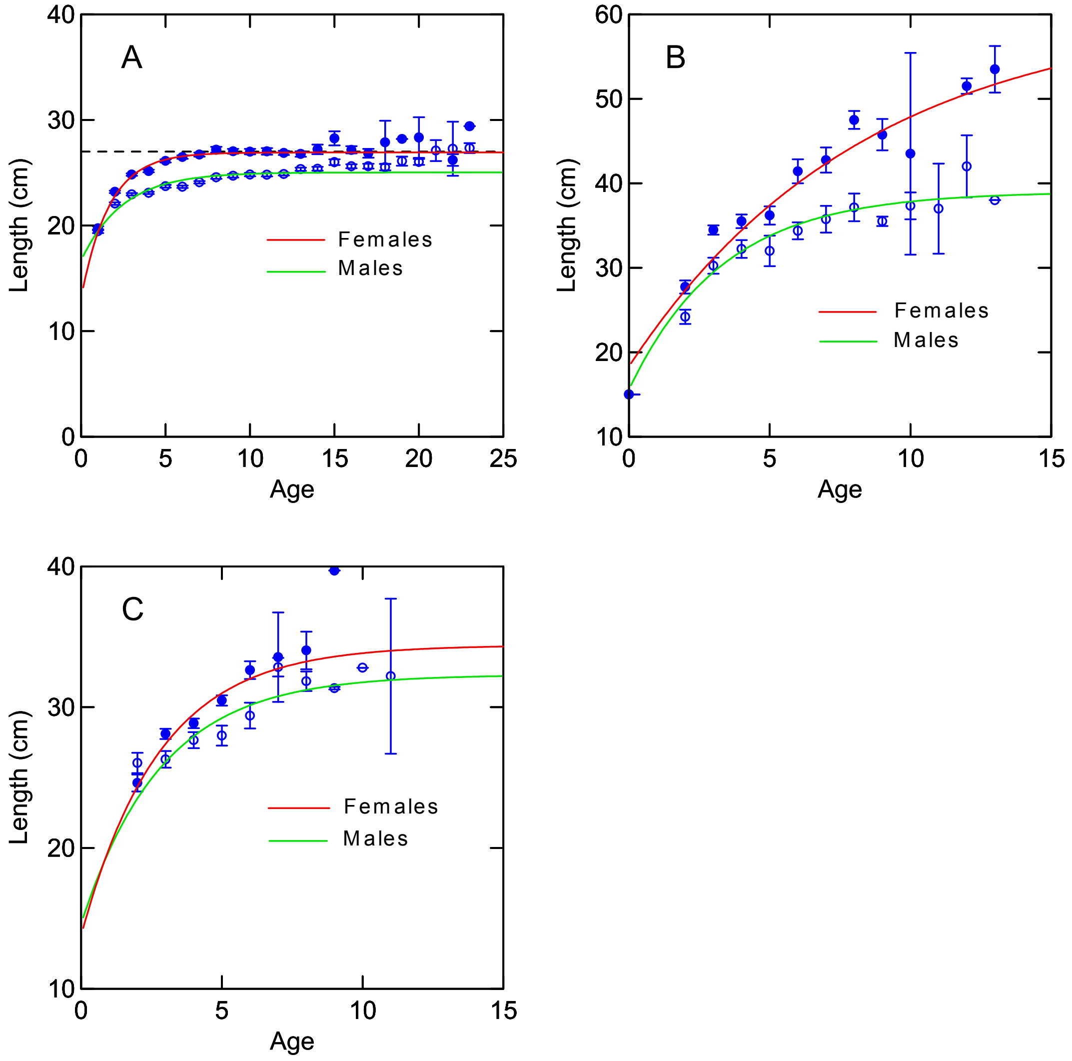

Figure 26 Age-length relationships for male and female sand flathead collected from A) PPB, B) Bass Strait and C) SE Tasmania in 2011/12. Von Bertalanffy growth curves plotted against mean (± SE) length of each age class. Dashed line in A) indicated minimum legal length in Victorian coastal waters.

Comparison of growth rates between PPB and Bass Strait

Sand flathead in PPB grow at a slower rate and attain a smaller maximum size than fish caught from Bass Strait (Figure 23). Most of the variation in linear mixed-effect model describing variation in growth increments is explained by age (Table 12). This is simply because as fish age and grow the width of the increments decreases (Figure 27). Differences in sex and region also explained significant variation in incremental width with age. This is because females grow faster than males; and flathead from Bass Strait grow faster than flathead from PPB. Gender differences were consistent across age and region for females as indicated by the absence of a significant interaction between either sex*age or sex*region (i.e. increments wider for females regardless of age or region) (Table 12).

Table 12 Linear effects model analysis of variance table displaying variation for fixed effects terms age, sex and region.

Source	Df	MS	F-value	Prob.
Age	12	198.68	2675.8	<0.001
Sex	1	1.44	19.3	<0.001
Region	1	1.92	25.8	<0.001
Age*Sex	11	0.11	1.4	ns
Sex*Region	1	0.04	0.5	ns
Age*Region	11	0.21	2.8	<0.05

In contrast to gender differences, regional differences in growth rates were not consistent across all age classes (hence the age*region interaction). This is because growth in PPB fish is lower between the ages 2–6 (t-test, P <0.05), but similar to Bass Strait fish thereafter (t-test, P>0.05). Figure 27 indicates that the differences in growth occur during the early years when sand flathead growth is at its highest. From seven years onwards growth increments largely plateau and there is no difference between the regions during these latter years.

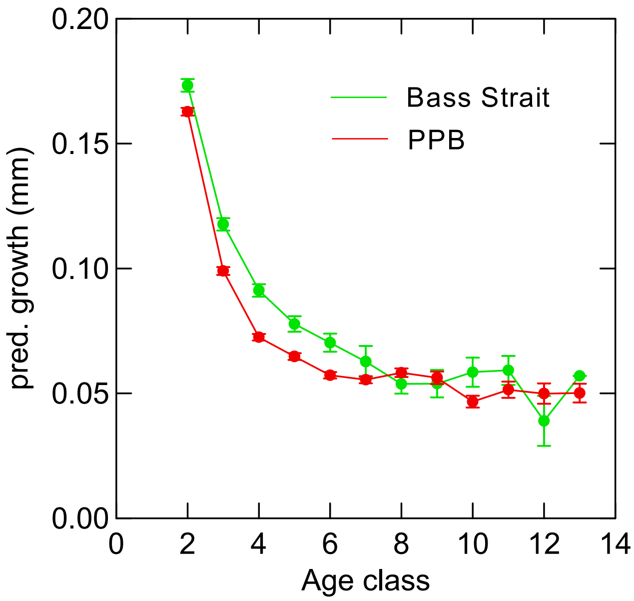

Figure 27 Predicted annual growth increment (± se) for ages 2–13 years from sand flathead collected from PPB and Bass Strait in 2011/12.

Causes of decline

Fishery exploitation

In both years the recreational fishery accounted for >95% of the total fisheries mortality in PPB (Table 13). The commercial by-catch fishery is also likely to incur mortality due to discards, but is unknown in this instance, and given the small overall size of the commercial fishery is likely to be negligible. Total fishery mortality (i.e. catch + discard mortality) was nearly three times larger in 2000/01 than 2006/07.

Table 13 Estimates of fishing mortality for recreational and commercial sectors of sand flathead fishery in PPB

Mortality estimate (tonnes)	2000/01	2006/07
Retained by rec anglers	322.8	107.3
Discarded by rec anglers	10.6	3.6
Commercial catch	5.0	4.5
Total fishery mortality (tonnes)	338.4	115.4

The exploitation rate for the fishery was calculated using the minimum, median and maximum fishing efficiency scenarios to provide a realistic spread of possible exploitation rates for this fishery. Fisheries exploitation rates remained relatively stable between 2000/01 and 2006/07 (Table 14Table 14). In 2000/01 the fishery exploited 15–28% of the stock biomass (median = 21.1%). Six years later following the second the phone survey, in 2006/07, the fishery was estimated to have exploited 13–24% (median = 18.3%) of the stock biomass. The exploitation rate for this population has remained relatively stable over this period, despite the significant decline in overall stock biomass, due to a three-fold reduction in the total catch between 2000/01 and 2006/07 (Table 14). In 2000/01 the total catch was estimated at 338 tonnes, six years later in 2006/07 is was estimated to be 115 tonnes.

Table 14 Fishery exploitation rate for sand flathead population in 2000/01 and 2006/07. Exploitation rates were calculated using population estimates for sand flathead stocks based on minimum and maximum fishing efficiency scenarios for the trawl years 2002 and 2007

Year	Stock biomass (t)	Catch (t)	Exploitation rate (%)
2000/01	1210 – 2289	338	15 – 28
2006/07	478 – 906	115	13 – 24

Recruitment trends

Recruitment variability for sand flathead in PPB was examined using two independent measures: A) the abundance of 0+ aged sand flathead collected by snapper pre-recruit surveys (2000–2013), and B) the abundance of 2+ aged sand flathead caught by the PPB trawl survey (1990-2011). The latter was lagged by 2 years to provide a measure of recruitment over the period 1988–2009.

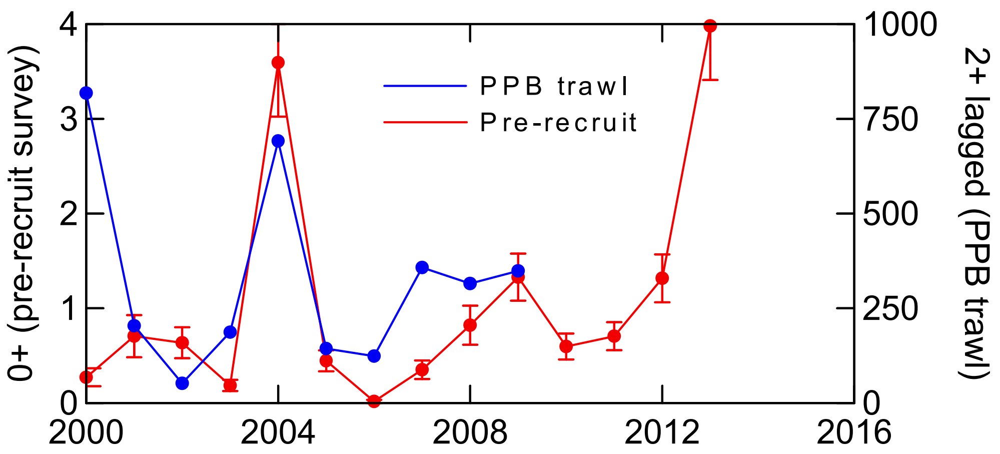

Figure 28 Recruitment trends for sand flathead in PPB derived from pre-recruit snapper survey (0+) and PPB trawl (2+ lagged) surveys for the period 2000–2013

With the exception of 2000, 0+ and 2+ indices lagged by 2 years provided comparable measures of recruitment variability over the period in which they overlap 2000–2009 (R^2 =0.72; P = 0.002) (Figure 28). It is unclear why there is such a large discrepancy for 2000, but as this was the first year of the pre-recruit survey we have decided to use the trawl data as a measure of recruitment variation for this year.

A single measure of recruitment variation for sand flathead for the period 1988–2013 was developed by combining the PPB trawl (1988–2000) and pre-recruit (2001–2013) estimates of recruitment variability (Figure 29). Recruitment prior to 2001 was standardised using the linear regression trend between pre-recruit and PPB annual trawl recruitment indices between 2001 and 2009 (y=0.005x – 0.434; R^2 =0.72; P = 0.002; n=9). This enabled the measure of recruitment variability derived from the PPB survey to be represented on the same scale as the pre-recruit survey.

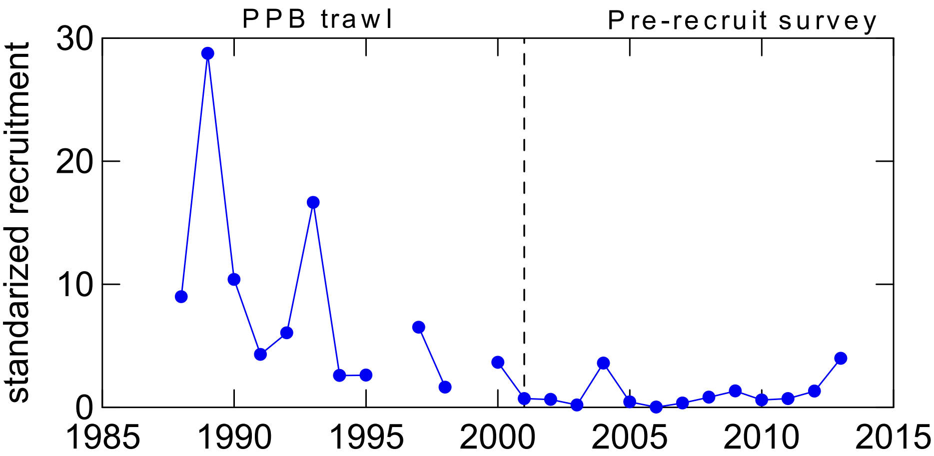

Figure 29 Standardized recruitment index for sand flathead in PPB generated by combining PPB annual trawl and pre-recruit surveys over the period 1988–2013.

Sand flathead recruitment from 1988–2013 was characterised by two key features: A) high inter-annual variability, and B) a clear overall negative trend over time (Figure 29). The negative linear trend between log_e transformed standardized recruitment and year was highly significant (linear regression; F-ratio=22.3; P<0.001). The late 1980s to early 1990s were typified by high recruitment years, particularly 1989 and 1993 and to a lesser extent 1988 and 1990. Seven of the highest recruitment years recorded from 1988 to 2013 occurred in the period 1988–2000 (1988–1993 and 1997). In contrast, recruitment remained very low from 2000–2012, with the exception of 2004. The recruitment pulse recorded by the pre-recruit survey in 2013 (Figure 28) may be the highest recruitment event recorded since 1997 (i.e. in 16 years).

The link between recruitment and population abundance is illustrated by superimposing the recruitment index for the PPB trawl onto trends of stock biomass for sand flathead in PPB from 1990 to 2011 (Figure 30). Recruitment influences population abundance in both the short- and longer-term as peaks in stock biomass follow recruitment pulses, and declining stock abundance tracks declining recruitment. Peaks in sand flathead stock biomass correspond with the emergence of strong year classes which follow strong recruitment events. For example, peaks in biomass for 1991, 1996, 2000 and 2006 correspond respectively with recruitment pulses in 1989, 1993, 1997 and 2004 (Figure 30).

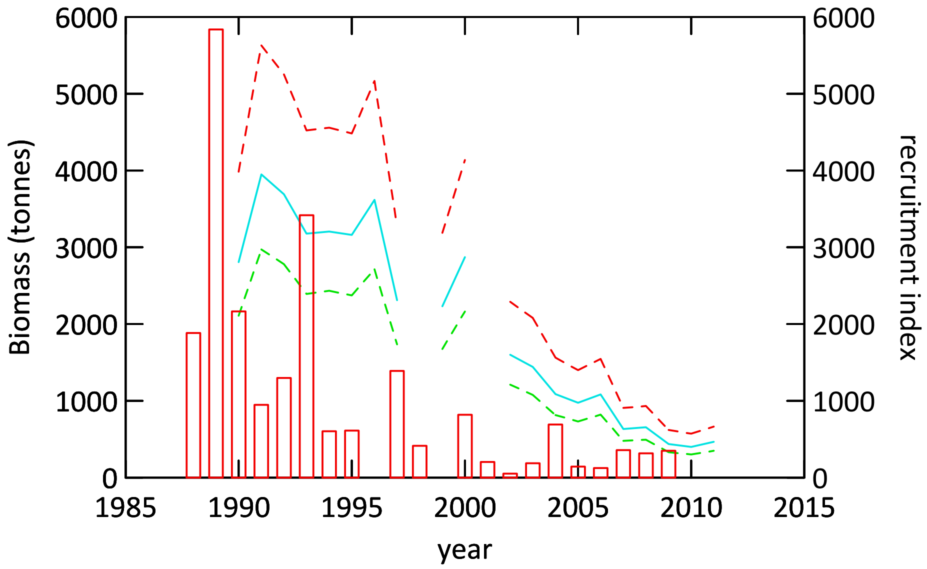

Figure 30 Recruitment index (based on abundance of 2+ fish caught in each survey) displayed as bars superimposed onto trends in sand flathead stock biomass (tonnes) using minimum, median and maximum net efficiency estimates for the period 1988–2011

A longer time-series of recruitment variation for sand flathead in PPB was generated from catch-curve residuals of age structure from 1990-2011. The mean residuals are a measure of the relative strength of recruitment variation for each year class from 1970 to 2006 and allow investigation of trends in recruitment variation prior to 1988. The time-series was validated by correlating the mean residual scores for each year class with the recruitment index (abundance of 2+ fish) for years 1988-1998 and overall there was a good correlation between the two measures (Pearson correlation, $r = 0.767$, $P = 0.01$) (Figure 31).

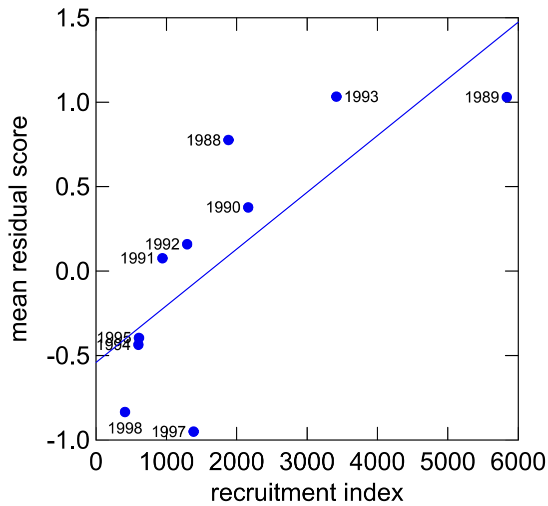

Figure 31 Relationship mean catch-curve residuals and recruitment index for the years 1988-1998

The catch curve residual time series reveals that the high recruitment pulses in the late 1980s and early 1990s were preceded by a period of relatively modest recruitment going back to the 1970s (Figure 32). This analysis suggests that the recruitment events in 1988, 1989 and 1993 were among some of the strongest for this species in the last four decades (1970-2010). Conversely, the period following this period of high recruitment is characterised by some of the lowest recruitment. However, the magnitude of the peaks and troughs in this time series should be interpreted with caution, because the residuals are only a relative measure of recruitment variation and are not scaled to abundance. Consequently, the recruitment peak in 2004 reflects the relative strength of recruitment in this year during a period of very low recruitment through the 2000s and despite its high mean residual score is not actually comparable to the recruitment events of the late 80s/early 90s. Recruitment in 2004 was actually only 10% of recruitment in 1989 (see Figure 29).

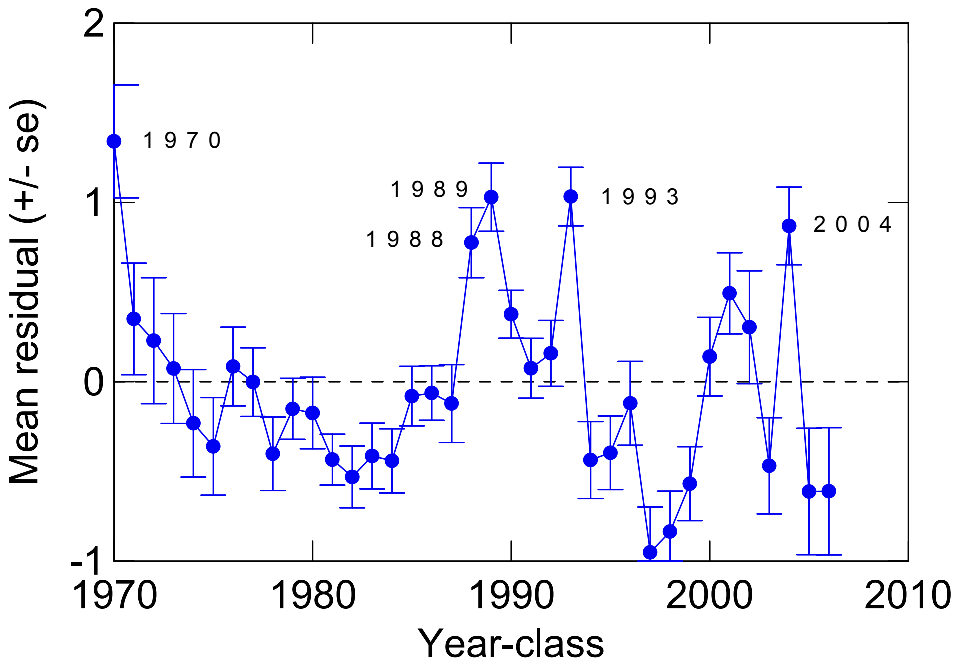

Figure 32 Mean (± se) catch-curve residuals for each year class from 1970 to 2006. Positive values are indicative of above average recruitment and negative values are indicative of below average recruitment. Note residual scores are a relative measure of recruitment variability and are independent of population size.

Environmental drivers of recruitment

The last two decades has been a period of dramatic climatic variability in Victoria and more broadly in southern Australia. Victoria has just emerged from the most pronounced drought on record (from 1997-2009) (Figure 33). River flows from the Yarra River (which accounts for 70% of all catchment flows into PPB) and the contribution of nitrogen into PPB from the WTP and catchments declined throughout this period (Figure 34). Nutrients inputs (in particular nitrogen) are critical to productivity in PPB. These nutrients stimulate phytoplankton productivity that provides food for zooplankton which in-turn feed fish larvae. The drought from 1997–2009 was preceded by a brief period of wetter than average years and was directly followed by two wetter than average years (i.e. 2010 and 2011) (Figure 33).

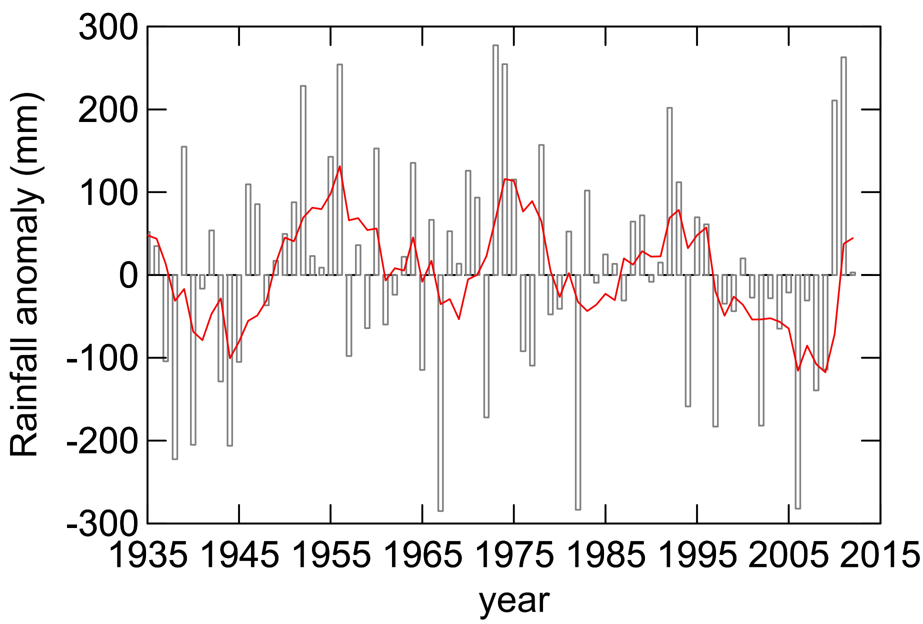

Figure 33 Annual rainfall anomalies for Victoria 1935-2010. Higher than average years occur above the line, whilst the lower than average occur below the line. Five year moving-average shown as red trend line. Mean rainfall = 647 mm/year

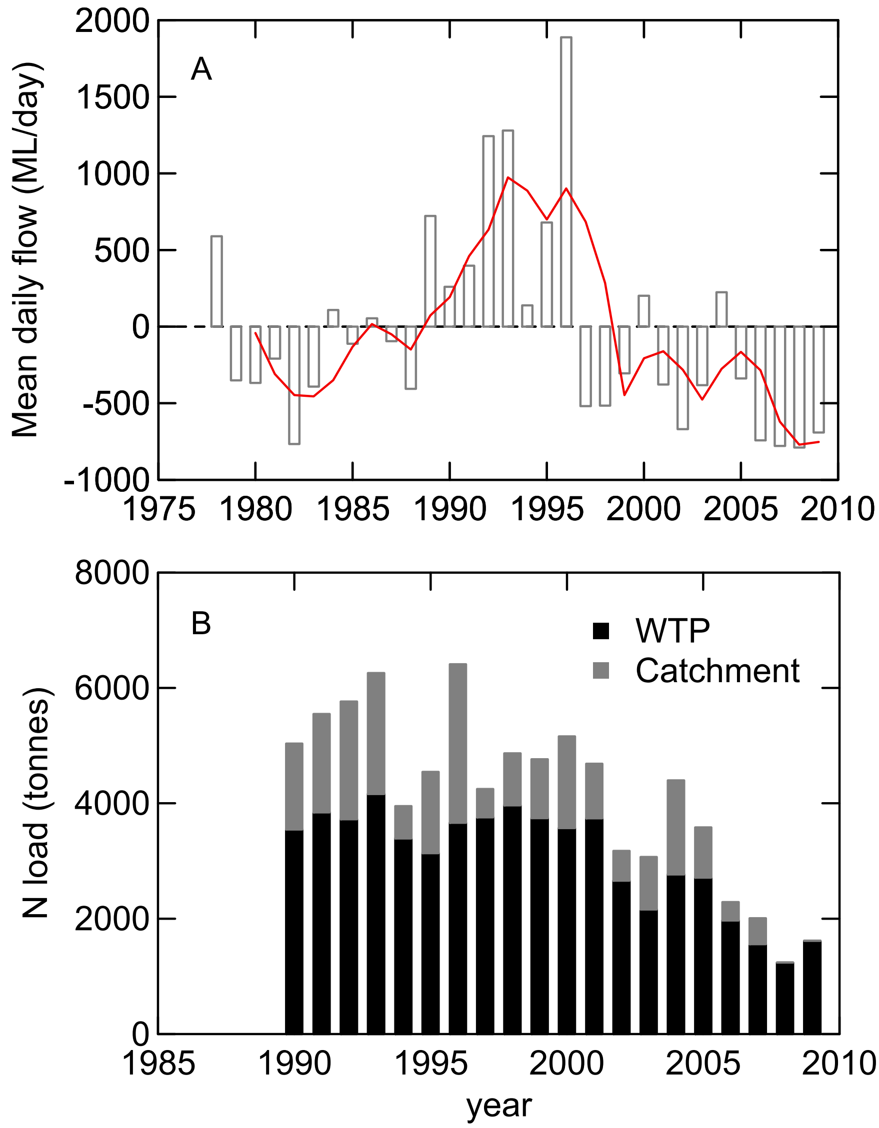

Figure 34 Environmental trends in Port Phillip Bay A) annual anomalies in mean daily flows (ML/day) for the Yarra River for the period 1976 to 2009 (red line = 3-year moving average) and B) annual nitrogen load (tonnes) discharged from Western Treatment Plant (WTP) and PPB catchments

Back-calculation of peak larval period using daily ageing of 0$^+$ fish

The relationship between age (in days) and length for 0+ aged fish caught in 2012 and 2013 is shown in Figure 35. ANCOVA indicated there was no significant difference between growth rates for 0+ age-cohort fish collected in 2012 and 2013 (ANCOVA; $F_{1,47}$=0.311, P=0.858). Linear regressions were significant at P<0.001 and explained 60–70% of the variance between length and age. Hatching dates for 0+ fish ranged from late-October to late-December for fish caught in 2012, and from mid-October to early January for fish caught in 2013.

Peak hatching periods for sand flathead in PPB were estimated using modal length structure for the 0+ age-cohort. 0+ aged cohorts in 2012 and 2013 comprised fish <18 cm in length (Figure 36). This cut-off seems reasonable as the mean length of 1+ year old fish aged in this study was 19.32 ± 2.7 cm (±SD). Size structure in both years was bi-modal for the 0+ age cohort indicating at least two periods of peak hatching for newly recruited sand flathead in these years (Figure 37). The position of the modes was similar in each year (first mode at 10–11 cm and a second mode at 15–16 cm).

The majority of 0+ age cohort sand flathead in 2012/13 hatched between late October and early December (Table 15). The oldest 0+ aged fish (at approximately 18 cm length) are likely to have hatched no earlier than early to mid-October, whereas the youngest, and smallest fish, hatched no later than late December/early January. When combined with information on larval duration (30–40 days) these dates suggest that majority of larvae occur in the water column for a 2 month period from late October to late December (i.e. mode 1 and 2 hatching dates + 30–40 day larval period). November and December is thus likely to be a critical period for the survival of sand flathead larvae in PPB and accordingly we have modelled this period as part of an analysis of environmental-recruitment relationships in PPB.

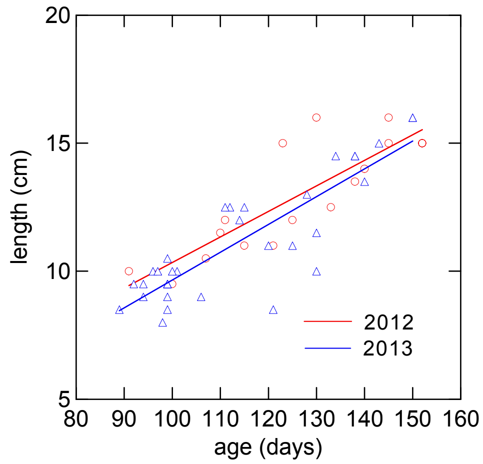

Figure 35 Relationship between age and length for 0+ aged fish caught in 2012 and 2013

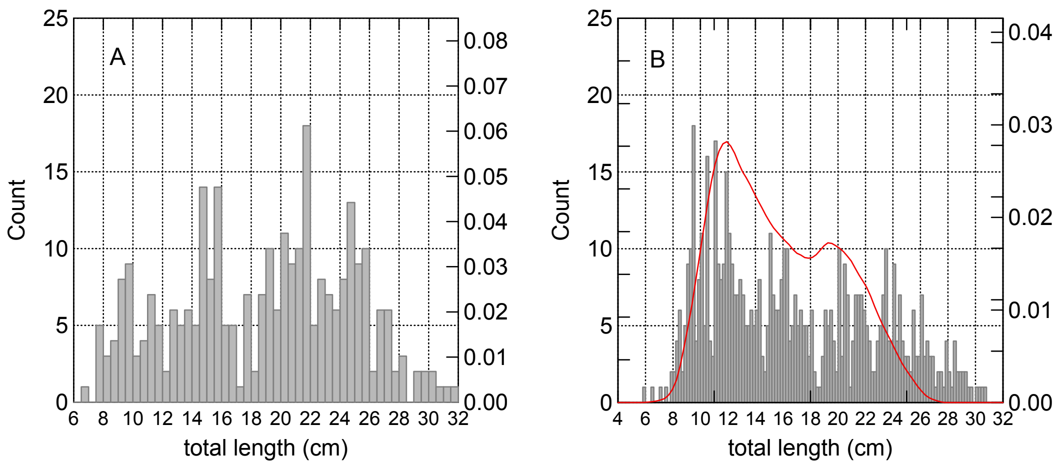

Figure 36 Length-frequency distribution for sand flathead caught by beam trawl surveys in A) 2012, and B) 2013. Red line = kernel density estimate of length-frequency distribution: 0+ age cohort comprises fish <18 cm total length

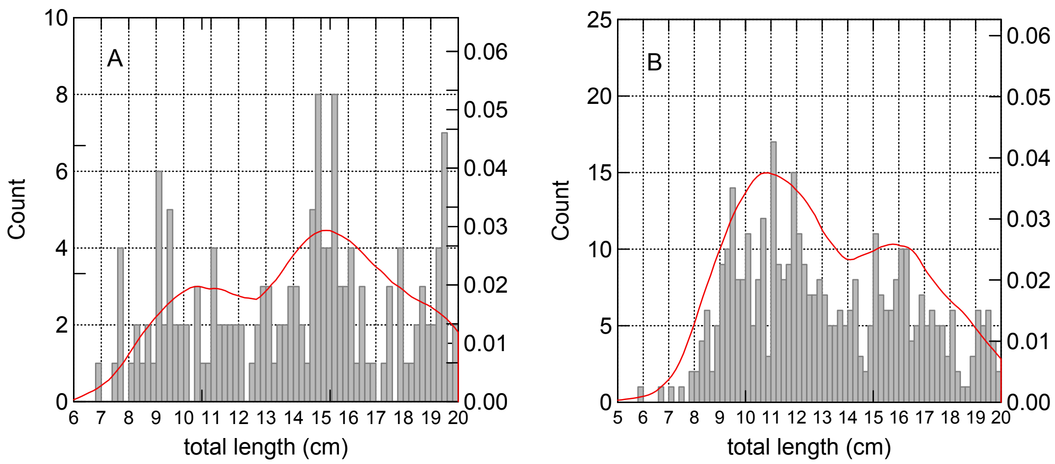

Figure 37 Length-frequency distribution of 0+ age fish sampled in A) 2012, and B) 2013. Red line = kernel density estimate of length-frequency data highlighting length modes at 10–11 cm and 15–16 cm

Table 15 Peak hatching dates estimated from the relationship between age(days) and length for minimum, mode 1 and 2, and maximum length 0+ aged fish sampled in 2012 and 2013. The majority of fish were hatched between the two modes (grey shaded area) (see Figure 37)

Modes	Length (cm)	Age (days)	DOC*	Hatch date	Approx. date
2012					
min	6.8	84	24/03/2012	31/12/2011	Late Dec.
mode 1	10	106	24/03/2012	9/12/2011	Early Dec.
mode 2	15	140	24/03/2012	4/11/2011	Early Nov.
max	18?	161	24/03/2012	14/10/2011	Mid Oct.
2013					
min	5.9	77	24/03/2013	5/01/2013	Early Jan.
mode 1	10.5	109	24/03/2013	4/12/2012	Early Dec.
mode 2	16	147	24/03/2013	27/10/2012	Late Oct.
max	18?	161	24/03/2013	13/10/2012	Mid Oct.

*Date of collection (DOC) midpoint for surveys in 2012 and 2013

Environmental-recruitment relationships 1988–2013

There was a positive correlation between $\log_{10}$ transformed recruitment and stock biomass (Figure 38A), negative correlations between recruitment and temperature and wind speed (Figure 38B and C), and a non-linear relationship between recruitment and mean river flows (Figure 38D). The latter indicates that the relationship between flow and recruitment is positive up to about 3000 ML/day, but is negative for high flow periods in excess of 3000 ML/day. All correlations were significant at P<0.05.

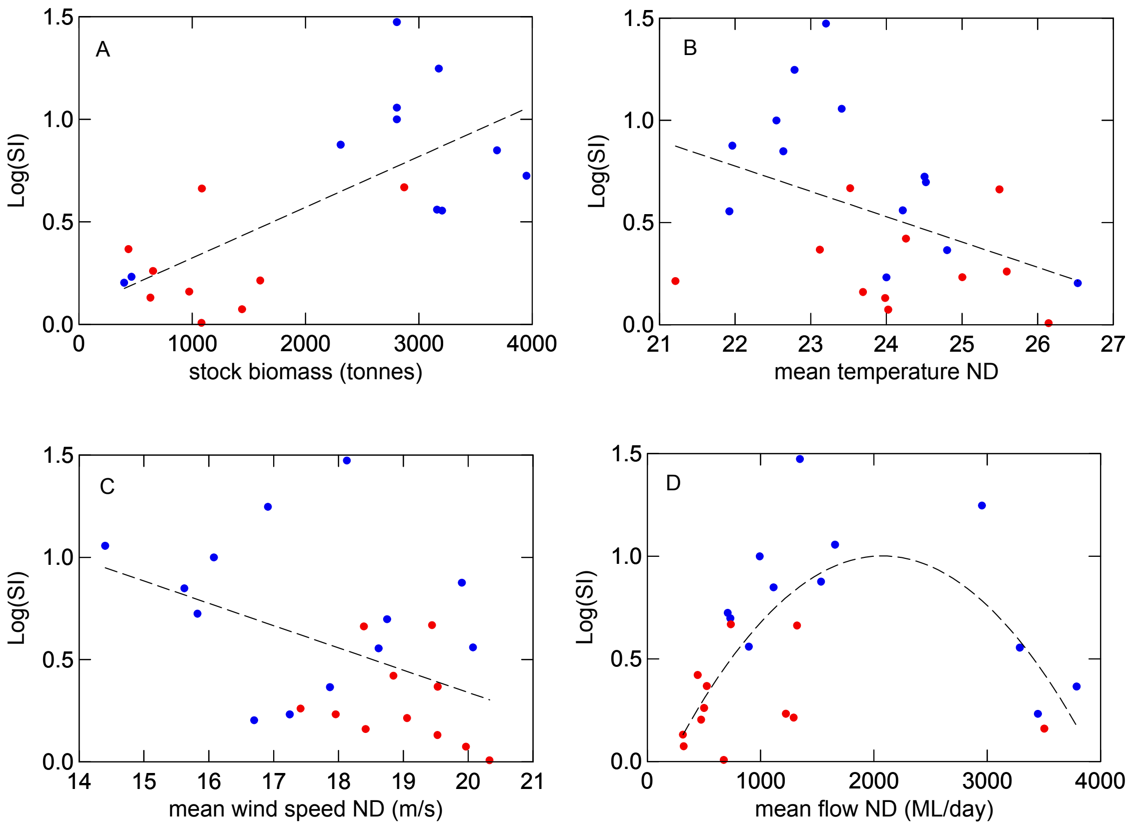

Figure 38 Relationships between $\log_{10}$ (standardized recruitment index) and A) stock biomass in the preceding year, B) mean daily temperature, C) mean 3-hourly wind speed, and D) mean daily flow during November and December. Symbols = ● non-drought and ● drought years

About 64% (r^2 = 0.64) of the variation in log recruitment can be explained by a combination of the four explanatory variables (multiple linear regression; $F_{4,12}$=8.19, R=0.002) when modelled for flows <3000 ML/day. Regression analysis was restricted to flows below 3000 ML/day because the relationship between recruitment and flow appears to be highly non-linear beyond this point and is not easily modelled. Tolerance for each variable was high suggesting that despite some level of correlation among the explanatory variables, collinearity was not a serious problem (Table 16). The majority of variance in recruitment was explained by variation in log mean flows (t=2.53, P=0.027). None of the other variables were significant.

Table 16 Multiple linear regression examining the relationship between log standardized recruitment index and log river flows, wind speed, air temperature during November-December and stock biomass in the preceding year for river flows <3000 ML/day

Source	Std. Coef	Tolerance	t	P
Log (river flow ND)	0.494	0.582	2.523	**0.027**
Wind speed ND	-0.190	0.749	-1.102	0.292
Air temperature ND	-0.060	0.675	-0.332	0.746
Stock biomass	0.320	0.555	1.594	0.137

The best model comprised the variables log river flow and stock biomass (log likelihood-ratio test; F-ratio = 8.18, P=0.01). This model explains about 55% of the variance in recruitment, compared with 64% for the model containing all four environmental variables. However, it should be noted that the relationship between recruitment and stock biomass is not independent, because whilst recruitment may be related to stock biomass levels, recruitment is also clearly a significant driver of stock population levels (and is heavily implicated in the decline of this species over the period 2000–2010). Moreover, this variable is of limited future predictive value as estimates of sand flathead stock biomass are only available for the period of the PPB annual trawl.

Overall poor recruitment events were associated with both very low and very high flows (Figure 39). All low recruitment events associated with low flow events (<700 ML/day) occurred during the drought (i.e. 1998, 2003, 2006–2010). High recruitment events tended to be associated with intermediate flows in the range of 700 to 2900 ML/day during both drought and non-drought years. However, the relationship between recruitment and flow is less satisfactory in explaining the very high recruitment event in 1989 and the low recruitment events in 2001 and 2002 which experienced similar intermediate flows. The linear relationship between recruitment and river flows in November and December over the period 1988–2013 explains about 48% (r^2=0.476) of the variation between these two variables for flow events less than 3000 ML/day.

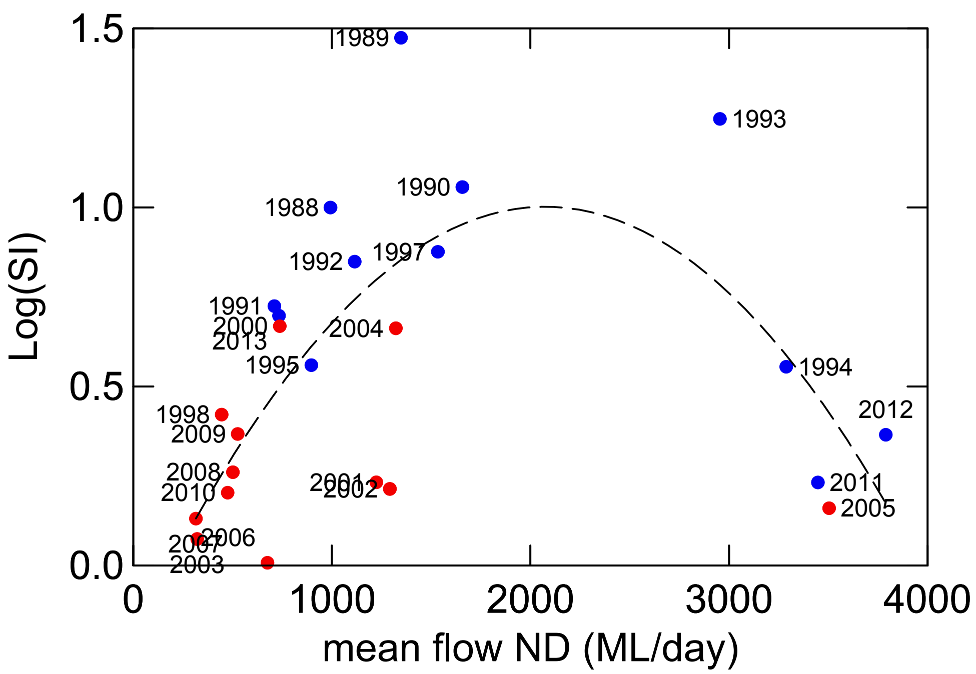

Figure 39 Relationship between log_{10} (standardized recruitment index) and mean daily flow during November and December with years displayed. Symbols = ● non-drought and ● drought years

Dietary analysis 1996–2007

Sand flathead diets were dominated by pelagic fish, benthic fish and crabs (Figure 40). These three taxonomic groups accounted for approximately 75% of the total diet of sand flathead in PPB from 1996-2007. A range of other groups including polychaetes, shrimp decapods, opisthobranchs and amphipods comprised the remaining 25% of the diet. The most common prey species found in the stomachs of sand flatheads from 1996–2007 were the crab *Halicarcinus rostratus*, the anchovy *Engraulis australis* and the opisthobranch *Philine angasi*.

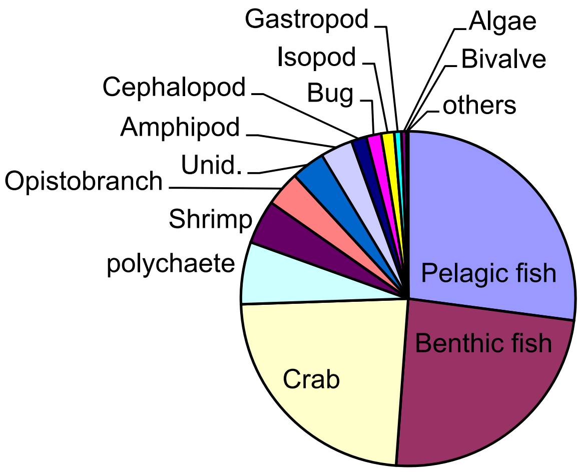

Figure 40 Composition (% total volume) of sand flathead diets in Port Phillip Bay 1996-2007

Temporal trends in diet composition for sand flathead collected from intermediate and deep depth sites were summarised using non-metric MDS (Figure 41).There was a visible shift in diet following 2000 for sand flathead collected from deeper sites, although the differences were not statistically significant (ANOSIM R=0.206, P=0.1). There was no clear temporal pattern for diets from sand flathead collected from intermediate depth sites (ANOSIM R=0.179, P=0.148). Differences between pre- and post-2000 diets amongst sand flathead collected from deeper sites were explained by changes in the average % volume of fish and invertebrate groups (Table 17). Crabs and other invertebrate prey such as polychaetes, amphipods, shrimps and opistobranchs were more abundant in the diets of sand flathead from deep sites in the period 1996-2000, whereas pelagic and benthic fish was more abundant in the period 2002-2007 (Table 17). In general crabs were a less important component of the diet of sand flathead after 2000, whilst fish were more important.

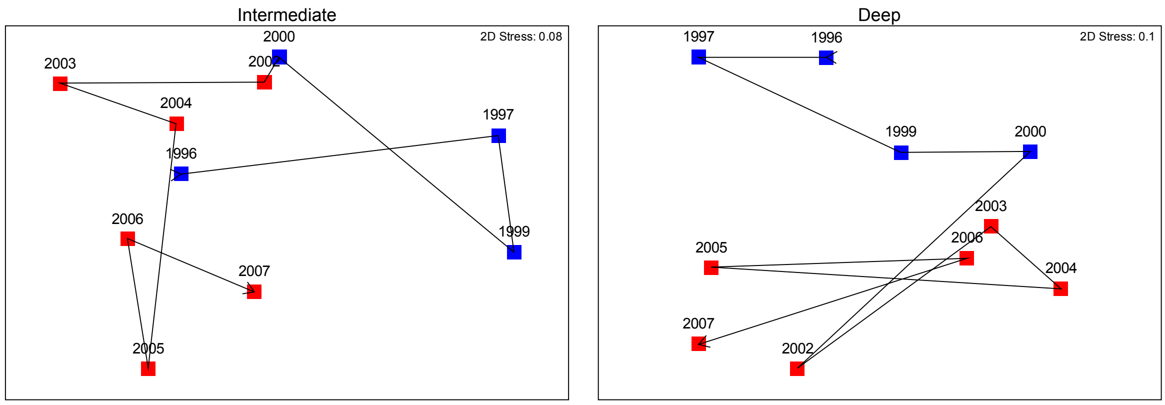

Figure 41 Non-metric MDS ordination plots displaying the position of sand flathead diets in multivariate space for intermediate and deep sites from 1996-2007. Lines show inter-annual temporal trend in diet composition. Symbols: ■ 1996-2000; ■ 2002-2007 stomach contents

Table 17 SIMPER (similarity percentages) analysis comparing the stomach contents of sand flathead collected from deep sites between the years 1996-2000 and 2002-2007. Differences in the composition of pelagic and benthic fish and crabs explained 62% of the dissimilarity between the two periods

Prey group	Average % composition		Dissim. % contribution	Cumulative % contribution
	1996-2000	2002-2007		
Pelagic fish	18.45	32.86	25.07	25.07
Benthic fish	9.61	33.69	22.11	47.18
Crabs	31.71	17.72	15.37	62.55
Polychaetes	10.56	3.00	7.92	70.47
Amphipods	7.24	0.36	6.29	76.76
Shrimps	6.43	2.79	6.22	82.98
Opisthobranchs	5.40	1.82	3.90	86.88

Growth trends 1953–2009

The growth chronology developed for sand flathead collected from Beaumaris at 22 m spans a 56 year period from 1953–2009. The year random effect represents the extrinsically driven sources of variation in growth for the average sand flathead over this period (i.e. predicted growth in mm). Annual predicted growth displayed considerable inter-annual variation during this period, with deviation from the long-term average indicating periods of high and low growth (Figure 42). The most notable feature of the growth chronology was the pronounced period of very low growth from 1992 to 1996. There was also a period of low growth from 1963-1965, and a period of above average growth from 1971 to 1975. The highest growth year was recorded in 1988 and the lowest in 1994.

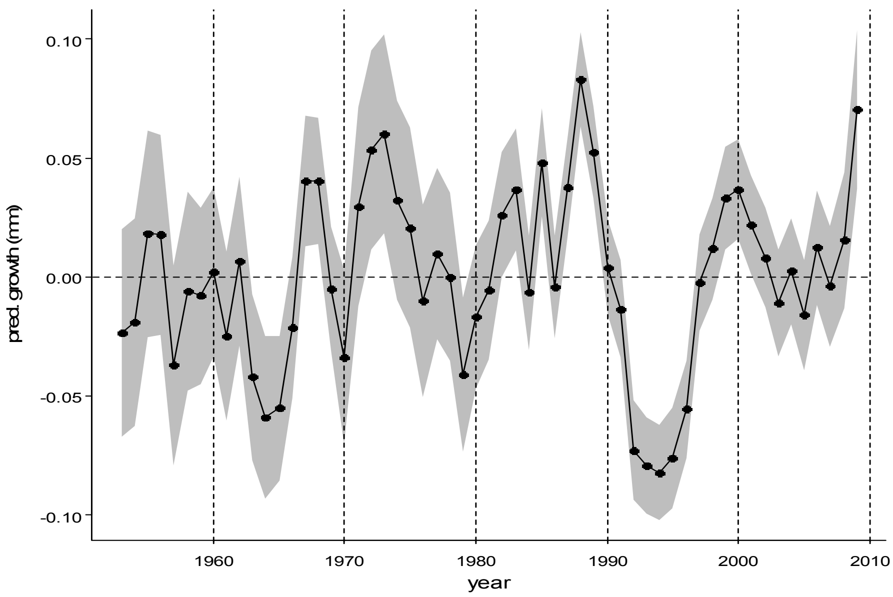

Figure 42 Predicted annual growth (± se shaded area) for sand flathead from 1953–2009. Horizontal line at 0 is the average predicted growth in mm; positive values indicate greater than average growth, whereas negative values indicate lower than average growth. The predicted growth represents the portion of growth that is attributed to environmental effects in each year

The year class random effect partitions extrinsic sources of growth variation into those that can be attributed to the year in which fish were spawned. Figure 43 displays the predicted growth of fish spawned in different years (year classes) across their entire lifespan (i.e. until caught). Deviations from the long-term average indicate year classes with higher or lower than average predicted growth rates compared to fish spawned in different years. Year classes spawned in 1966 and 1989 experienced very low growth across their lifespans compared to fish spawned in other years. By comparison fish spawned in 1990 experienced the highest average growth of all the year classes analysed.

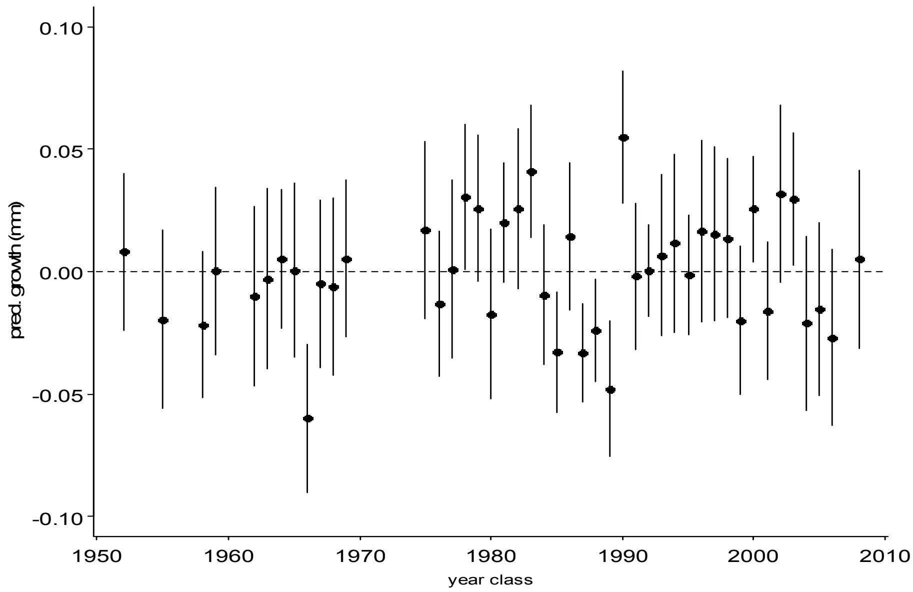

Figure 43 Predicted growth (± se) for each year class from 1953–2009. The horizontal line at 0 is the average growth in mm. Positive values indicate year classes with higher than average growth over their entire lifespan, whereas negative values indicate year classes with lower than average growth

Relationships between environmental variables and growth were examined via correlation. There were strong correlations between growth and both mean annual sea-surface temperature (SST) and air temperature over the period 1993–2009 (Figure 44A and B; Table 18). This correlation is driven by a shift from a period of low growth, accompanied by below average annual temperatures from 1992–1996, to a trend of above trend growth and temperatures from 1997–2009. However, when the relationship between growth and mean annual air temperature was examined across the entire time-series from 1953–2009 the overall correlation was weak (Figure 44B; Table 18). Correlations for mean annual air temperature, Yarra River flows, and air temperature and river flows combined, only explained minor amounts of the total variance in the annual growth trend (i.e. <14% of the total variance, Table 18).

Table 18 Correlations between annual predicted growth and environmental variables

Variable	period	R^2	P
Annual SST	1993–2007	0.56	0.001
Annual air temp	1993–2007	0.45	0.004
Annual air temp	1953–2009	0.07	0.021
Yarra river flows	1959–2009	0.14	0.004
Annual air temp + flows	1959–2009	0.13	0.013

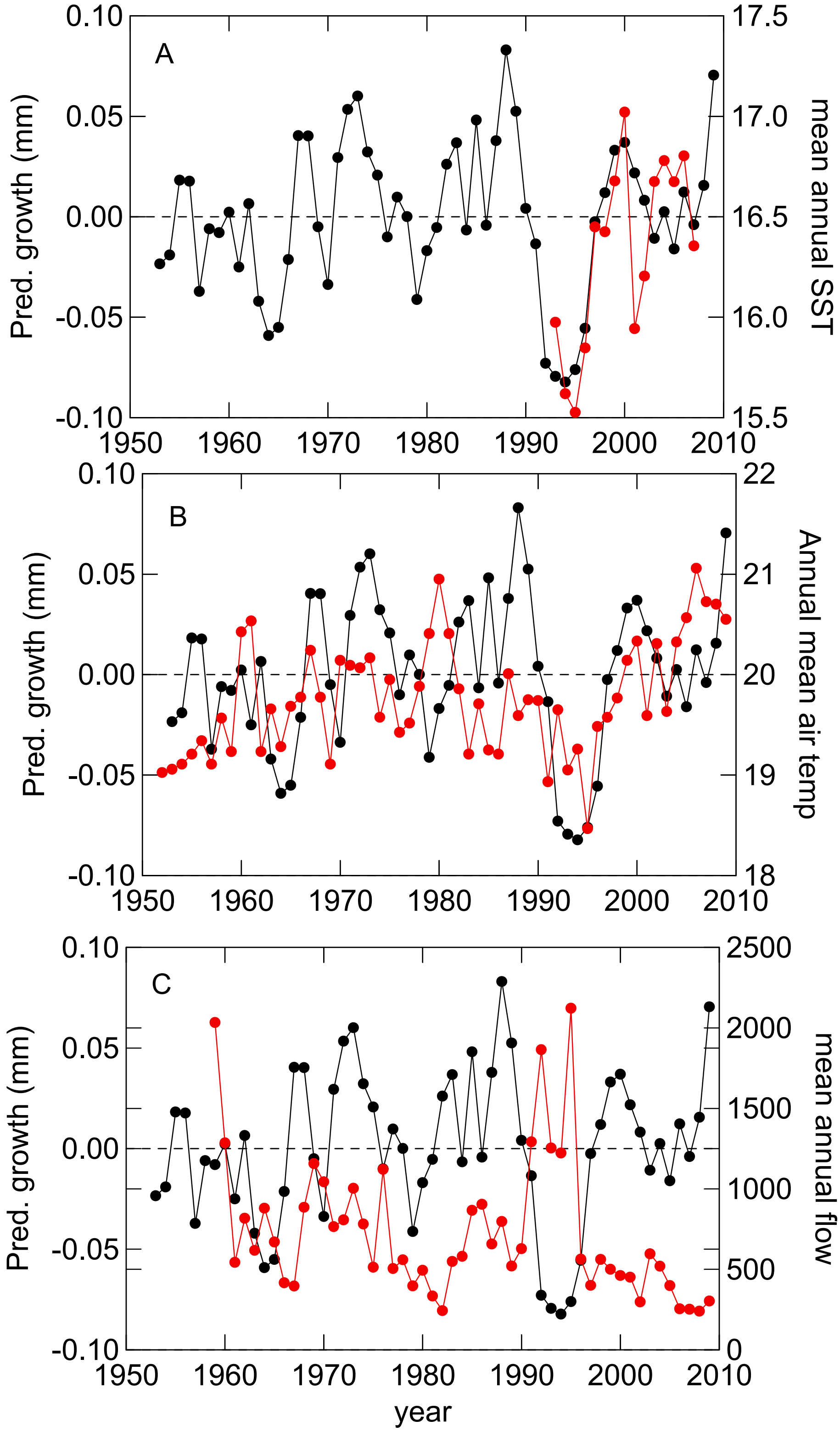

Figure 44 Environmental data superimposed on predicted annual growth (mm) variation for A) mean annual SST (1993–2007), B) mean annual daily temperature (1953–2009) and C) mean annual Yarra River flows (1959–2009)

Growth chronologies can also be used to examine the impact of specific events on growth. The severe and prolonged drought from 1997–2009 appears to have had little impact on growth during this period as predicted growth was either higher than, or consistent with, the long-term trend over the 56 year time series (Figure 45). Moreover, river flows were found to explain little of the overall variance in sand flathead growth from 1953–2009. There was little evidence that the growth of sand flathead in PPB was affected by the Northern Pacific starfish (*Asterias amurensis*) following its introduction into PPB in the mid-1990s. This is because growth rates were higher than average during the period when starfish densities were highest in PPB (1999–2000, see Figure 45). Growth rates declined after 2000, returning to trend during the mid-2000s.

The most unusual feature of the growth chronology is the period of very low growth from 1992–1996. Predicted growth during this period was visibly lower than any other period in the 56 year chronology and follows a period of very high recruitment from 1988–1993. This period of low growth and high recruitment coincided with a spike in the commercial CPUE, indicative of higher sand flathead abundance from 1993. During this period the population was dominated by fish from three strong recruitment cohorts: 1998, 1989 and 1993.

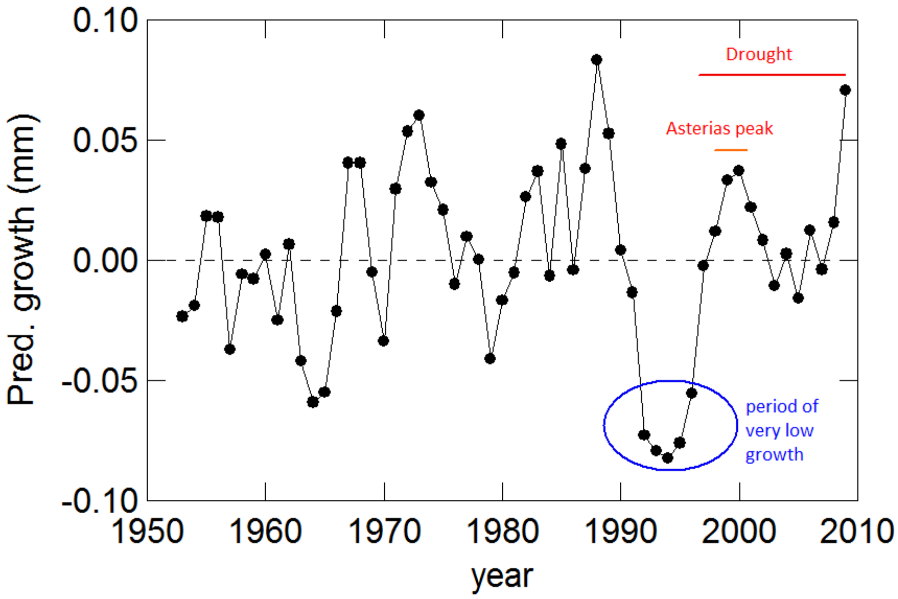

Figure 45 Important features of growth chronology highlighting period of very low growth (1992–1996), drought (1997–2009) and peak *Asterias amurensis* biomass in PPB (1999–2000, see Figure 9).

Yank flathead fishery in PPB

PPB supports two other flathead fisheries: yank flathead (*Platycephalus speculator*) and rock flathead (*Thysanophrys cirronasus*). Yank flathead are caught by recreational and commercial fishers on hooks, whereas rock flathead are caught principally by commercial fishers as part of a seine net fishery and are seldom caught by recreational fishers. The importance of the yank flathead fishery has increased over time as the differences in the relative abundance of the major recreational flathead stocks in PPB has diminished (Figure 46). Whilst sand flathead stocks declined by 87% in the last decade, yank flathead stocks remained steady over this period (mean stock biomass = 123 tonnes). In the final year of the trawl, in 2011, there was an estimated 180 tonnes of yank flathead in PPB compared to 460 tonnes of sand flathead (a ratio of 2.6:1). However, during the 1990s this ratio often exceeded 30:1 and in some years exceeded 50:1.

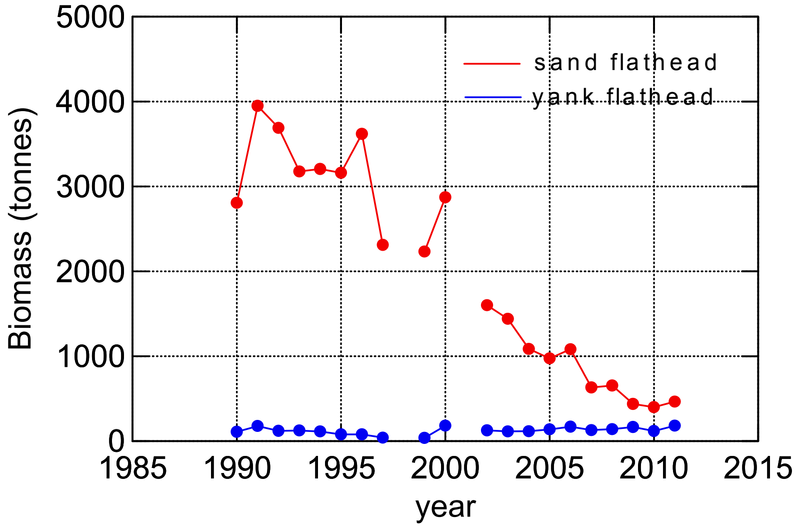

Figure 46 Biomass trends for sand flathead and yank flathead from 1990–2011. Trends derived using median net efficiency estimates for both species of flathead

The other feature of the yank flathead fishery that has contributed to its increasing importance since 2000 is the larger size of fish. Yank flathead are on average 7 cm longer than sand flathead caught in PPB and this pattern has been consistent since measurements of both species began in 1996 (Figure 47). Aside from the benefit to recreational fishers of being able to catch larger fish, this difference means that a larger proportion of the yank flathead caught by recreational fishers will be of legal size (reducing the discard rate).

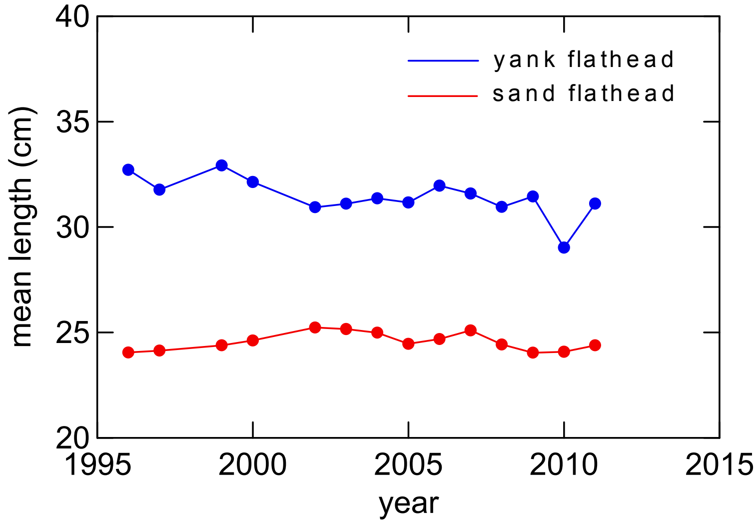

Figure 47 Mean length (cm) of sand and yank flathead caught by the PPB annual trawl from 1996–2011

Management settings

How important is the sand flathead fishery in PPB?

Changes to management settings (which require time and resources) need to be weighed against the importance of this species as a recreational fishery in PPB. There is a perception that sand flathead is a less important recreational fishery because it is rarely targeted by recreational fishers. However, there are few direct assessments of the importance of this species to the recreational fishery in PPB. Here we present a summary of the creel recreational survey data for the period 2009–2013 (see above) comparing the catches for a range of recreational species caught in PPB.

Flathead, of which approximately 80% are estimated to be sand flathead, accounted for 31% of all recreational catches retained in PPB during the period 2009–2013 (Table 19). This compares with King George whiting which accounted for 22%, and snapper 14%, of all catches retained during this period. Flathead were the most caught and retained recreational species in PPB.

Table 19 Recorded number of recreational species kept, released and caught by recreational fishers surveyed at boat ramps during a five year period from 2009–2013. N = 6 most abundant species kept in PPB.

Species	Kept (K)	Released (R)	Total caught (K+R)	% Kept
Flathead, all*	12409	22630	35039	31.4
King George whiting	8844	3224	12068	22.4
southern calamari	6797	151	6948	17.2
snapper	5668	16264	21932	14.4
garfish	3066	163	3229	7.8
Australian salmon	954	702	1656	2.4
Total fishery	39484	49912	89396	

* sand, yank and unspecified

Changes to size limits

Reducing the minimum size limit from 27 cm to 24 cm dramatically increases the proportion of both male and female sand flathead caught by the PPB trawl that are legal size (Figure 48). Conversely increasing the size limit from 27 cm to 29 cm reduces the proportion of male and females in the population that exceeded the minimum size. At the current size limit (27 cm) 32% of female and 15% of males caught by the PPB annual trawl in 2011 exceeded the minimum size limit. At 24 cm 70% of females and 64% of males exceeded the minimum size limit, but at a minimum size limit of 29 cm <1% of males caught by the trawl were of legal size (Figure 48).

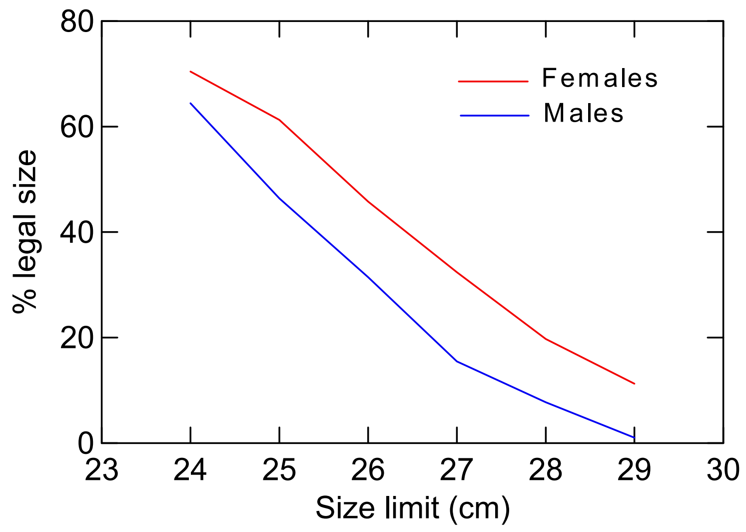

Figure 48 Proportion (%) of male and female fish caught at size limits ranging from 24 to 29 cm

At the current setting (a minimum size limit of 27 cm) there are approximately 2.1 females for every male caught. If the size limit is increased to 28 cm the ratio of females to males increases to 2.5 and at 29 cm it is 10.9 females for every male. Conversely, managers could potentially increase the likelihood that males and female sand flathead are caught in equal numbers by reducing the minimum size limit (i.e. the ratio approaches 1.0) (Figure 49).

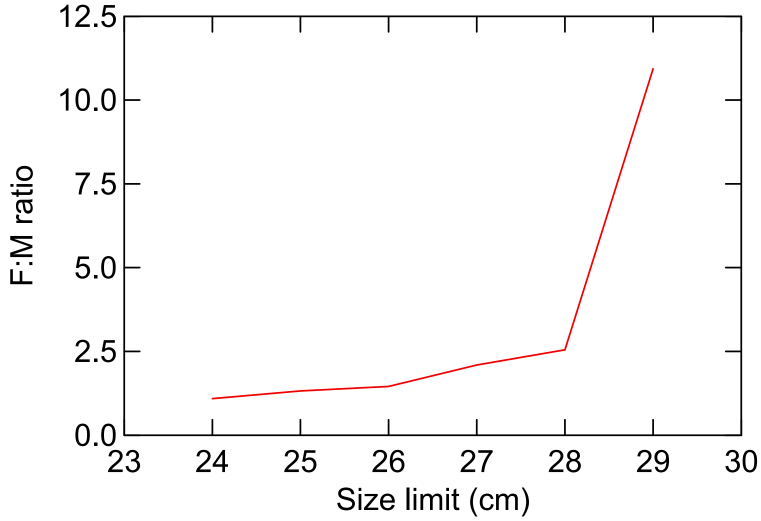

Figure 49 Ratio of females to males caught at size limits ranging from 24 to 29 cm

Changes to bag limits

Eighty-seven % of angler trips survey from 2009–2013 resulted in no flathead being retained. The majority of angler trips surveyed (where sand flathead were retained from 2009–2013) comprised bags ≤ 5 sand flathead (Figure 50). Bag sizes ≤ 5, 10 and 15 fish accounted for 90%, 97% and 99.5% of all angler trips surveyed (Figure 50).

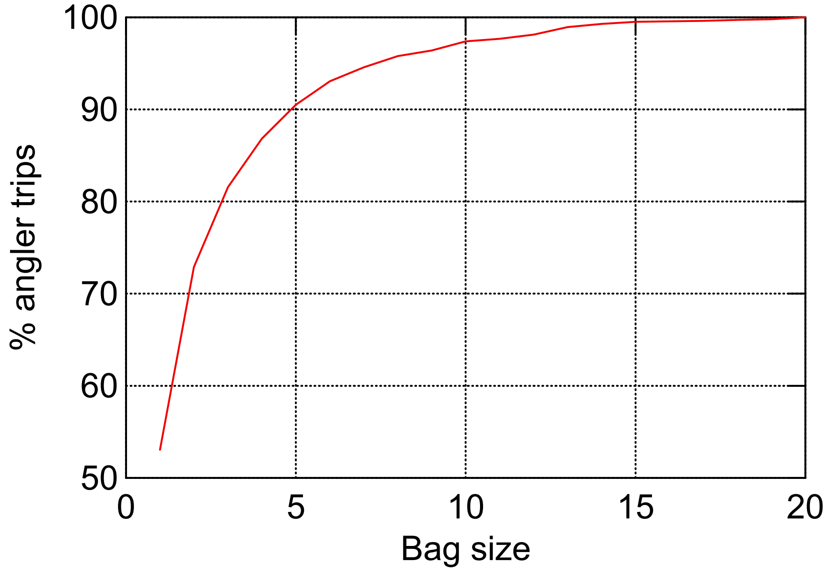

Figure 50 Cumulative percentage (%) of angler trips for bag sizes 1–20.

By comparison, bag sizes of ≤5, 10 and 15 sand flathead accounted for 64%, 85% and 96% of the total number of sand flathead caught by anglers surveyed from 2009–2013 (Figure 51).

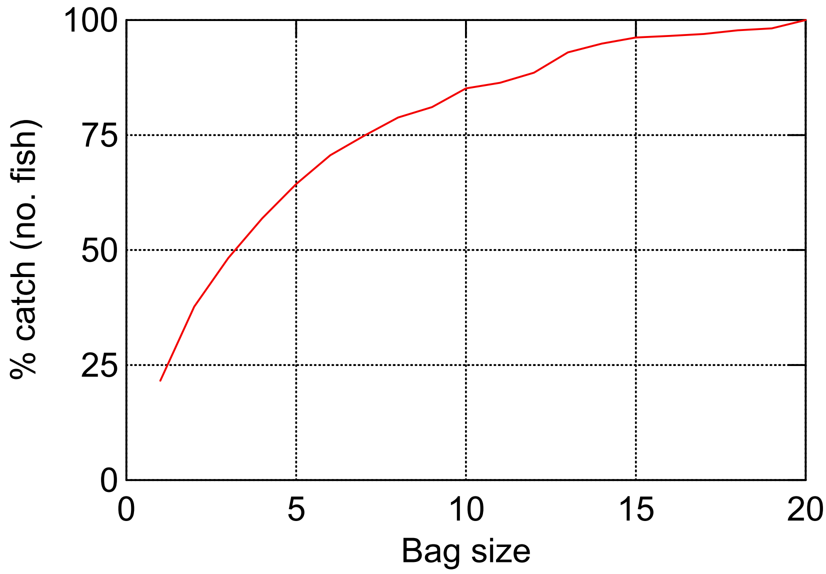

Figure 51 Cumulative percentage (%) of total sand flathead catch (no. fish) for bag sizes 1–20 (n = 4425 sand flathead)

The impact of reducing maximum bag sizes was modelled by allocating total fishing effort for the period 2009–2013 across a range of maximum bag limit scenarios and estimating the impact on the fishing mortality (total catch). Changes in maximum bag limits had modest impacts on the total sand flathead catch in Port Phillip Bay. Lowering the maximum bag limit to 15, 10 and 5 fish reduced the total catch by 0.7%, 4.2% and 16.3%, respectively (Table 20).Accordingly, it would require a reduction in the bag limit from 20 to 3 to achieve a reduction in sand flathead catch of approximately 30% (Table 20).

Table 20 Bag limit scenario modelling: reduction (%) in sand flathead fishing mortality/total catch achieved by restricting maximum bag limit from 20 to 1 fish. Catch rate = catch/total angler effort. Grey bands highlight outcomes for 15, 10 and 5 bag limit scenarios

Bag limit	catch	effort (total angler trips)	catch rate	% reduction in F (total catch)
20	4445	14271	0.31	0.0
17	4426	14271	0.31	-0.4
15	4407	14271	0.31	-0.9
12	4338	14271	0.30	-2.4
10	4247	14271	0.30	-4.5
8	4104	14271	0.29	-7.7
5	3707	14271	0.26	-16.6
3	3136	14271	0.22	-29.5
2	2647	14271	0.19	-40.5
1*	1801	14271	0.13	-59.5

*1801 angler trips in which at least a one sand flathead was recorded from 2009-2013

Discussion

Sand flathead stock biomass in PPB declined by 80–90% in the decade between 2000 and 2010. This decline was consistent for three independent sources of information: fisheries-independent trends in sand flathead catches using a fixed site survey, and commercial and recreational fishery catch-per-unit-effort (CPUE) trends. We estimated that sand flathead biomass in PPB declined by on average 250 tonnes per year during this decade. This caused a significant reduction in the total recreational catch, from 322 tonnes in 2000/01 to 107 tonnes in 2006/07. This was largely driven by declining catch rates for this species, but also increased abundance of more highly targeted species such as snapper and King George whiting during this period (Kemp et al. 2012a, b).

There was no evidence the decline observed in PPB was part of a broader pattern for this species across its geographical range in southern Australian waters. Stocks in Western Port and south-eastern Tasmania have remained relatively stable during the period highlighted in this report.

This report examined the evidence that the decline was related to fishing and/or a range of environmental impacts.

Fishing impacts

The impact of fishing on sand flathead stocks in PPB was investigated by examining changes in exploitation rates between 2000/01 and 2006/07. The exploitation rate is the proportion of the stock that is either caught or lost through mortality, and hence exploited, annually. We investigated whether increasing exploitation rate was coupled with declining stock abundance in PPB. Despite a significant decline in the overall stock biomass during this period, fisheries exploitation rates remained relatively stable between 2000/01 and 2006/07, due to a three-fold reduction in the total catch over this period. In 2000/01 the fishery exploited 15–28% of the total stock biomass and 13–24% of the stock in 2006/07. During the same period the total catch for sand flathead declined from 338 tonnes in 2000/01 to 115 tonnes in 2006/07. This analysis indicates that there is little evidence that fishing pressure was the initial cause of the sand flathead decline over the period 2000–2010 or that the population was overfished during this period. However, continued fishing may impede the natural recovery of this stock and should be reviewed as part of a management response (see below).

The resilience of the sand flathead population in PPB to the threat of overfishing is possibly explained by two factors. First, sand flathead is principally a recreational, non-targeted fishery where catches are often incidental to other targeted species. This means that as catch rates declined so did the total catch as fish became scarcer and harder to catch. In contrast to high-value target fisheries there is no incentive to maintain catches against a backdrop of falling catch rates and stock levels by modifying fishing gear or effort patterns. The second feature of this fishery that may have protected it from overfishing is the potential for fishers to switch to, and target, other flathead species in PPB when sand flathead were scarce. Whilst sand flathead stocks declined by 87% in the last decade, yank flathead (*Platycephalus speculator*) stocks have remained steady over this period. Yank flathead are on average 30% longer than sand flathead in PPB and as sand flathead stocks dwindled this fishery has become increasingly important to recreational fishers.

Sand flathead in PPB grow more slowly and reach a smaller maximum size than sand flathead collected from other parts of their geographic range (e.g. Bass Strait, Western Port, Corner Inlet and SE Tasmania). On average sand flathead in PPB were 30% shorter than fish collected from Bass Strait and 20% shorter than fish collected from SE Tasmania. Consequently, a smaller proportion of sand flathead caught in PPB will be of legal size (currently 27 cm length) than in other parts of their geographic range. In the early 1990s <10% of the population were legal size, but by the early 2000s this proportion was >30% and remained above 20% through to 2011, despite the decline in the population. This finding is counterintuitive but occurred because fewer large cohorts of younger-smaller fish entered the population in the late 1990s and 2000s resulting in a gradual ageing of the population in PPB. In terms of the fishery this means that although the number of overall fish declined, the relative number of fish of legal size fish increased. This phenomenon may have partially off-set the overall decline in the fishery.

The other potentially more serious issue posed by the current size limit for sand flathead in PPB relates to the sexually dimorphic growth of sand flathead. Female sand flathead grow faster and reach a greater maximum size than males and therefore a greater proportion of females are likely to be caught and retained by anglers. Thirty nine percent of females caught by the PPB trawl from 1990-2011 were legal size compared to only 15% of males over this period. This suggests that large female sand flathead are being removed from the population at more than twice the rate of males, and with them a significant proportion of the spawning (egg producing) biomass of the sand flathead population in PPB. The impact of this effect on declining recruitment trends in PPB is unknown, but requires further investigation.

Environmental causes of decline

Environmental impacts were investigated by examining changes in sand flathead recruitment, environmental drivers of recruitment, growth and diet. The evidence presented in this report overwhelmingly supports the conclusion that declining recruitment from the mid-1990s onwards led to the decline of sand flathead stocks from 2000. In comparison, there is little evidence that sand flathead growth was affected by either the introduction of the exotic seastar *Asterias amurensis* in the late 1990s or the drought from 1997–2009.

Variation in recruitment has long been known to be an important driver of fish population abundance as year-classes of varying strength enter and progress through the population. Without replacement fish belonging to existing cohorts will age, grow and die, and the population will diminish. Sand flathead recruitment was characterised by very high recruitment pulses in the late 1980s and early 1990s, but little recruitment from 1997 onwards. In the 2000s, with the exception of 2004, recruitment was exceptionally low. Annual recruitment in the 2000s was 89% less than the period from 1988–1998. As consequence, there was a clear shift in the age structure of the sand flathead population in PPB over this period. The age structure of sand flathead in the 1990s was dominated by fish recruited in 1988, 1989, 1993 and 1997, and these cohorts comprised a high proportion of the population through to about 2005. By comparison, the 2000s were characterised by the absence of similarly strong year classes, indicative of a period of prolonged poor recruitment.

The decline in recruitment for this species coincided with a period of prolonged drought in Victoria from 1997–2009. This period was characterised by substantially lower rainfall and hence river flows. We found that sand flathead recruitment was significantly correlated with river flows during November and December – the period when the majority of sand flathead larvae were estimated to occur in the water column (based on a larval duration of approx. 30–40 days). However, the relationship between recruitment and river flows is not linear. The relationship between flow and recruitment was positive up to 3000 ML/day, but negative for flows in excess of 3000 ML/days. This means that recruitment was lowest in years when flows were either very low or very high and greatest in years with intermediate flows between 1000 and 3000 ML/day. Almost all low flow years during the drought corresponded with low recruitment. This analysis suggests that sand flathead recruitment in PPB is heavily influenced by environmental conditions.

Jenkins et al. (2010) found a similar non-linear relationship between black bream (*Acanthopagrus butcheri*) recruitment and river flows in the estuarine Gippsland Lakes system between 1987 and 2000. They related this relationship to the preference of juvenile bream for highly stratified waters with intermediate salinities. However, as PPB is a relatively deep, well-mixed marine embayment this is unlikely to account for the relationship between river flows and sand flathead recruitment observed in this study.

We hypothesize that the relationship between river flows and recruitment is related to the productivity of planktonic ecosystems in PPB. River flows carry a range of nutrients including nitrogen and phosphorous which are washed from the catchment. These nutrients stimulate phytoplankton (algae) productivity that feed zooplankton, which in turn, are food for fish larvae. Mortality is typically very high during the larval stage due to high vulnerability to predation and starvation. If there isn't sufficient food then larvae are unable to grow and survive. If larval survival is lower than average then recruitment will be low, because few fish survive to settle-out of the plankton. Conversely, if survival is higher than average then recruitment may be stronger in these years. The relationship between very high flows (floods) and low recruitment is not well understood at this point, but may be related to the high disturbance associated with flood events, particularly reduced salinities and increased turbidity.

River flows are directly related to rainfall that in turn is influenced by climatic cycles in southern Australia (e.g. El Nino Southern Oscillation, Indian Ocean Dipole). Recruitment trends for sand flathead are therefore likely to be influenced by both shorter and longer-term climatic cycles and trends. The drought from 1997–2009 was the longest and most severe drought on record in southern Australia (Ummenhofer et al. 2009). Victoria experienced 13 consecutive years of below average rainfall, leading to reductions in river flows and a 40% reduction in the modelled nitrogen load into PPB (Hirst unpub.). This in large part explains why there has been no major recruitment for the sand flathead population in over 16 years and why the population declined so dramatically.

Over the longer term there is no clear historical relationship between commercial catches and annual rainfall patterns from 1914–1960 (i.e. during a period in which catches may reflect stock abundance prior to the decline in fishery effort in the early 1960s) (Figure 52). Commercial catches fell approximately 5 years after the WWII drought (1937–1945) and approximately 10 years after the period of drought from 1906–1915 and at the end of the 1920s; however, it is impossible to know whether these patterns actually reflect changes in stock abundance. In all cases there was a clear lag between the period of drought and the down-turn in the commercial catch. In contrast sand flathead stocks in PPB declined during the most recent drought between 2000 and 2009 and appear to have begun to recover following the end of the drought in 2009. The most recent drought was, however, the most severe drought on record and hence there is little historical precedence on which to assess the current decline or judge the prospects for recovery.

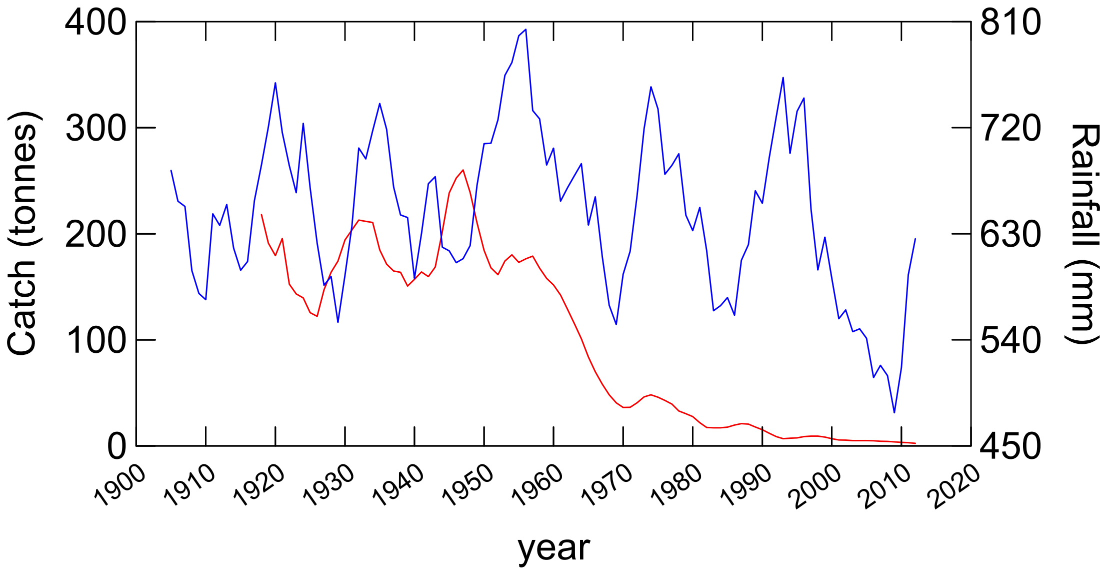

Figure 52 Five year moving average trends for commercial catch in PPB (–) and annual rainfall (–) from 1905–2012.

Following the end of the drought in 2009, sand flathead stocks stabilised in 2010–2011, and CPUE rates increased from 2010 to 2012 for both the recreational and commercial fisheries. Moreover in 2013, sand flathead recorded the highest recruitment pulse in 16 years (i.e. comparable to 1997). Evidence of recovery following the end of the drought also supports the conclusion that the drought (through its impact on river flows) was primarily responsible for declining recruitment and stock biomass.

Population cycles for other fisheries in PPB also appear to be linked to a range of climatic related environmental factors (Hirst and Hamer 2013). For example, commercial catches of King George whiting and snapper in PPB display decadal cycles that reflect periods of strong and weak recruitment (Jenkins 2005, Kemp et al. 2012). Snapper recruitment dynamics in PPB are linked to larval survival which, similar to sand flathead, appears related to river flows (Jenkins 2010). Recent excellent conditions for the snapper fishery in PPB come on the back of high recruitment in 1998, 2001 and 2004 that corresponded with intermediate river flows into PPB, but were preceded by a period of prolonged weak recruitment during the 1980s and 1990s that was associated with lower commercial catches (Kemp et al. 2012). Commercial catches of King George whiting are correlated with the strength of Zonal Westerly Winds that are believed to influence larval transport across Bass Strait and into PPB, and/or planktonic productivity in coastal waters, and in turn recruitment success (Jenkins 2005).

The introduction and subsequent expansion of the exotic seastar *Asterias amurensis* has been broadly implicated in the decline of sand flathead stocks in PPB (Winstanley 2008). *Asterias amurensis* was introduced into Port Phillip Bay in 1995, and by 2000, its population biomass was estimated to have reached 2800 tonnes (Parry et al. 2004). In March 2000 *A. amurensis* biomass was estimated to be equivalent to 56% of the total fish biomass in depths >22 m in PPB (Hirst unpub.). As sand flathead stocks began to decline shortly after this point it was obvious to consider an association between the two events. A shift in the diet of sand flathead (away from invertebrates to one dominated by fish) was detected after 2000 for fish collected from deeper habitats, although there was no evidence that this change in diet affected the growth of sand flathead. Non age-specific growth rates remained similar to, or higher than, the long-term average during this period. The results of the dietary analysis indicate that *A. amurensis* may have affected the structure of benthic communities in deeper parts of PPB and hence the availability of prey; and this may have led to sand flathead consuming a greater proportion of fish in their diets. However, for this change to have had any impact on the mortality of sand flathead over this period we would expect to see a substantial reduction in the growth over this period. There is no evidence this occurred.

The other line of evidence that suggest that *A. amurensis* had a limited impact on sand flathead stocks in PPB is the slope and spatial extent of the decline. Sand flathead stocks declined gradually from 2000 to 2010, consistent with the gradual loss and non-replacement of ageing cohorts. Moreover, this trend was relatively uniform across all depths sampled (7, 12, 17 and 22 m). If *A. amurensis* had a detectable impact on sand flathead stocks in PPB, we would have expected to see a sharp reduction in sand flathead abundance after *A. amurensis* biomass peaked in 2000, and that this change would be largely restricted to deeper habitats in PPB where the seastars were most abundant (Hirst unpub.)

Prospects for recovery

Sand flathead stocks stabilised in 2010/11, in the wake of the drought from 1997–2009, and began to recover slowly in subsequent years. All three independent measures of stock biomass in PPB steadied in 2010 and increased from 2011 onwards. CPUE in the commercial long line fishery had increased from 1.4 kg/1000 hook lifts in 2009/10 to 3.2 kg/1000 hook lifts in 2012/13. However, the commercial CPUE in 2012/13 was still 70% lower than the 1990s and 50% lower than the 1980s. Encouragingly, recruitment in 2013 was also the highest recorded in 16 years. This raises two questions: 1) what are the prospects for a full recovery for this fishery, and 2) what is most appropriate baseline by which we can assess recovery for this stock?

We will address the second question initially, before considering the first. What is an appropriate baseline for this stock in PPB? All estimates of the magnitude of the decline presented in this report have been calculated by comparing 2010 levels against 1990s levels. However, this research suggests that the abundance of sand flathead stocks in the 1990s may have been unusually high. Recruitment variation prior to 1988 was estimated from sand flathead age structure using catch-curve residuals methods. This time-series indicated that the period of high recruitment in the late 1980s/early 1990s was preceded by relatively modest recruitment dating back to the early 1970s. The high recruitment pulses in the late 1980s/early 1990s therefore appear to be among the highest in the past 40 years for this species in PPB and bolstered the population heavily in the 1990s. This influx of large numbers of new recruits into the population during this period resulted in a significant spike in the commercial CPUE from 1994/95 and substantial reduction in growth rates from 1992–1996. The latter tentatively linked to increased competition between sand flathead individuals during this period. This information indicates that a baseline based on 1990s stock levels may not be an entirely realistic target for recovery.

The choice of an appropriate baseline is also likely to be limited by what tools are available to monitor the ongoing recovery of this stock. In the absence of the PPB trawl survey (1990–2011) ongoing monitoring will be heavily reliant upon CPUE data from the recreational and commercial fisheries. Despite the fact that the fishery is almost exclusively recreational, commercial CPUE will remain an important indicator for this fishery because it is based on a long and continuous time series dating back to 1978. It would seem realistic in the short-to-medium term to aim for, at a minimum, a commercial CPUE of 5.9 kg /1000 lifts for sand flathead. This is the mean CPUE for the commercial long line snapper fishery from 1978/79 to 1993/94 (prior to the spike in CPUE in the mid-1990s). There is no equivalent recreational CPUE data for the same period; however, the recreational CPUE for this period can be estimated from the relationship between commercial and recreational CPUEs which closely track one another (linear regression, $F_{1,12}$ =93.4, $P<0.001$, R^2=0.88). Using this relationship we calculated that a commercial CPUE of 5.9 kg/1000 lifts was comparable to a recreational CPUE of approximately 0.95 fish/angler hour. The most recent commercial and recreational CPUE (3.2 kg/1000 lifts and 0.52 fish/hour, respectively in 2012/13) are currently 50% lower than this mark.

The recovery of sand flathead stocks in Port Phillip Bay will be highly dependent on improving recruitment. However, in the short-term fishery CPUEs may not be the most sensitive tool for monitory this. Although, sand flathead recorded its highest recruitment in 16 years in 2013, this event was still 60% lower than recruitment levels recorded in the late 1980s/early 1990s, and it will take 5–6 years before many of these fish are of sufficient size to be caught legally (see Figure 18). Consequently, there is likely to be a lag between recruitment and significant changes to CPUE. For example, the large spike in commercial CPUE in 1994/95 came 6 years after the largest recruitment event recorded in the lasts 25 years in 1988/89 and was sustained by other large recruitment events in 1989/90 and 1992/93. It is for this reason that we would recommend continued monitoring of sand flathead recruitment in the short-term. It is likely that recovery of sand flathead stocks in PPB will depend upon sustained recruitment of the level recorded in 2012/13, or a couple of large recruitment events of a similar magnitude to those recorded in the early 1990s.

In summary, we recommend:

- A baseline target of 5.9 kg/1000 lifts for the commercial CPUE and 0.95 fish/angler hour for the recreational CPUE (based on the creel surveys) to assess recovery in PPB, and
- Continued monitoring of sand flathead recruitment in PPB via the snapper pre-recruit survey.

What are the prospects for recovery in the short-to-medium term and the future of the fishery in the longer-term? Over the past three years, sand flathead stocks have transitioned from steady decline to slow recovery. The drought is over and the future outlook for Victoria's climate in the short-term is for average rainfall (i.e. IOD and ENSO climate indicators are neutral with a slight chance of El Nino developing, Predictive Ocean Atmosphere Model for Australia (Bureau of Meteorology). This should lead to enhanced river flows, particularly in spring, and if the relationship between river flows and recruitment holds, overall better recruitment. For the first time in a decade the signs are positive for this fishery, but it is unclear how long it might take for stocks to fully recover.

In a review of 230 depleted fishery stocks worldwide Hutchings (2000) and Hutchings and Reynolds (2004) found little evidence of rapid recovery up to 15 years after a collapse. Hence they concluded that although the effects of overfishing can be reversed, the time required for recovery may be considerable. They attributed this to a range of factors that are known to be influenced by high exploitation such as degradation of habitats, changes to species assemblages, genetic responses to exploitation and declining population growth due to an irreversible reduction in spawning biomass. However, there is little evidence that the decline of sand flathead stocks in PPB was related to overfishing (high exploitation) and appears principally related to environmental factors. Such a gloomy prognoses may therefore not apply in this case.

Other fisheries in PPB display decadal cycles that reflect periods of strong and weak recruitment. Over the past 100 years King George whiting commercial catches have fluctuated on a 10–15 year cycle (Jenkins 2005). Hence the distance from trough to peak in commercial catches may be as little as 5 years for a fishery like King George whiting. The likely recovery time for sand flathead stocks in PPB is difficult to estimate because the decline in sand flathead stocks is unprecedented. However, the significant spike in the commercial fishery CPUE in 1994/95 five years after the large recruitment pulses of the late 1980s (see Figure 12); indicate that given similarly strong recruitment the sand flathead population could recover to pre-2000 levels in as a little 5-6 years. There has not been a recruitment event of this size in over 20 years.

These two fisheries also differ from sand flathead in that they are entirely, or at least partially, dependent on the arrival of new recruits or spawning adults from outside PPB. King George whiting recruitment is dependent on the influx and subsequent survival of larvae from Bass Strait and there is no spawning adult population within PPB. Snapper recruitment is at least partially dependent on arrival of spawning adults over the warmer months from Bass Strait, in addition to the presence of suitable conditions for the growth and survival of larvae. Consequently, recruitment in either fishery is not strongly dependent on stock biomass within PPB.

The best statistical model describing the relationship between sand flathead recruitment and environmental variables in PPB included both Yarra River flows and stock biomass. This suggests that sand flathead recruitment may be currently limited by low spawning biomass. However, this relationship should be interpreted cautiously because the relationship between recruitment and stock biomass is not independent. Whilst recruitment may be related to stock biomass levels, recruitment is also clearly a significant driver of stock population levels. The impact that current fishing practices may have on abundance of legal size females is also likely to be of concern when considering this possibility. Myers and Barrowman (1996) found a strong limiting relationship between recruitment and spawner abundance amongst 364 spawner-recruitment time series. Hence concerns about the limiting effect of low spawner biomass should not be discounted.

This effect is also likely to be further exacerbated if the sand flathead population in PPB is relatively isolated from external sources of recruitment (e.g. Bass Strait). This is because the fishery would be entirely reliant upon recruitment originating from within PPB. It is currently unknown how much connection there is between sand flathead stocks in PPB and Bass Strait, although it is believed that adults are relatively immobile (Brown 1977). Most of the evidence for this belief comes from studies of the heavy metal content of sand flathead tissues which display strong regional patterns within PPB - suggesting adults do not move very far over their lifespans (Walker 1982). However, little is known regarding the movement of larvae. Specifically, it is unknown whether sand flathead stocks in PPB benefit from an influx of larvae into PPB from Bass Strait (which may assist in the recovery of depleted stocks). This aspect will be covered in a later report that examines the level of connectivity between PPB and Bass Strait populations of sand flathead using two complementary techniques: otolith microchemistry and DNA (genetic) analysis

Whilst the short-to-medium term outlook may be reasonably positive, the longer-term outlook for this fishery is not. This is because south-eastern Australia’s future climate is expected to become drier on average as consequence of anthropogenic global warming (IPCC AR5 2013). Projected decreases in rainfall coupled with increased temperature and evaporation rates are expected to reduce run-off across south-eastern Australia by between 20–36% by 2060 (Hirst and Hamer 2013). Increasing intensification of the ENSO (El Nino events) in the western Pacific is also expected to result in higher incidence of drought in eastern Australia (Power et al. 2013, Santoso et al. 2013). If the relationship between river flows and recruitment holds for sand flathead in PPB, then a drier climate is likely to herald less optimal conditions for sand flathead recruitment over the longer-term.

Adequacy of current management settings

Are the current management settings sufficient to allow sand flathead stocks to recover naturally? Given there is evidence of recovery for this population we would advocate a monitor and review approach in the short term prior to making changes to current management settings. This review would be based on assessment of:

- commercial and recreational CPUE indicators for sand flathead during 2013/14 and 2014/15
- sand flathead recruitment in 2013/14 and 2014/15 measured using the pre-recruit survey

The current and target (baseline) indicator levels are shown in Table 21. In the case of the CPUE indicators we would aim to see an improvement on current levels before concluding that recovery is proceeding naturally. There is no recommended baseline level for sand flathead recruitment, however, for the stock to continue to recover the review would need to observe continuing recruitment at 2012/13 levels or higher over the next two years.

Table 21 Sand flathead assessment targets indicating current level and baseline level for CPUE estimates of abundance and recruitment

Indicator	Current (2012/13)	recommended baseline
commercial CPUE (long-line fishery)	3.2 kg/1000 lifts	5.9 kg/1000 lifts
recreational CPUE (Creel survey)	0.52 fish/hour	0.95 fish/hour
Recruitment (no. <15 cm fish)	4.0 fish / 1000 m^2	

If a change to management settings for this species in PPB is deemed to be necessary then options are limited. However, any changes adopted would need to be directed at the recreational fishery in PPB because this is where >95% of the catch occurs. The management options available include changes to minimum size limits and/or bag limits. The current minimum legal size limit for sand flathead recreational fishery in Victorian coastal waters is 27 cm. The current bag limit for sand flathead is 20 legal sized fish.

Size limits

As discussed earlier, the current size limits for the sand flathead in PPB potentially pose a problem for female catches. This is because larger females appear likely to be caught and retained at twice the rate of males. This may have unknown impacts on the spawning biomass of the sand flathead population in PPB, particularly following the decline of the population between 2000 and 2010.

Under the current size limits we estimated that there are approximately 2.1 females for every male fish of legal size in PPB. However, by reducing the size limit from 27 to 24 cm we found that we could lower the sex ratio from approximately 2.1 at 27 cm to 1.1 at 24 cm. In theory this would allow fishers to catch equal numbers of males and females, assuming the same selectivity for each sex.

In practice, however, there are a number of problems with changing the size limit to reduce the skewed female catch. First, it assumes that there is no selectivity in terms of the size, or sex, of the fish caught (and the hook size used) and/or retained. Anglers prefer larger fish that yield larger, more manageable, fillets for consumption. Larger fish yield proportionately larger fillets, because there is an exponential relationship between the length and weight of fish (see Figure 7). Consequently, a 25 cm fish will be half the weight of a 30 cm fish and yield half as much fillet. Second, as the size limits apply to all flathead species (except Dusky flathead) this may adversely affect opportunities in other flathead fisheries, particularly Yank flathead. Third, changing the size limit may potentially affect the CPUE statistic, which we recommend using to monitor the recovery of this stock, by increasing the proportion of fish that can be legitimately retained. This may lead to difficulties in interpreting the CPUE trend following the change to size limits.

Bag limits

Changes to bag limits for flathead are likely to be the only tool available for further regulating sand flathead catches in PPB. Bag limits are output controls that seek to limit total catch by placing a ceiling on the catches of individual anglers. Fisheries managers can potentially reduce the total recreational catch for a fishery by lowering bag limits. However, the extent to which reductions in bag limits may work will depend on how effectively bag limits are currently utilised by anglers.

The majority of angler trips (85–90%) surveyed from 2009–2013 comprised bag sizes ≤ 5 flathead. Hence changes to maximum bag limits will have only modest impacts on the total sand flathead catch in Port Phillip Bay. Lowering the maximum bag limit to 15, 10 and 5 fish is projected to reduce the total catch by 0.7%, 4.2% and 16.3%, respectively (Table 22). The exploitation rate in Port Phillip Bay was estimated at 13–27% of the stock biomass in 2006/07, hence a 4.2% and 16.3% cut to the recreational catch will result in a 0.5–1.1% and 2.1–4.4% reduction in the exploitation rate (Table 22). It is unclear how effective such cuts would be, but it is anticipated that a reduction in total catch in excess of 10% is likely to be required to have any meaningful impact on the recovery of this stock in Port Phillip Bay. Assuming natural population increase (largely recruitment), growth and mortality remain constant, a 16% reduction in recreational catch, achieved by implementing a bag-limit of 5 fish, would achieve an increase in stock biomass, relative to no change, of between 2.1–4.4%. Over the course of a decade such changes may be quite effective in assisting the recovery of this stock.

Table 22 Reductions in total recreational catch and exploitation rate (2006/07) for Port Phillip Bay sand flathead fishery achieved by adopting 15, 10 and 5 bag limit scenarios

Bag size	% reduction in catch	% reduction in exploitation rate
20	0.0	0
15	0.7	negligible
10	4.2	0.5 - 1.1
5	16.3	2.1 - 4.4

Substantial changes to bag limit regulations for flathead in Victorian coastal waters will also have an impact on other flathead species targeted by recreational anglers, and in other parts of Victoria, because it is managed singly as a multi-species fishery. The impact of imposing greater bag limit restrictions on yank flathead in Port Phillip Bay and the flathead fishery in Western Port are considered in more detail in Hirst and Conron (2014). Reductions in bag size limits are unlikely to have a major impact on the yank flathead fishery in Port Phillip Bay, and the flathead fishery in Western Port, as most bags for these fisheries contained ≤ 3 fish (98% and 88% of angler trips, respectively) (Hirst and Conron 2014).

Changes to the current bag limit regulations for flathead may also contribute to reductions in total catch for sand flathead by encouraging anglers to retain yank, in preference to, sand flathead. This is because revised bag limits for flathead in Port Phillip Bay may result in anglers retaining, generally larger yank flathead. This may contribute to an overall reduction in the sand flathead catch, whilst allowing anglers to continue to bag preferred yank flathead at similar rates for the period 2009–2013.

Regardless of the future management settings adopted, sustainable recreational fishing practices should be promoted within this fishery. This should include encouraging the use of circle hooks over conventional hooks. This practice has been demonstrated to increase the survival of discarded sand flathead (Lyle et al. 2007). Anatomical (deep) hooking is major source of mortality in discarded sand flathead. Lyle et al. (2007) found that 100% of fish hooked in the lip or mouth survived, compared to only 64% of fish that were 'deep' hooked in the throat or gut and that such hooking was typically associated with conventional hooks. Overall, survival rates for line-caught sand flathead were high. Over 99% of fish caught using circle hooks survived compared to 94–97% of fish caught with conventional hooks.

Conclusions

All three independent measures of sand flathead abundance: the PPB trawl, commercial long-line fishery CPUE and recreational CPUE; corroborate the strength of the decline for this fishery in PPB. Stock biomass in PPB declined by between 82–87% from 2000 to 2010.

There is little evidence that sand flathead has declined to a similar extent in other parts of its geographic range (southern Australia and Tasmania). Recreational CPUE rates for sand flathead in Western Port (Victoria) and commercial and recreational catches in SE Tasmania have remained relatively stable over the period in which sand flathead declined in PPB. Hence, the decline appears largely confined to the sand flathead population within PPB.

The evidence considered in this report indicates that sand flathead stocks declined principally in response to declining recruitment associated with lower river flows into PPB during the drought from 1997–2009. There was less evidence that the decline in sand flathead stocks was related to impacts on adult fish such as overfishing, adverse competition with the introduced starfish *Asterias amurensis*, or other environmental impacts on growth and survival.

Sand flathead stocks stabilised in 2010/11, in the wake of the drought from 1997–2009, and displayed evidence of modest recovery in the commercial and recreational CPUE rates from 2010/11 to 2012/13. However, the commercial CPUE rate in 2012/13 was still 70% lower than levels in the 1990s and 50% lower than the 1980s. Stock biomass estimates generated by the annual PPB trawl were not available from 2012 onwards as the program was discontinued in 2011.

The choice of an appropriate baseline with which to assess the recovery of this stock will be limited by the tools available. In the absence of the PPB trawl survey, ongoing monitoring will be heavily reliant upon CPUE data from the commercial and recreational fisheries. We recommend a **baseline of 5.9 kg/1000 lifts** for the commercial CPUE and **0.95 fish/angler hour** for the recreational CPUE (based on the creel surveys). This is the mean CPUE for the commercial long line snapper fishery from 1978/79 to 1993/94 (i.e. prior to the spike in CPUE in the mid-1990s), and an equivalent recreational CPUE calculated for the same period.

Ultimately, the recovery of sand flathead stocks in PPB will be highly dependent on improved recruitment. However in the short-term, fishery CPUEs may not be the most sensitive tool to monitor this. This is because it take 5–6 years before newly recruited fish are of sufficient size to be caught legally (and included in CPUE statistics). It is for this reason that we would recommend continued annual monitoring of sand flathead recruitment in the short-term via the snapper pre-recruit survey.

Following the end of the drought in 2009 the prospects for recovery in the short-to-medium term for this fishery appear more positive, although it is unclear how long it will take to recover to baseline levels. However, the longer-term outlook for this fishery is less positive. This is because south-eastern Australia's future climate is expected to become drier on average as consequence of anthropogenic global warming. Projected decreases in rainfall coupled with increased temperature and evaporation rates are expected to reduce run-off across south-eastern Australia by between 20–36% by 2060. If the relationship between river flows and recruitment holds for sand flathead in PPB, then a drier climate is likely to represent less optimal conditions for sand flathead recruitment over the longer-term and overall lower stock biomass.

Despite the decline, sand flathead remain one of the most frequently caught and retained recreational fish species in the bay. As the stock is beginning to recover we propose a monitor and review approach in the short term, but consider what changes to management settings may assist future recovery. Alterations to management settings are only likely to be successful if they target the recreational sector of the fishery in PPB (which comprises >95% of the current total catch for this fishery). Changes to bag limits for flathead are likely to be the only tool available for further regulating sand flathead catches in PPB and a range of scenarios are presented within this report.

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Integral to this report is the catch, age and dietary information collected by the Port Phillip Bay annual demersal trawl program operated by Fisheries Research from 1990 to 2011. This program was supervised by Greg Parry, for much of this time, with considerable assistance from many staff at DPI Queenscliff and the crews of RV *Sarda*, FV *Castella Rosa* and FV *Western Alliance*. Greg Parry also produced the review of net efficiency estimates used in this report.

Annual and daily ageing of sand flathead otoliths was performed by Kyne Krusic-Golub and Andrew Brown (Fish Ageing Services), Queenscliff. Kyne also undertook cross-validation of Victorian and Tasmania otoliths used in this report, and assisted with the generation of the growth increment chronology. Previous ageing was undertaken by Matt Koopman.

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