Feasibility of stocking to enhance flathead fisheries

Recreational Fishing Grants Program
Research Report

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VICTORIA State Government

Feasibility of stocking to enhance flathead fisheries

January 2019

Recreational Fishing Grants Program Research Report

Published by the Victorian Government, Victorian Fisheries Authority (VFA),
January 2019

Authorised by the Victorian Government, 1 Spring Street, Melbourne.

Preferred way to cite this publication:
Ingram, B.A. (2019) Feasibility of stocking to enhance flathead fisheries. Recreation Fishing Grants Program Research Report.

ISBN 978-1-76090-063-2 (print)
ISBN 978-1-76090-064-9 (pdf/online/MS word)

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Executive summary

Several species of flathead are very important and highly popular species targeted by recreational anglers fishing bays and inlets across Victoria. Stocks of some species, however, have declined significantly in recent decades which has become a key issue for both The Victorian Fisheries Authority (VFA) and stakeholders.

Stocking hatchery-bred fish occurs globally in freshwater, estuarine and marine environments to replenish, maintain or enhance populations. Stocking is used by fisheries managers to restore depleted populations of recreationally and commercially significant fish species, and may be a potential management option to ameliorate impacts of prolonged recruitment failure in some flathead stocks.

The objective of this study was to determine the feasibility of establishing a program for stocking hatchery-bred flathead fingerlings to recover and enhance flathead stocks in selected estuaries, bays and coastal lagoons of Victoria. The study aimed to identify the need, constraints and opportunities for stocking flathead into Victorian waters, review available information on techniques and resources required to breed flathead in captivity and review previous flathead stocking programs.

Previous studies have indicated there is interest from stakeholders in stocking flathead into selected water to recover stocks and enhance fisheries, particularly dusky flathead on the east coast and sand flathead to the west. There is a considerable amount of information on the biology and ecology of flathead that will assist in developing captive breeding techniques for target species, such as size at maturity, spawning season and habitat, fecundity and larval growth. Techniques for hatchery production of dusky flathead fingerlings have already been developed. Hatchery facilities for production of flathead require access to good quality filtered seawater, tanks for holding broodstock, eggs and larvae, large ponds for growth of fry, and facilities for culturing food species (rotifers and brine shrimp). These techniques may be adapted for breeding other flathead species.

There have been concerns about the status of some stocks of flathead in Victoria. Sand flathead in PPB have exhibited sustained limited recruitment over the last 20 years. There is some uncertainty regarding declining catch rates of some dusky flathead fisheries on the east coast.

Stocking is one option for managing fish stocks, particularly where recruitment is limited. Stocking programs release juveniles produced in captivity (hatcheries) on a regular basis to conserve, restore or enhance fisheries. This approach can have a range of benefits including the recovery threatened species and stocks that have been depleted and increase yields in fisheries that are below the carry capacity of the environment. Stocking programs also require access to sufficient numbers of juveniles of appropriate species and stock (genetic structure) that will survive and growth after release and remain in the area to enter the fishery. Several estuaries, inlets, bays and coastal lagoons in Victoria that may be considered for stocking with flathead were identified in this report.

However, not all stocking programs are successful. While some have increased yields and generated economic and social benefits, others have either failed to live up to expectations, or their effectiveness have not, or could not be, assessed. For example, there has only been one flathead stocking trial program in Australia. During a 3-year project conducted between 1996 and 1997; 100,000 juvenile dusky flathead were released in the Maroochy River, QLD, as a pilot project and partly to recover stocks following a fish kill. Although stocked dusky flathead first appeared in fishery independent surveys five months after release, representing, and were detected in both recreational and commercial fisheries, assessments failed to detect a significant change in the size of the population and an economic assessment was unfavourable. Consequently, a responsible approach to stocking, with well-defined management objectives and rationale for stocking, and plans for their monitoring and evaluation, is promoted by fisheries scientists and managers.

Flathead species are considered as potential candidates for stocking Victorian estuaries because:

- They are a highly popular recreational angling species.
- Some stocks may need supplementation to overcome periods when recruitment is limited.
- They are relatively sedentary and so are less likely to move away from the area stocked.
- They can be bred in captivity.

This report has indicated that it is feasible to produce juvenile flathead for stocking and that there are a number of waters that may be considered for enhancing with hatchery-bred fish. For stocking to occur there is a need to:

1. Determine the need and objectives, which should consider cost, angler demand, expected returns & environmental suitability. This should involve stakeholders in the planning process, and assess the potential contribution of releases as well as alternative options for achieving the goals of fisheries management objectives for the fishery.

2. Identify estuaries requiring enhancement by stocking, such as where there is sustained limited recruitment. This will require knowledge of the abundance and level of recruitment of stocks within these estuaries.
3. Estimate carrying capacity (productivity) of the environment to determine the level of stocking needed for recovery within the carrying capacity of the water.
4. Determine genetic structure of Victorian flathead stocks to ensure genetic integrity of stocks being supplemented with hatchery stocks are maintained.
5. Support the establishment of flathead hatchery production. Currently no hatcheries in Australia are breeding flathead. Although there appears to be no capacity to breed flathead in existing hatcheries in Victoria, both government and at least one private hatchery interstate may be capable of this.
6. Design and implement a stocking program, incorporating monitoring and evaluation plans to determine the value and contribution of stocking to receiving fisheries, and whether management objectives were met.

Sand flathead is a popular angling species in Port Phillip Bay (Photo: Simon Conron).

Introduction

Several species of flathead are very important and highly popular species targeted by recreational anglers fishing bays and inlets across Victoria. Stocks of some species, however, have declined significantly in recent decades which has become a key issue for both The Victorian Fisheries Authority (VFA) and stakeholders. For example, both the commercial and recreational catch of sand flathead (*Platycephalus bassensis*) in Port Phillip Bay (PPB) have declined substantially, and anglers claim the average size has also decreased. Reasons for this decline are unclear, though poor juvenile recruitment has been implicated (Hirst *et al.* 2014), and the likelihood of recovery in the future is uncertain. . However, a recent fishery assessment suggests that stock declines have stabilised and may being showing signs of increase in recent years (VFA, unpublished data). There is some uncertainty regarding declining stocks of dusky flathead (*P. fuscus*). Catch rate information suggests that the abundance of dusky flathead in three major east Gippsland fisheries (Mallacoota Inlet, Lake Tyers and Gippsland Lakes) has been declining since the mid-late- 2002s, although in recent years catch rates appear to be stabilising (Conron and Hamer 2018).

Stocking hatchery-bred fish occurs globally in freshwater, estuarine and marine environments to replenish, maintain or enhance populations. Stocking is used by fisheries managers to restore depleted populations of recreationally and commercially significant fish species, and may be a potential management option to ameliorate impacts of prolonged recruitment failure, such as experienced by sand flathead in PPB.

Stocking typically involves the release of large numbers of early-lifestage animals (fingerlings) that are mass-produced in hatcheries. Captive breeding techniques have been developed for dusky flathead, and stocking trials conducted in southern Queensland in the late 1990's suggested contributions to the commercial catch was up to 28%. Despite this, currently there is no on-going stocking programs for flathead. This study will review information on techniques and resources required to breed flathead in captivity.

The objective of this study was to determine the feasibility of establishing a program for stocking hatchery-bred flathead fingerlings to recover and enhance flathead stocks in selected estuaries, bays and coastal lagoons of Victoria.

More specifically the project aimed to:

a) Identify the need, constraints and opportunities for stocking flathead into Victorian waters

b) Review available information (nationally & internationally) on techniques and resources (hatchery facilities) required to breed flathead in captivity

c) Review previous flathead stocking programs

d) Subject to the above, develop and cost a staged project plan for implementation of a flathead stocking program.

Target species of this study will be sand flathead, dusky flathead and to a lesser extent rock flathead (*P. laevigatus*). While sand flathead and dusky flathead are targeted by recreational anglers, the take of rock flathead is relatively minor, but increasing.

As a feasibility study, the project reviewed current information on sand flathead, dusky flathead and rock flathead stocks, and determined the feasibility of using stocking to support their recovery and enhancement. This review also considered results from a previous flathead stocking program conducted in Queensland.

The project synthesised current information required to breed flathead in captivity, which was used to identify resources (e.g. hatchery facilities/infrastructure, broodstock sources, expertise, costs) needed to establish a breeding program.

Information reviewed during this project will include published material, existing fishery databases, interviews with experts in relevant fields, and visits to selected finfish hatcheries.

Stock enhancement

"Stock enhancement" is a broad term used to describe many forms of fish stocking that are intended to facilitate an increase in the size of the stocks, irrespective of purpose. Stocking, which typically uses large numbers of hatchery-produced juveniles, occurs in freshwater, estuarine and marine environments worldwide (Cowx 1994, Cowx 1998a, Welcomme and Bartley 1998, De Silva and Funge-Smith 2005, Bell *et al.* 2006, Bartley 2007, Bell *et al.* 2008, Ingram and De Silva 2015, Lorenzen *et al.* 2016, Hunt and Jones 2017).

Stocking is a fisheries management tool that has numerous purposes including augmentation and enhancement, creation of new fisheries, conservation, mitigation community change and environmental change (Table 1). Stocking hatchery-produced fish is seen as a means of meeting the demands for fish for both sport (recreational angling) and food, and stocking programs are playing an important role in the conservation and recovery of threatened species. Stocking is used by fisheries managers to restore depleted populations of recreationally and commercially significant fish species, and may be a potential management option to ameliorate impacts of prolonged recruitment failure, such as experienced by sand flathead in PPB (Hamer *et al.* 2010, Hirst *et al.* 2014).

Table 1. Stocking purposes, rationale and assumptions

Stocking purpose	Rationale	Key assumptions	Examples
Augmentation and enhancement	Improve production over natural condition	Stocking carried out to supplement an existing fishery where habitat is below carrying capacity or fishery recruitment is limited.	Stocking to enhance recreational and sport fishing opportunities
Create new fisheries	Fill a vacant niche	Species performance in new environment acceptable, the environment can support stocking and is below carrying capacity. The resource base will not change substantially.	Creating fisheries in newly created artificial reservoirs, or waters where there is no fishery, or where new species are introduced into existing fisheries.
Conservation	Recover threatened species/populations	Stocking within historical range of species. The environment can support stocking and is below carrying capacity.	Re-establishing populations in areas where threatened species have become extinct.
Mitigation	Counter disturbance to the environment	Disturbance event has passed. The environment can support stocking and is below carrying capacity.	Recovery of stocks/fisheries affected by flood, drought or fire events.
Community change	Improve production over natural condition	Species performance in new environment acceptable, habitat is below carrying capacity and resource base will not change substantially.	Replenishing stocks in culture-based fisheries.
Environmental change	Control environmental conditions and aquatic pests	Species stocked will achieve desired outcome.	Examples. Biomanipulation. Control algal blooms in eutrophic ecosystems by enhancing herbivores through a reduction of planktivorous fish and introduction of piscivorous fish. Stocking of selected fish species to control of mosquito larvae.

Marine stock enhancement

Marine stock enhancement, including stocking into estuaries and coastal lagoons, is widely practiced globally (e.g Bell *et al.* 2008, see also http://www.searanching.org), but not so much in Australian waters (Taylor *et al.* 2005, Taylor 2006). In developed countries there is a strong demand from stocking marine environments from the recreational fishing sector (Loneragan 2015), and not surprising this demand is growing in Victoria (Futurefish Foundation 2009, Taylor 2010).

Stock enhancement in Victoria

Stocking of fish to establish and enhance recreational fisheries, and to support conservation efforts, has been long practiced for freshwater fish in Victoria (Wharton 1969, Ingram *et al.* 1990, Cadwallader *et al.* 1992, Gooley 1992, Ingram 2013). Stockings have focused predominantly on salmonids (mainly brown trout, rainbow trout and Chinook salmon) since the 1800s and native species (mainly golden perch, Murray cod, trout cod and Macquarie perch) since the 1980s. Salmonid stockings have been undertaken to enhance recreational fisheries while native fish stocking to enhance recreational fisheries and support conservations efforts for threatened species.

More recently, however, stockings on coastal, estuarine and marine species have occurred (Appendix I). "The State Government has committed to implementing a marine species stocking program as part of its Target One Million commitment to get more people fishing, more often" (https://vfa.vic.gov.au/recreational-fishing/target-one-million/marine-stocking). The Target One Million Program was launched in 2015 (https://vfa.vic.gov.au/recreational-fishing/target-one-million/budget).

Australian bass stockings have occurred since 1996. During the late 1990s and early 2000s fish were produced at a small commercial hatchery on Phillip Island with the assistance of the Fisheries Department (Mosig 2002), and Native fish Australia. From 2010, Australian bass fingerlings for stocking have come from commercial intestate hatchery using broodstock from Victoria, as have estuary perch since 2012 waters (https://vfa.vic.gov.au/recreational-fishing/fish-stocking/inland-estuary-perch-fisheries) (Gordon 2013). During early 2000s the VFAs Queenscliff facility produced black bream juveniles for research purposes. In 2004, the then Fisheries Victoria stocked 20,000 juvenile black bream into the Gippsland Lakes in response to declining recruitment (Morison 2006). In 2013, 1.3 million eastern king prawn larvae were stocked into Lake Tyers to improve recreational fishing opportunities (https://vfa.vic.gov.au/recreational-fishing/fish-stocking/eastern-king-prawn-stocking-in-lake-tyers). Trail stockings of juvenile mulloway occurred in 2015/16 (https://vfa.vic.gov.au/recreational-fishing/target-one-million/marine-stocking).

A number of reviews have been undertaken to explore marine stocking enhancement in Victoria (Futurefish Foundation 2009, Taylor 2010). Recreational anglers on the east coast were by and large happy with most of their fisheries, and indeed expressed concerns that these may be harmed or changed by stocking (Futurefish Foundation 2009). In contrast, anglers on the west coast strongly supported stocking particularly to increase catch rates, and promote tourism and improve economic benefits to communities (Futurefish Foundation 2009).

Stocking in Victoria is undertaken in accordance with the "Fish stocking for recreational purposes" Policy (https://vfa.vic.gov.au/operational-policy/strategy-and-policy/policy-statements/fish-stocking-for-recreational-purposes). The Policy outlines the principles for stocking waters to enhance recreational fisheries and applies to stocking all Victorian waters. Although there is no specific policy for marine and estuarine stocking in Victoria, all translocations in the state, including those into marine and estuarine waters are managed in accordance with the Policy. With the exception of recurring stockings, all new stocking proposals are evaluated by a Translocation Evaluation Panel, which may request that a full impact and risk assessment be submitted for evaluation before permits to stock are granted.

Currently annual stocking plans are developed in consultation with relevant stakeholders, regarding waters to be stocked and species composition number size and timing of stocking.

Biology and current status of important Victorian flathead stocks in Victoria

Flatheads (Platycephalidae) are predominantly marine and brackish water species of the Indo-Pacific region. Flatheads are moderate-sized fish that typically have an extremely depressed head that is bony and spiny, with the eyes located on the top of the head (Figure 1). The body is elongate and cylindrical, tapering towards the tail. Although there are more than 40 species in the family in Australian waters, several species, including dusky flathead (Figure 1a), rock flathead (Figure 1b) and sand flathead (Figure 1c), are commonly targeted by commercial and recreational anglers in coastal waters of Victoria (Figure 2). A summary of key biological and fishery information for species is provided in Appendix II.

Flatheads are bottom-dwelling species that often burrow into the substrate for concealment and generally sedentary in habit. For example, dusky flathead spend much of their life in the same estuary and rarely move between estuaries (Hindell 2008, Gray and Barnes 2015). Flathead are ambush predators, feeding on fish and invertebrates, such as crabs and prawns. Dusky flathead is an important and popular species in eastern Victorian estuaries where it is targeted by recreational anglers particular, Gippsland lakes, Mallacoota Inlet and Lake Tyers (Conron and Oliveiro 2016, Ingram *et al.* 2016). Sand flathead are targeted by anglers fishing in PPB (Conron and Oliveiro 2016), whereas rock flathead are not commonly targeted by anglers, but interest is increasing (Kemp *et al.* 2014).

Size at maturity

Size at maturity of dusky flathead varies across the range, with TL at 50% maturity for females being 328 mm TL in eastern Victoria (Hicks *et al.* 2015) and 568 mm TL in NSW (Gray and Barnes 2015).

Size and age at maturity of sand flathead for both sexes varies annually and by location (Bani and Moltschaniwskyj 2008). Size at which 50% for males was 21.7 cm and all were mature at 31 cm TL, and females 50% mature at 24.7-26.3 cm and >95% mature at 28 cm (Bani and Moltschaniwskyj 2008). Age at maturity was 2.5-3.5 years for males and 2.6-5.2 for females (Bani and Moltschaniwskyj 2008). In Tasmania 50% are mature at 21- and 23 cm TL for males and females respectively (Jordan 1998).

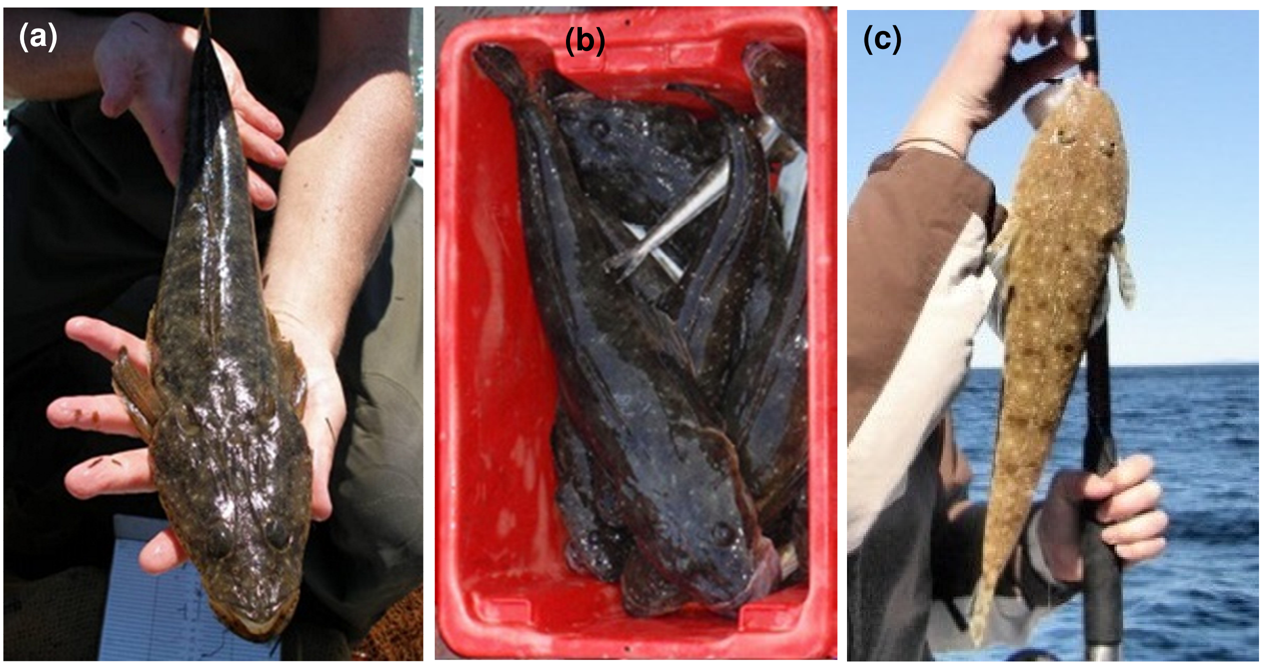

Figure 1. Some Victorian flathead species. (a) Dusky flathead. (b) Rock flathead. (c) Sand flathead.

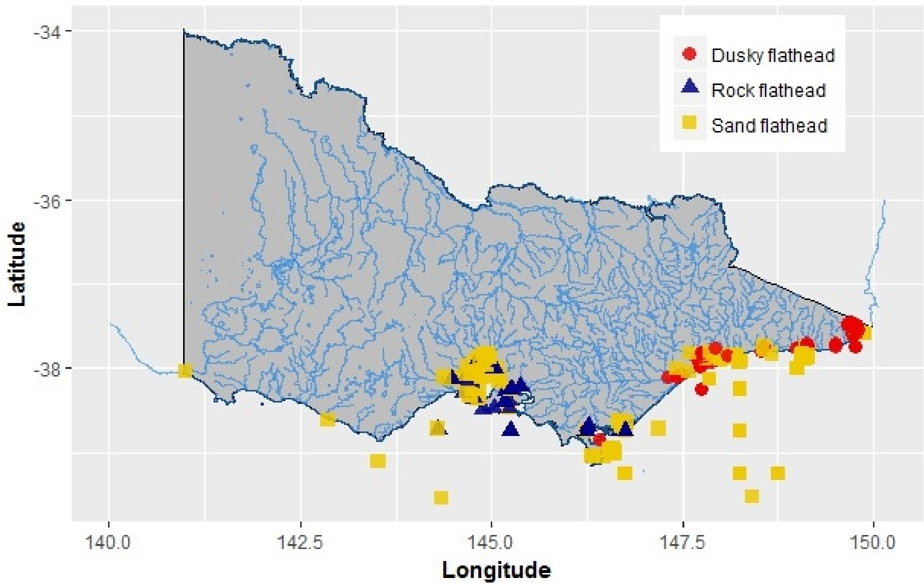

Figure 2. Distribution of dusky flathead, rock flathead and sand flathead in Victoria (Data source: Atlas of Living Australia (https://www.ala.org.au/).

Spawning and early life history

Flathead species spawn mainly in spring and summer (Table 2). Initiation and duration of the spawning season may vary between locations (spatially) (Table 2) and years (annually). Spawning in southern species of flathead, is likely to be influenced by increasing temperature and daylength. Salinity may also influence spawning success. For example, Bani and Moltschaniwskyj (2008) suggested that lower salinities (30-31 ‰) in the Tamar River (Tas.) reduced reproductive output of sand flathead.

Table 2. The spawning season of dusky flathead, rock flathead and sand flathead.

Species	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Source
Sand flathead – VIC (PPB)											Brown 1977
– NE coast Tasmania											Jordan 1998, Jordan 2001, Bani and Moltschaniwskyj 2008, Bani *et al.* 2009
– E coast Tasmania											
Rock flathead – VIC											Koopman *et al.* 2004
Dusky flathead - NSW											Gray and Barnes 2008, Gray and Barnes 2015
- VIC											Hindell 2008

Sand flathead spawn in estuaries, inlets, coastal bay and shelf waters (Jordan 2001). Sand flathead are serial spawners (as indicated by asynchronous gamete development) capable of spawning multiple batches of eggs in a season (Bani and Moltschaniwskyj 2008, Bani *et al.* 2009). Female sand flathead may spawn every 4-5.3 days with larger females spawning more frequently than smaller fish, and the peak in spawning activity occurring during the day particularly at first light (Bani *et al.* 2009). For this reason, it is difficult to estimate annual egg production from individual females as size of batches of eggs produced over the season may vary.

Dusky flathead in spawning condition are found in lower reaches of estuaries and coastal waters, but it is uncertain as to whether fish spawn in the estuary or move to coastal waters just before spawning (Gray and Barnes 2015). Dusky flathead are thought to be able to spawn multpe times within the season (Gray and Barnes 2015). It is not known if dusky flathead spawn in Lake Tyers, though the population is thought to be self-sustaining and anglers report large females are almost always gravid leading into the spawning season (Nicholson and Gunthorpe 2008). Potential annual fecundity[1] of dusky flathead in eastern Victoria 0.112 mil. eggs for smaller fish (32 cm TL) and up to 4.8 mil eggs (76.4

[1] Total number of post-vitellogenic oocytes and, in ovaries without atresia or post-ovulatory follicles.

cm TL), egg quality and mean relative fecundity[2], which does not change with body size, was 704 eggs/g body mass (Hicks *et al.* 2015). Mature oocytes of dusky flathead (i.e. post-vitellogenic stage) is >0.4 mm dia. (Hicks *et al.* 2015).

Eggs and larvae

Eggs and larvae of flathead are planktonic and are dispersed by tides and currents. At hatching larvae of dusky flathead are small, <2.6 mm, and are pelagic until settlement, which occurs around 9.9-12.8 mm in length (Neira and Miskiewicz 1998). Rock flathead initially settle (become benthic) on bare sand flats before moving into seagrass beds (Jenkins *et al.* 1993). The early growth of dusky flathead is more rapid than all other Australian platycephalid (Coulson *et al.* 2017)

Sand flathead larvae have been found throughout PPB (Hamer *et al.* 2010) from October-April, with the peak occurring in November (Jenkins 1986). In coastal waters larvae have been collected in December (Neira *et al.* 2000). The larvae settle from around 21 mm in length (Jordan 1998). Otolith aging suggests the larval stage lasts for 20-30 days (>3 cm) (Hamer *et al.* 2010). Sand flathead settle onto shallow (nearshore) unvegetated areas (Jordan 2001)

Juveniles

Juvenile dusky flathead (<12 cm) prefer intertidal mud-sand and mud flats (Butcher *et al.* 2000e).

Growth

Growth length and age parameters for Australian platycephalid species were summaries in Appendix III.

Genetic considerations

The genetic structure of Australian flathead species has not been well studied (limited studies e.g. Roberts *et al.* 2014). However, the ability of flathead to move between estuaries and along the coastline, along with dispersal of eggs and larvae in coastal currents, suggests there is mixing between populations. Although genetic studies on dusky flathead are limited, they do suggest a potentially panmictic population.

Fisheries and their status

<u>Dusky flathead</u>

During the early 2000s There was a noticeable decline in dusky flathead catches, in particular the proportion of larger fish (≥ 50 cm TL) in eastern estuaries such as Mallacoota Inlet and Lake Tyers (Conron *et al.* 2010, Conron and Oliveiro 2016). This was attributed more to increased targeting by anglers than variable spawning and recruitment success (Conron *et al.* 2010). Recreational fishing regulations were changed in 2012 to include both a lower and upper size limit. Angler diary surveys in subsequent years suggested this regulation has improved the proportion of larger dusky flathead (≥ 50 cm TL) (Conron and Oliveiro 2016). Status of recreational stocks in eastern estuaries are variable; Mallacoota Inlet – Uncertain, Sydenham Inlet – Limited data and Lake Tyers – Sustainable (Ingram *et al.* 2016). At a state level the species stock status is defined as Sustainable (McGilvray *et al.* 2016).

<u>Sand flathead</u>

Sand flathead is an important recreational and commercial species in bays, inlets and coastal waters of Victoria, and is the most important recreational angling species PPB (Hamer *et al.* 2010, Conron and Oliveiro 2016, Victorian Fisheries Authority 2017).

Fishery independent surveys conducted since 1990 have clearly shown that the abundance of sand flathead in PPB has declined, and that the rate has increased dramatically since the late 1990s with stocks declining by 80-90% between 2000 and 2010 (Hamer *et al.* 2010, Hirst *et al.* 2014), and there has been little recover since then (Hamer *et al.* 2016). This decline considered to be due to persistent poor recruitment, which may be related to environmental conditions, especially lower rainfall and river flows in November and December due to prolonged drought (Hirst *et al.* 2014). However, high or prolonged recruitment events have not occurred since the Millennium drought ended in 2010. Recent assessments of stocks have defined sand flathead stocks in Victoria as Environmentally limited (Andrews *et al.* 2016, Victorian Fisheries Authority 2017). However, the most recent assessment (2018) indicates that the sand flathead in Port Phillip Bay is classified as a recovering stock (Hamer *et al.* in preparation).

<u>Rock flathead</u>

Rock flathead are commercially harvested in Victoria from mainly Corner inlet (77% of catch) and PPB (23% of catch) (Kemp *et al.* 2014). The species is not commonly targeted by anglers, but interest is increasing (Kemp *et al.* 2014). The species stock status is defined as Sustainable (Victorian Fisheries Authority 2017).

[2] Relative fecundity: potential fecundity / ovary free body mass (g).

Hatchery production of flathead fingerlings

There is limited information on captive breeding of flathead. In Australia, dusky flathead were bred at the Bribie Island Research Centre (BIRC), Woorim, Qld (Queensland Department of Agriculture and Fisheries) over three years between 1995 and 1997 to support a stocking program (Palmer *et al.* 2000). Sand flathead have been induced to spawn in the laboratory, but no attempt was made to fertilise eggs hand-stripped from fish (Bani *et al.* 2009). Overseas, production of flathead is limited to bartail flathead (*Platycephalus indicus*). In China up to100,000 bartail flathead fry are produced annually (Hong and Zhang 2003), while in Japan, bartail flathead are produced for stock enhancement (Sugaya 2006). Despite the lack of published information, however, the general feeling amongst experts in the captive breeding of marine species consulted during this study is that can juvenile flathead can readily be produced for stocking programs.

The review of hatchery production of flathead (below) draws mainly on published information about dusky flathead breeding at the BIRC (Palmer *et al.* 2000), and conversations with Dr Paul Palmer of the Queensland Department of Agriculture and Fisheries (QDAF). A summary of resources for different life stages required for hatchery production of flathead is provided in Table 3.

Broodstock

Broodstock were sourced from the wild locally and, after a quarantine period, maintained in large fiberglass tanks. At the BIRC, 10,000L tanks with up to 25 fish (at 0.5-5 kg/fish) were used and, although flathead are known to bury in the substrate, the tanks were not provided with substrate material to facilitate monitoring of fish and tank maintenance. When disturbed, broodstock tended to exhibit a flight response and consequently would bump into the sides of the tank (P. Palmer, *pers comm.*). This could have been expected to cause some stress, but the fish did not seem overly affected. Broodstock therefore held in reduced light conditions and disturbances were kept to a minimum. Broodstock were fed chopped fish (e.g. pilchards) supplemented with vitamins, and were not weaned onto artificial diets.

Based on growth and age at maturity information (Appendix III) broodstock will need be at least 22.7 cm, 24.7 cm, and 54 cm in length for female sand flathead, rock flathead and dusky flathead, respectively, and 20.7 cm, 27.7 cm and 37.1 cm in length for males sand flathead, rock flathead and dusky flathead, respectively (values for 50% maturity).

Spawning

Mature dusky flathead could readily be induced to spawn using a single injection of luteinizing hormone – releasing hormone analogue (LHRHa) at a dose rate of 25-30 µg/kg (type of LHRHa not described) (Palmer *et al.* 2000). Mature oocytes of dusky flathead are >0.4 mm in diameter (Hicks *et al.* 2015). The eggs from ovulated females were hand-stripped and fertilised with sperm stripped from males. The latency period (the time between injection and stripping) is not described.

Mature, wild-caught, sand flathead have been induced to ovulate and spawn by injection with either 50 µg/kg LHRHa (Sigma) or 500 i.u./kg human chorionic gonadotrophin (HCG) (Bani *et al.* 2009). After injection fish were held in seawater in 1,000L tanks maintained at 15ºC. Ovulation occurred by 12 hrs post-injection.

Although natural spawning following hormone injection was not recorded in the work with dusky flathead, this method has been used for bartail flathead in which the buoyant fertilised eggs were collected daily from broodstock tanks (Hotta 2000). Fertilisation rates for artificially inseminated dusky flathead eggs ranged from 50-95% (P. Palmer, *pers comm.*).

Since flathead are thought to spawn multiple times within the season (Bani and Moltschaniwskyj 2008, Gray and Barnes 2015), it may be possible that broodstock that were induced to spawn early in the season can be re-conditioned and induced to spawn later in the season.

Table 3. Flathead fingerling production requirements.

Life stage	Life stage size	Duration of life stage	Activity	Facilities & resources	Nutrition (diet)	Comments and issues
Broodstock	Mature		Maintenance	Large (10,000L) fibreglass tanks: 10,000L (up to 25 fish per tank) suppled with seawater.	Fresh fish supplemented with vitamins	May swim into sides of tanks when disturbed. May require subdued lighting and minimal disturbance to reduce stress and flight response. Will not readily wean onto artificial diets.
			Spawning	Anesthetics for sedating fish. LHRHa or HCG for induction of spawning. 10,000 L tanks supplied with seawater to hold broodstock after injection.	Nil.	Gametes are hand-stripped and mixed together to obtain fertilised eggs. Natural spawning in captivity not described.
Eggs	<36 hrs		Incubation	Filtered seawater in 1,000 L tanks	Nil.	Incubation temperature may depend on species.
Larvae to fry	Up to 11-15 mm	15-19 days	Larval rearing	Static, aerated, greenwater culture in 5,000L tanks containing microalgae. (around 23^{o}C, salinity 30 ppt, pH 7.8-8.4 and total ammonia <1 ppm)	Rotifers, newly hatched brine shrimp and nutritionally boosted brine shrimp nauplii	Will not wean onto artificial diets.
Fry to fingerlings	11-15 mm to 25-60 mm	3 – 6 weeks	Fry and fingerling rearing	Outdoor extensive (greenwater) nursery ponds (0.04 ha), fertilised to encourage growth of zooplankton.	Zooplankton	Two sequential nursery pond phases are necessary to grow fish to a size of 40-50mm. Harvested fingerlings difficult to wean.

Egg incubation and rearing larvae

At the BIRC, fertilised dusky flathead eggs were incubated in filtered seawater in 1,000L tanks (Palmer *et al.* 2000). Fertilised eggs are positively buoyant, which helps to separate them from negatively buoyant non-fertile eggs. The larvae and fry of dusky flathead were reared using methods similar to those for barramundi and a range of other estuarine species (Palmer *et al.* 1992, Palmer *et al.* 2007).

Initial rearing of dusky flathead larvae at the BIRC was undertaken in 5,000 L outdoor flat-bottomed tanks using controlled low-water exchange greenwater culture (GWC) methods (Palmer *et al.* 2007). Tanks, which had smooth light grey or light blue walls, were stocked with microalgae (*Nanochloropsis ocilata*), continuously aerated and covered with shade cloth to provide for low natural lighting. Larvae were transferred to the tanks prior to onset of feeding. Tanks were stocked with rotifers (*Brachionus plicatilis*), newly hatched brine shrimp (*Artemia*) nauplii and later nutritionally boosted brine shrimp nauplii as food for the larvae (Palmer *et al.* 2000, Butcher *et al.* 2003). Tanks were maintained at around 23ºC (using immersion heaters), salinity 30 ppt, pH 7.8-8.4 and total ammonia <1 ppm. Survival rates to metamorphosis during this stage, although difficult to estimate due to small size and fragility of larvae, were very generally high (>90%) (P. Palmer, *pers comm.*).

After about 15-19 days (18-22 days old), when larvae had metamorphosed to fry (approximately 11-15 mm in length), they were transferred to pre-fertilised nursery ponds (24-26.5ºC) for on-growing using natural plankton blooms.

Figure 3. Dusky flathead fingerlings (Photo: Paul Hamer).

Fry rearing (nursery culture)

Rearing the fry of dusky flathead at the BIRC was undertaken in outdoor fertilised nursey ponds (0.04 ha) using an extensive pond culture ("greenwater culture") technique described by McGuren and Palmer (1997). In these ponds, fertilizers were added to encourage the growth of phytoplankton and, in turn, zooplankton (predominantly crustacean copepods), which become food for the fry that were stocked into the pond. Fry were stocked at densities up to 80,000 fry per 0.04 ha pond (up to 200 fry/m^2), although lower stocking rates may have improved survival rates. (Palmer *et al.* 2000). Nursery pond temperatures were around 24-26.5ºC. Two sequential nursery pond phases, each lasting around 3 weeks, were often necessary to grow fish to a larger fingerling size(40-50mm). In this particular stocking program, fingerlings were harvested from the ponds and released at an average size of 25-58 mm (see Table 4).

In comparison to dusky flathead, bartail flathead larvae reach a size of 31-40 mm TL with a survival rate of 11-27% by 50 days after hatching (Hotta 2000).

Survival rates of dusky flathead during the two nursery pond phases were highly variable(12-100% for phase 1 and 20-68 % for phase 2), which Palmer *et al.* (2000) attributed to :

- Irregular (and unpredictable) development of zooplankton blooms in the ponds,
- Entanglement of fingerlings in mats of filamentous algae during harvest. Being demersal, fingerlings tended to stay in the pond until the last minute before retreating to the collection sump as the pond drained. If there was

filamentous algal growth in the ponds many fish would become became stranded and entangled resulting in a reduced survival rate (i.e. <20%), and

- Cannibalism, which is also a problem in the culture of juvenile bartail flathead (Hotta 2000).

Diseases and health management

There were no major diseases encountered in dusky flathead in captivity (Palmer *et al.* 2000). At the BIRC a standardized quarantine procedures involved treating newly collected wild broodstock with baths of freshwater and formalin reduce parasite loads, and if injury had occurred at the time of capture they were treated with OTC to minimize development of secondary bacterial infections (P. Palmer, *pers comm.*). Overseas, mass mortality of hatchery reared flathead larvae due to viral nervous necrosis has been reported in bartail flathead (Song *et al.* 1997).

Nutrition

There is no published information on the nutritional requirements of flathead in captivity. Experiences at the BIRC indicated that both broodstock and juveniles harvested from ponds were very difficult to wean onto artificial diets (pellets), but with persistence this was achieved for at least one group of larger fingerlings (P. Palmer, *pers comm.*). This weaning difficulty has also been observed in bartail flathead (*P. indicus*) (Hotta 2000). Instead young fish have been fed on either live food (e.g. brine shrimp), or fresh or thawed food (e.g. pilchards).

Options for supply of juvenile flathead for stocking

Source of fingerlings

Hatchery-bred flathead fingerlings are currently not available from any hatchery in Australia. The only hatchery to have mass-produced flathead fingerlings for stocking is the BIRC (Palmer *et al.* 2000), however this hatchery is no longer producing flathead. For flathead fingerlings to be available for stocking waters in Victoria in the near future, hatchery production of flathead will need to be established at an existing hatchery. An overview of potential hatcheries, both within Victoria and interstate, government and private, that may be able to undertake flathead breeding is provided in Appendix IV.

Hatcheries in Victoria

The VFA has significant investment in a freshwater fish production facility (Snobs Creek Hatchery, Eildon) that is dedicated to producing salmonids and freshwater native species for the state's stocking program (https://vfa.vic.gov.au/recreational-fishing/fish-stocking). Species include brown trout, rainbow trout, Chinook salmon, Murray cod, trout cod and Macquarie perch. However, this hatchery is not able to produce flathead species because the facilities is outside the range of flathead species, does not have access to seawater and is committed to freshwater species only.

The VFA has a marine hatchery facility located at the Queenscliff. Previously this hatchery was used to breed and rear black bream for research purposes, and in 2004, 20,000 black bream fry produced at Queenscliff were released into Gippsland Lakes (Nicholson River and Lake Victoria) as a trial stocking project (Morison 2006). The facility has access to good quality filtered seawater, tanks for holding broodstock and eggs, and rearing larvae and fry, but does not have outdoor earthen nursery ponds for rearing fry. The facility is also capable of culturing food species (microalgae, rotifers and brine shrimp). Currently, however, the facility is leased to a commercial consortium through to the year 2023 for production of mussel and oyster spat for commercial grow out. Also, the VFA no longer has technical staff capable of operating the hatchery.

Deakin University, Warrnambool, maintains a recirculating aquaculture system (RAS) which has a range of facilities for breeding and rearing both marine and freshwater fish. However, these facilities are for research purposes only and not used for commercial production. Despite this, Deakin University is able to provide specific R&D services that will assist with developing and refine flathead fingerling production techniques.

The South East Australia Maritime Education Centre (SEAMEC), a part of the East Gippsland Institute of TAFE, manages an aquaculture research facility on Bullock Island, Lakes entrance. This facility, which was originally developed by the RMIT (http://www2.rmit.edu.au/departments/rd/highlights/frame8.html) for ecotoxicology and marine aquaculture research was capable of undertaking intensive breeding of both finfish and shellfish species. Currently, however, the facility is defunct, with much of the original equipment being removed. Water supply to the facility remains, and a private company is using a small outdoor area.

Hatcheries interstate

The South Australian Aquatic Sciences Centre (SAASC), South Australian Research and Development Institute (SARDI) operates a large marine R&D aquaculture facility at Westbeach SA, which includes facilities for holding, breeding and rearing both shellfish and finfish species as well as algal production (http://www.pir.sa.gov.au/research/research_centres_and_facilities/south_australian_aquatic_sciences_centre). The SAASC has been involved in developed breeding and rearing techniques for both yellowtail kingfish and southern blue tune. The capacity of the SAASC to undertake commercial production of flathead species that occur in the western part of Victoria (i.e. sand flathead and rock flathead) is not clear.

The NSW Department of Primary Industries' Port Stephens Fisheries Centre (https://www.dpi.nsw.gov.au/about-us/research-development/centres/psfi), operates a marine and brackish water hatchery for aquaculture R&D on both shellfish and finfish, including yellowtail finfish and southern bluefish tune, as well as routine production Australian bass and mulloway fingerlings for the state's stock enhancement program. The facility is considering producing dusky flathead fingerlings for stocking enhancement.

Narooma Aquaculture, Narooma (NSW) is a small private hatchery producing both Australian bass and estuary perch for stock enhancement. Currently, this hatchery receives Australian bass and estuary perch wild broodstock from the VFA for production of fingerlings that are released into Victorian waters (https://vfa.vic.gov.au/recreational-fishing/fish-stocking/inland-estuary-perch-fisheries) (Gordon 2013). The hatchery operator is currently considering breeding dusky flathead and has some broodstock on site.

Information on the production dusky flathead at the Bribie Island Research Centre (BIRC), Woorim (Qld) is provided in Section *Hatchery production of flathead fingerlings*. Although the BIRC is no longer breeding dusky flathead, the facility has both the capabilities and capacity to recommence breeding should there be a demand for fingerlings.

Cost of fingerlings

Cost of producing juvenile flathead for stocking is difficult to estimate given that no hatcheries are current producing flathead. However, the cost is likely to be similar to other estuarine/ marine species currently bred in captivity (i.e. barramundi, mulloway, estuary perch Australian bass), which typically range from $0.50 to $2.50 / fish, depending on the species, size of fish and number ordered. In estimating the cost of stocking Victorian waters with flathead fingerlings (see Section *Stocking flathead in Victorian waters*, a nominal cost of $1.25/fish was used.

Review of previous flathead stocking programs

Overseas, bartail flathead are being produced for stock enhancement in Japan (Sugaya 2006), but no information is available on outcomes of these stockings; success or failure, cost-effectiveness and contribution to fisheries.

In Australia, there has been only one short-lived pilot flathead stocking program, in which hatchery-bred dusky flathead fingerlings were released into the Maroochy River over two years in the late 1990s (Butcher *et al.* 2000a, Butcher *et al.* 2000c, Butcher 2006). The Maroochy River, located 120 km north of Brisbane, was selected for the pilot project as there had been multiple fish kills in 1993 and 1994, which were thought to have diminished populations of prime recreational fish species, including dusky flathead. Dusky flathead was selected as the species was sedentary and so less likely to move away from stocking area (P. Palmer, *pers comm.*). Sand whiting (*Sillago ciliata*) were also stocked ((Butcher *et al.* 2000a). The broad objectives of this program were to:

1. Develop technology to undertake large-scale breeding of finfish.
2. Undertake extensive stocking.
3. Develop protocols to monitor the effectiveness.
4. Undertake monitoring program

The project saw the first three objectives completed, but the 4th objective was not achieved because the project terminated before the effect of stocking could be fully assessed (Butcher *et al.* 2000a).

Table 4. Number of dusky flathead fingerling released into the Maroochy River, Qld (after Butcher *et al.* 2000a).

Date	Number stocked	Size at stocking (mm)
December 1996	65,000	25-58
December 1997	33,000	30-55
Total	**100,000**	

Figure 4. Releasing fingerlings into the Maroochy River, Qld (reproduced from Butcher *et al.* 2000a).

Prior to stocking fishery-independent surveys were carried out to estimate the density of existing populations and to estimate target stocking numbers that would give a reasonable chance of subsequently detecting a signal in the population as a result of the stocking trial.

Between December 1996 and December 1997 approximately 100,000 juvenile dusky flathead released into the Maroochy River (Table 4). Flathead were 25-58 mm in length at stocking. To ensure that the success or otherwise of the stocking trial could be properly evaluated, scale pattern analysis (SPA) was used to distinguish the stocked fish from wild fish. SPA relied on all hatchery reared fingerlings developing a unique circulus pattern on the inner portion of the scale that was different to that in wild fish (Butcher *et al.* 2003, Butcher 2006).

Survival of fingerlings in the days after release was determined by placing a small number of fish into cages at the release site. Results suggested that post-stocking survival varied considerably between different batches of fish, ranging from < 50% to >90% after 48 hrs (Butcher *et al.* 2000d).

Monitoring of the stockings used fishery-independent surveys (over 30 sites using a variety of nets) conducted more or less monthly since stocking commenced through to December 1998, recreational angling club catch records and commercial catch records (Butcher *et al.* 2000c, Butcher 2006). Some stocked flathead survived, grew and recruited into the recreational and commercial fisheries. Stocked flathead grew from an average of 45 mm in December 1996 to around 75 mm in March 1997 and 160 mm in December 1997 (Butcher et al. 2003).

Stocked flathead first appeared in fishery-independent surveys five months after stocking, representing 0-31% of the catch (14% of all flathead caught) (Butcher *et al.* 2000b) (Figure 5). Although there was a clear pulse of stocked flathead observed in the first 6 months after release their presence declined in subsequent months (Butcher *et al.* 2003). Low returns of stocked dusky flathead was attributed to post-stocking mortality, combined with continual recruitment of wild flathead (Butcher *et al.* 2000c). Post-stocking surveys failed to highlight any significant increase in the flathead population compared to pre-stocking surveys, which was attributed mainly to there being too much natural variation in population size, a large fish kill during sampling in February 1998, and the monitoring program being terminated before being able to detect any effect of the second stocking in December 1997 (Butcher *et al.* 2000c, Butcher 2006). Stocked flathead were also detected in the commercial fishery and during in two recreational fishing club trips undertaken after the first stocking were identified as being stocked fish (Butcher *et al.* 2000b).

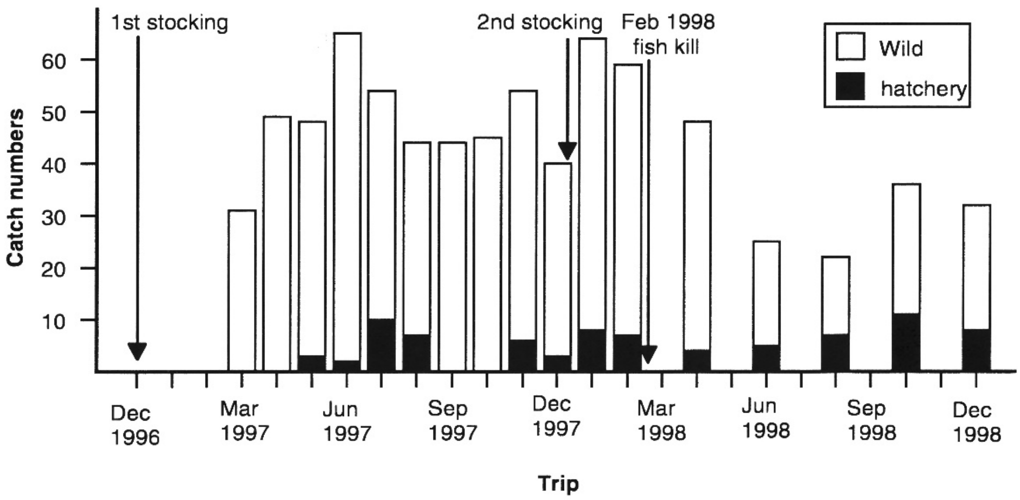

Figure 5. Numbers of hatchery-origin and wild dusky flathead caught during fishery-independent surveys of the Maroochy River (reproduced from Butcher *et al.* 2000b).

Statistic analyse indicated that the population density of flathead increased (>30%) during the first 12 months after stocking, but declined substantially after the flood related fish kill of February 1998, which confounded the assessment of the first stocking event (Butcher *et al.* 2000c). Sampling was however, terminated before the effects of the second stocking could be assessed, which meant that it was not possible to prove conclusively that stocking enhanced the population size in the Maroochy River. (Butcher *et al.* 2000c). The program was terminated for several reasons:

- There was not enough evidence that stocking contributed to the fishery (due in part to lack of long term data to compare against)

- Unfavourable economic assessment
- It was decided that marine stocking was not part of government policy.

The pilot program did, however, show that flathead can be bred in captivity for stocking purposes, and that stocked fish can survive, grow and recruit to fisheries. Butcher (2006) concluded that:

- Estuarine stock enhancement is much more difficult (and expensive) than just buying and stocking fingerlings;
- Monitoring is essential to demonstrate success;
- Stock enhancement will only be successful in the presence of a recruitment bottleneck; and
- Any future proposal for estuarine stocking must follow a responsible approach which includes examining alternative methods of stock rehabilitation.

Stocking flathead in Victorian waters

Flathead species are considered as potential candidates for stocking Victorian estuaries because:

- They are a highly popular recreational angling species. Sand flathead are targeted for in PPB while dusky flathead are a commonly targeted in some estuaries along the east coast of Victoria.
- Some stocks may need supplementation to overcome periods when recruitment is limited. Sand flathead stocks in PPB have declined over the last 20 years and that the rate of decline has increased since the late 1990s (Hamer *et al.* 2010, Hirst *et al.* 2014). Annual monitoring of the abundance of juvenile sand flathead (0+age, pre-recruits, 4-15 cm in length) in Port Phillip Bay, which is used as an indicator of recruitment, clearly shows sustained limited recruitment (Figure 6). Between 1988 and 2000 the average catch rate (as a proxy for density) of 0-age sand flathead was 70.9 fish/ha whereas the recent (2009-2018) average catch rate was just 4.2 fish/ha, and catch rate has been above the long-term average 36.7 fish/ha only twice in the last 20 years.
- They are relatively sedentary and so are less likely to move away from the area stocked. For example, dusky flathead spend rarely move between estuaries (Hindell 2008, Gray and Barnes 2015).
- They can be bred in captivity (see Section *Hatchery production of flathead fingerlings*).

A number estuaries, inlets, bays and coastal lagoons in Victoria that may be considered for stocking with flathead have been identified (Appendix V).

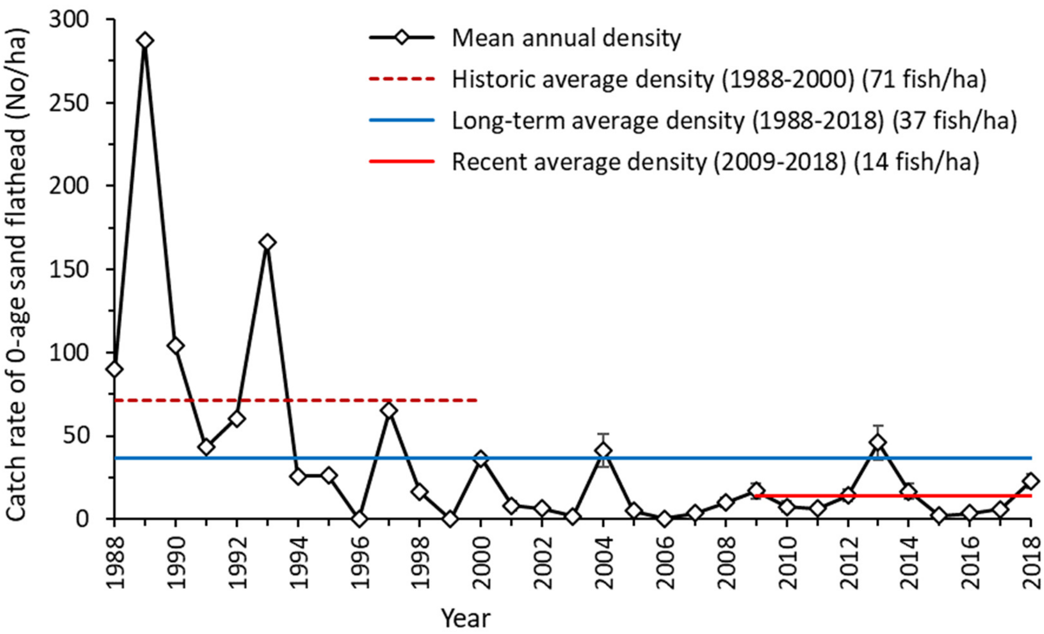

Figure 6. Average catch rate of juvenile (0+age) sand flathead in Port Phillip Bay and historic, long-term and recent average densities (data source: Hirst *et al.* 2014 and P. Hamer, unpublished data).

Stocking dusky flathead in eastern Victoria

Dusky flathead is considered to be a good candidate for stocking estuaries (Taylor 2006). Several eastern Victorian estuaries, bays and coastal lagoons have been identified as potential stocking sites for dusky flathead (Appendix V). The status of dusky flathead stocks has been assessed for some of these waters including Gippsland Lakes, Mallacoota Inlet, Sydenham Inlet and Lake Tyers (Conron *et al.* 2010, Conron and Oliveiro 2016, Ingram *et al.* 2016). Estimating the number of hatchery-bred dusky flathead juveniles required to recover stocks and/or enhance fisheries in selected waters in eastern Victoria is based on modelling dusky flathead stock enhancement in NSW (Blount *et al.* 2011, Blount *et al.* 2017). Modelling indicated that stocking rates for fingerling dusky flathead into riverine estuaries and coastal lagoons varied and was dependent on the size of fish being stocked, the type of water (lagoon or estuary) and the productivity of that water (Blount *et al.* 2011) (Table 5). The productivity of Victorian waters has yet to be estimated.

Based on the figures presented for stocking 50 mm dusky flathead in Table 5, the number required to stock a small estuary such as Wingan Inlet, would be around 25,000-30,000 fish, whereas a large inlet such as Mallacoota Inlet may require 0.5-1.0 mil. fish, depending on level of productivity (Figure 7).

Currently there are no estimates for cost of flathead fingerlings. Using a nominal price of $1.25/fish (See section *Options for supply of juvenile flathead for stocking*), stocking Wingan Inlet and Mallacoota Inlet as examples may cost $31,250 to $37,500 and $625,000 to $1.25 mil., respectively.

Table 5. Nominal stocking rates for dusky flathead fingerlings proposed for NSW coastal lagoons and (after Blount *et al.* 2011).

Size of fish (mm)	Dusky flathead stocking rate (fish/ha)			
	Coastal lagoon		Riverine estuary	
	Low productivity	High productivity	Low productivity	High productivity
25	307	457	272	517
50	253	373	225	432
100	222	328	200	381

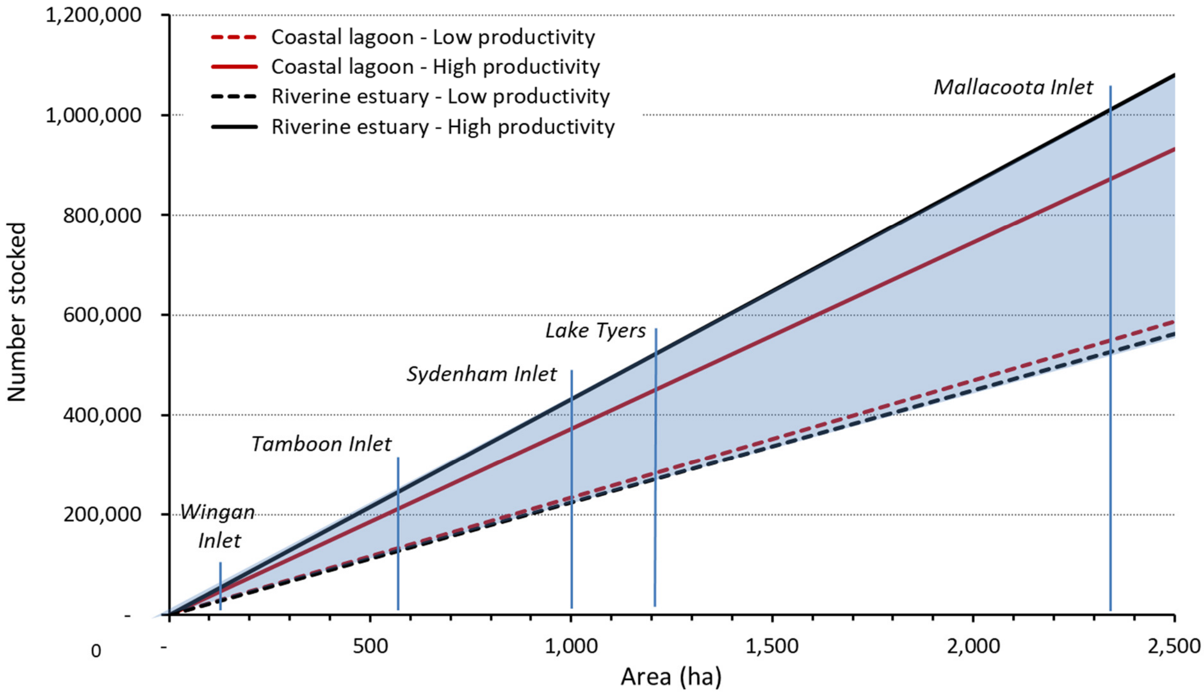

Figure 7. Nominal stocking rates for dusky flathead (50 mm in length) for different types and sizes of estuaries (based on Blount *et al.* 2011).

Stocking sand flathead in Port Phillip Bay and Corio Bay

Estimating the number of sand flathead to release into PPB to recover stocks aimed to increase the abundance of sand flathead juveniles (0+age, pre-recruits, 4-15 cm in length) from the recent average density to historic levels (Hamer *et al.* 2010, Hirst *et al.* 2014) (Figure 6). These levels are:

1. Historic average density (1988-2000) – 70.9 fish/ha.
2. Long-term average density (1988-2018) – 36.7 fish/ha.
3. Recent average density (2009-2018) – 14.2 fish/ha.

These densities are, however, likely to be underestimates as the beam trawl method of collecting juvenile fish does not collect all the fish present, for example only fish >3 cm are retained. There are no estimates for catchability of beam trawls for juvenile flathead. Consequently, the catchability was assumed to by 75% and so the target historic, long-term and recent average density values (as above) were adjusted to

1. Historic average density (1988-2000) – 94.5 fish/ha.
2. Long-term average density (1988-2018) – 48.9 fish/ha.
3. Recent average density (2009-2018) – 18.9 fish/ha.

In determining the number of juvenile sand flathead to release, the following assumptions were made.

- Sand flathead generally occupy waters below the 10 m contour (P. Hamer, unpublished data) (Figure 8), an area of about 115,000 ha.
- Size of sand flathead available for is 2.5 and 5 cm, which is based on hatchery-reared dusky and bartail flathead (see Section *Hatchery production of flathead fingerlings*). Note that this is smaller than the size used to estimate juvenile density in PPB.
- The percentage survival of sand flathead that are released and grow to at least 4 cm is 75%. Post-stocking survival of dusky flathead was < 50% to >90% after 48 hrs (Butcher *et al.* 2000d).
- Sand flathead fingerling cost $1.25 per fish (See section *Options for supply of juvenile flathead for stocking*).
- Stockings may occur annually for 1-5 years after which a period of monitoring to assess the effects of stocking is undertaken.

It may be necessary to undertake a small, pilot-scale, stocking trial to validate assumptions and assess changes to the fishery before committing significant resources to stocking PPB. Therefore, the same assumptions applied to PPB, were also used to estimate stocking levels for Corio Bay, with an area of 5,150 ha below the 5 m contour line (Figure 8).

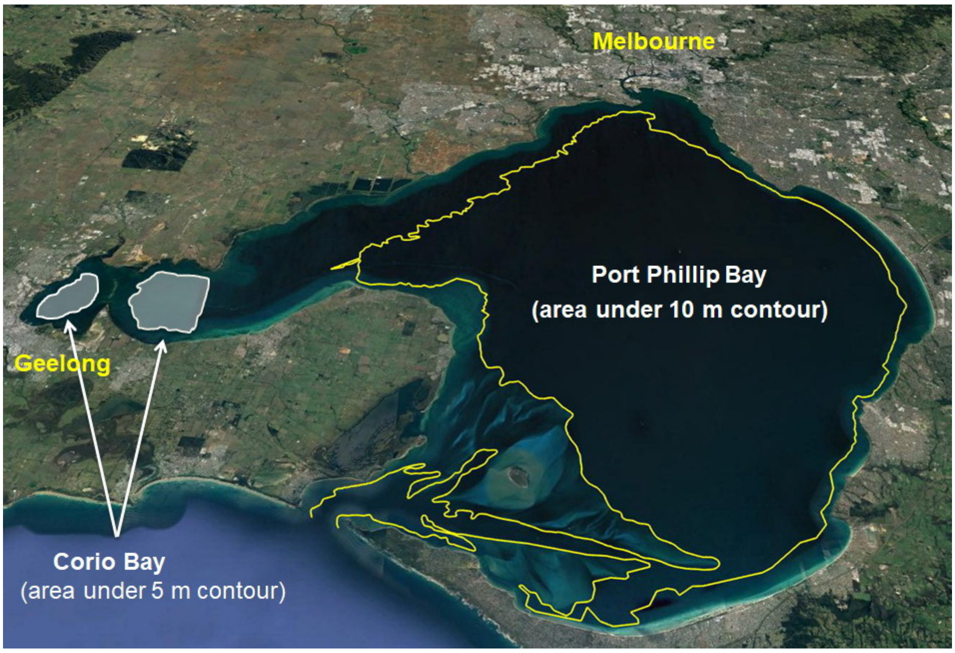

Figure 8. Area of Port Phillip Bay under 10 m contour and Corio Bay under 5 m contour.

The number of juvenile flathead required to increase the density of stock in PPB from the recent average density to the long-term average density and historic average density is 4.6 mil. and 11.592 mil., respectively (Table 6). Based on a fingerling price of $1.25/fish, this would cost $5.75 mil. and 14.49 mil., accordingly.

On a smaller, pilot-scale, number of juvenile flathead required to increase the density of stock in Corio Bay from the recent average density to the long-term average density and historic average density is 0.206 million ($0.257 mil.) and 0.519 mil. ($0.649 mil.), respectively (Table 6).

Based on estimates provided in Table 6, it may be unrealistic to use stocking as a means of recovering flathead stocks in PPB at this time. However, stocking sand flathead into other smaller Victorian estuaries, bays and coastal lagoons to enhance fisheries may be achievable, and a number of waters have already been suggested (see Appendix V). Estimating the number of hatchery-produced sand flathead needed to stock these waters may follow the approach used for dusky flathead (see Section *Stocking dusky flathead in eastern Victoria*).

The natural recovery of sand flathead in PPB is unlikely in the near future due to greatly reduced size of spawning stock biomass (Hamer *et al.* 2016). Since recovery of sand flathead in PPB may not be achievable through stocking alone, other options may need to be considered, including enhancement of natural recruitment through environmental flows and changes to fishing regulations. An inter-agency working group has been established to investigate replicating fresh water flows that have historically triggered recruitment of sand flathead (Victorian Fisheries Authority 2017). The number of commercial licences has been reduced and in 2009/10 the minimum legal size limit for recreational fishing was increased from 25 cm to 27 cm to help protect larger (spawning) fish.

Table 6. Level of stocking and cost of stocking required to increase density of juvenile sand flathead to long-term average density and historic average density in Port Phillip Bay and Corio bay.

Stocking scenarios	Port Phillip Bay		Corio Bay	
	Number of juvenile (mil.)	Cost ($mil.)	Number of juvenile (mil.)	Cost ($mil.)
Increase density recent average density (18.9 fish/ha) to long-term average density (48.9 fish/ha)	4.6	5.75	0.206	0.257
Increase density from recent average density (18.9 fish/ha) to historic average density (94.5 fish/ha)	11.592	14.49	0.519	0.649

Conclusions and recommendations

The objective of this study was to determine the feasibility of establishing a program for stocking hatchery-bred flathead fingerlings to recover and enhance flathead stocks in selected estuaries, bays and coastal lagoons of Victoria. The study aimed to identify the need, constraints and opportunities for stocking flathead into Victorian waters, review available information on techniques and resources required to breed flathead in captivity and review previous flathead stocking programs.

Previous studies have indicated there is interest from stakeholders in stocking flathead into selected water to recover stocks and enhance fisheries, particularly dusky flathead on the east coast and sand flathead to the west. There is a considerable amount of information on the biology and ecology of flathead that will assist in developing captive breeding techniques for target species, such as size at maturity, spawning season and habitat, fecundity and larval growth. Techniques for hatchery production of dusky flathead fingerlings have already been developed. Hatchery facilities for production of flathead require access to good quality filtered seawater, tanks for holding broodstock, eggs and larvae, large ponds for growth of fry, and facilities for culturing food species (rotifers and brine shrimp). These techniques may be adapted for breeding other flathead species.

There are concerns about the status of some stocks of flathead in Victoria. Sand flathead in PPB have exhibited sustained limited recruitment over the last 20 years. There is some uncertainty regarding the status of some dusky flathead fisheries on the east coast.

Stocking is one option for managing fish stocks, particularly where recruitment is limited. Stocking programs release juveniles produced in captivity (hatcheries) on a regular basis to conserve, restore or enhance fisheries. This approach can have a range of benefits including the recovery threatened species and stocks that have been depleted and increase yields in fisheries that are below the carry capacity of the environment. Stocking programs also require access to sufficient numbers of juveniles of appropriate species and stock (genetic structure) that will survive and growth after release and remain in the area to enter the fishery.

However, not all stocking programs are successful. While some have increased yields and generated economic and social benefits, others have either failed to live up to expectations, or their effectiveness have not, or could not be, assessed. For example, there has been one flathead stocking program in Australia. Over 2 years between 1996 and 1997; 100,000 juvenile dusky flathead were released in the Maroochy River, QLD, as a pilot project and partly to recover stocks following a fish kill. Although stocked dusky flathead first appeared in fishery independent surveys five months after release, representing, and were detected in both recreational and commercial fisheries, assessments failed to detect a significant change in the size of the population and an economic assessment was unfavourable. Consequently, a responsible approach to stocking, with well-defined management objectives and rationale for stocking, and plans for their monitoring and evaluation, is promoted by fisheries scientists and managers.

Ten principles for responsible marine release programmes have been identified by the *International Symposia on Stock Enhancement and Sea Ranching* (ISSESR) (http://www.searanching.org) (Blankenship and Lee 1995, Blankenship and Leber 1996, Lorenzen *et al.* 2010), which are:

1. Prioritize and select target species
2. Develop a management plan
3. Define measures of success
4. Use genetic resources management
5. Use disease and health management
6. Develop restocking objectives and tactics
7. Identify released individuals and assess stocking effects
8. Identify optimum release strategies
9. Identify economic and policy objectives
10. Use adaptive management.

Flathead species are considered as potential candidates for stocking Victorian estuaries because:

- They are a highly popular recreational angling species.
- Some stocks may need supplementation to overcome periods when recruitment is limited.

- They are relatively sedentary and so are less likely to move away from the area stocked.
- They can be bred in captivity.

Where to from here

This report has indicated that it is feasible to produce juvenile flathead for stocking and that there are a number of waters that may be considered for enhancing with hatchery-bred fish. For stocking to occur there is a need to:

1. Determine the need and objectives, which should consider cost, angler demand, expected returns & environmental suitability. This should involve stakeholders in the planning process, and assess the potential contribution of releases as well as alternative options for achieving the goals of fisheries management objectives for the fishery.
2. Identify estuaries requiring enhancement by stocking, such as where there is sustained limited recruitment. This will require knowledge of the abundance and level of recruitment of stocks within these estuaries.
3. Estimate carrying capacity (productivity) of the environment to determine the level of stocking needed for recovery within the carrying capacity of the water.
4. Determine genetic structure of Victorian flathead stocks to ensure genetic integrity of stocks being supplemented with hatchery stocks are maintained.
5. Support the establishment of flathead hatchery production. Currently no hatcheries in Australia are breeding flathead. Although there appears to be no capacity to breed flathead in existing hatcheries in Victoria, both government and at least one private hatchery interstate may be capable of this.
6. Design and implement a stocking program, incorporating monitoring and evaluation plans to determine the value and contribution of stocking to receiving fisheries, and whether or not management objectives were met. Longer-term stocking trials should be considered as short-term trials are at risk from detection problem over short time frames (Blankenship and Lee 1995, Cowx 1998b).

Acknowledgements

This project was undertaken with funds from the Victorian Government to improve recreational fishing in Victoria through revenue from Recreational Fishing Licences.

Dr Paul Palmer, Bribie Island Research Centre (BIRC), Queensland Department of Agriculture and Fisheries (QDAF), Woorim, Qld, provided advice on dusky flathead breeding at the BIRC in the mid 1990s. Dr Stu Fielder provided information on fish production at the NSW Department of Primary Industries' Port Stephens Fisheries Centre. Brad Lancaster (Federation Training) provided information on the Bullock Island facility at Lakes Entrance. Bruce Lawson provided information on fish production at the Narooma Aquaculture Facility. Pam Oliveiro (VFA), Paul Hamer (VFA) and Simon Conron (VFA) provided sand flathead photos.

The author wishes to thank Dr Paul Hamer (VFA) and Simon Conron (VFA) for their advice and Simon Conron (VFA) providing editorial comments on this report.

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Appendix I. Stockings of coastal, estuarine and marine species into Victorian waters

Years	Australian bass[1]	Black bream	Eastern king prawn	Estuary perch[2]	Mulloway	Total
1996	2,500					2,500
1997						
1998	20,000					20,000
1999	10,000					10,000
2000	40,000	1,000		1,000		42,000
2001	25,000					25,000
2002	67,000					67,000
2003	59,150					59,150
2004	10,000	20,000				30,000
2005						
2006						
2007						
2008						
2009						
2010	154,270					154,270
2011	94,000					94,000
2012	82,000			10,740		92,740
2013	82,000		1,300,000	50,000		1,432,000
2014	120,000			164,000		284,000
2015	120,017			153,500	5,000	278,517
2016	155,000			128,000	16,000	299,000
2017	414,500			51,000		465,500
	1,455,437	**21,000**	**1,300,000**	**558,240**	**21,000**	**3,355,677**

1. Australian bass are spawn in estuarine waters. Most of the stockings have been into freshwater lakes, dams and streams.
2. Estuary perch are spawn in estuarine waters. Stockings have been into both freshwater and brackishwater environments.

Appendix II. Flathead species summary descriptions

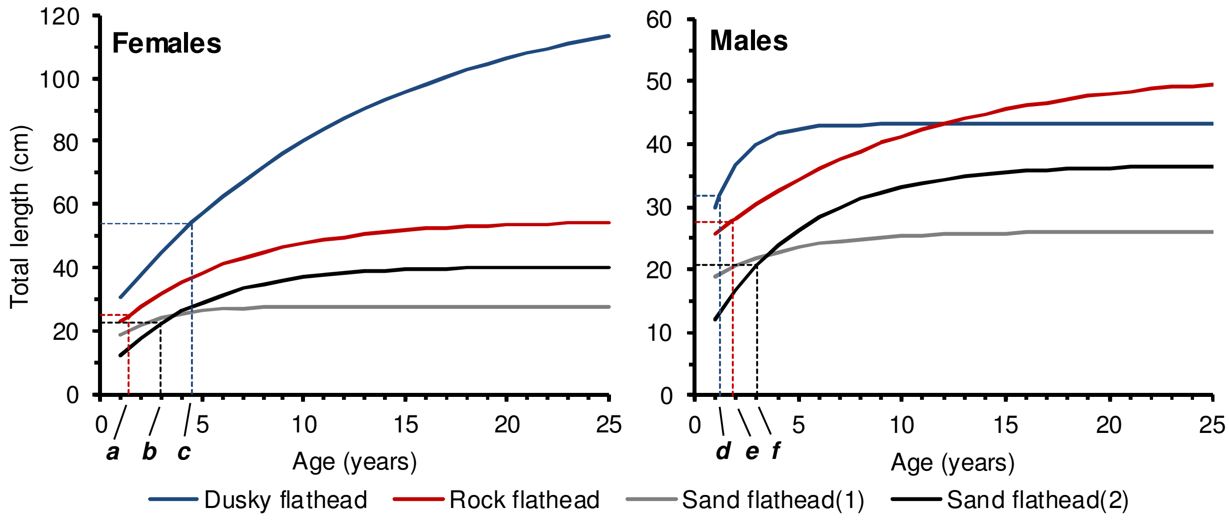
Species	Dusky flathead	Rock flathead	Sand flathead
Description	Moderately large fish with an elongate and depressed tapering body. Eyes on top of head. Colour brownish above with irregular mottling, and white below. Generally sedentary except during spawning movements. Some adult fish are known to migrate substantial distances up or down the coastline.	Moderate sized fish. Colour brownish black above, head and sides heavily marbled with dark brownish black spots, and yellowish or creamy below.	Moderate sized fish. Colour brownish or grey with many small reddish-brown spots above, and white below.
	Largest of Australian flathead species, reaching a size of 120 cm and 15 kg (commonly 40-80 cm and 0.5-6 kg). Females grow faster and attain a greater overall maximum size than males, but may take longer to mature than males. Reaches maturity at around 55 cm, but may occur at a smaller size in cooler (more southern) waters.	Size to 60 cm and 2 kg (commonly 30-50 cm and 0.5-1.2 kg). In Corner Inlet females grow to a larger size than males.	Size to 50 cm and 3.1 kg (commonly < 40 cm and 0.5 kg). Females grow larger than. Males and females reach sexual maturity at between 2 and 4 (mean length = 22 cm length) and 3 and 5years (25 cm).
	Ambush predator preying on fish, crabs, prawns, other crustaceans and polychaete worms.	Ambush predator preying on fish, squid, crabs and other crustaceans.	Ambush predator preying on fish, crabs, prawns, other crustaceans and polychaete worms.
	Thought to spawn from (November?) January to March in Victorian waters, in open coastal waters, or in estuaries. Eggs are planktonic.	Thought to spawn from September to February, with peak in October, in inshore coastal regions.	Thought to spawn in estuaries, coastal embayments and inshore shelf waters.
Distribution	Bays, estuaries and inshore coastal areas from Cairns in Queensland to the Gippsland Lakes in Victoria. To Wilson Promontory (Chinaman Creek), may enter freshwater a short distance above tidal influence. Rarely moves to sea from estuaries. Known to migrate between estuaries.	Shallow coastal areas, bays and estuaries of NSW, Victoria, Tasmania, SA and southern WA.	Shallow coastal areas, bays and estuaries, extending onto the continental shelf to depths of about 100 m, of southern NSW, Victoria, Tasmania and eastern South Australia.
Habitat	Demersal, over soft bottoms, mud, silt, sand and gravel beds, and seagrass beds, predominantly *Zostera mulleri*. May use different parts of the estuarine habitats at different times of the year.	Demersal, Juveniles (<80 mm SL) are found over unvegetated soft bottom whereas larger fish are found over reefs or amongst seagrass and algae.	Demersal, over sandy, shelly or muddy bottoms to 100 m. In PPB over silty and muddy bottoms > 15 m deep.

Species	Dusky flathead	Rock flathead	Sand flathead
Fishing methods	Commercial: Mesh nets and haul seines.	Commercial: mesh nets and haul seines.	Commercial: Hook and line, mesh nets, haul seines and otter trawls.
	Recreational: Baited fishing line and lures, especially soft plastics. Caught all year round, but may be harder to catch during winter as fish are less active.	*Recreational*: Baited fishing line and lures.	*Recreational*: Baited fishing line and lures and diving.
Management arrangements	*Commercial*: fishing gear and method restrictions, limited entry to fishery, size limit and spatial closure.	*Commercial*:	*Commercial*: limited entry, size limit, spatial closures and vessels restrictions.
	Recreational: Minimum legal size of 30cm and Maximum legal size of 55cm, bag/possession limit of 5 (http://agriculture.vic.gov.au/fisheries/recreational-fishing/recreational-fishing-guide, 2017).	*Recreational*: Flathead (all species except dusky flathead), Minimum legal size of 27 cm, bag/possession limit of 20 (http://agriculture.vic.gov.au/fisheries/recreational-fishing/recreational-fishing-guide, 2017).	
Comments	The biological stock structure of dusky flathead populations is unknown. Populations may be affected by loss of seagrass, sedimentation and changes in habitat and environment, particularly along east coast estuaries and inlets. Variable recruitment has been observed across it range, which is thought to be environmentally driven. There is considerable variation among individuals in length-at-age for both sexes.	Also known as grassy flathead. Supports a commercial mesh net fishery in Corner Inlet and PPB. Unlike other flathead species, rock flathead rarely burrow. The biological stock structure of rock flathead populations is unknown.	Also known as bay flathead, slimy flathead. Arguably the most important flathead species in Victoria based on commercial and recreational catches. Moderately long-lived (23 years) and, although growth is rapid in the first 3-4 years, are a slow growing species. Fish caught bass Strait grow faster than fish in PPB. There is evidence of regional sub-population structure with differences in physical characteristics, recruitment dynamics and growth rates, but biological stock structure has not been studies. Populations may be affected by loss of seagrass, sedimentation and changes in habitat and environment, particularly along east coast estuaries and inlets.
Key references	Kailola *et al.* 1993, Yearsley *et al.* 1999, Gray *et al.* 2002, Gray *et al.* 2004, Gray and Barnes 2008, Nicholson and Gunthorpe 2008, Stokie *et al.* 2010, McGilvray *et al.* 2014, Gray and Barnes 2015.Butcher *et al.* 2000a, McGilvray *et al.* 2016	Yearsley *et al.* 1999, Victorian Fisheries Authority 2017 Klumpp and Nichols 1983, Koopman *et al.* 2004, Gomon *et al.* 2008, Koopman and Morison 2010, Kemp *et al.* 2014	Yearsley *et al.* 1999, Koopman *et al.* 2004, Koopman *et al.* 2009, Andrews *et al.* 2016, Victorian Fisheries Authority 2017 Brown 1977, Jordan 2001, Bani and Moltschaniwskyj 2008, Gomon *et al.* 2008, Hirst *et al.* 2014

Appendix III. Flathead growth parameters

The von Bertalanffy growth curve parameters L∞, k and t0, length and age at maturity (L50 and A50, respectively), maximum age and maximum total length (TL) for important flathead species in Victoria (after Coulson *et al.* 2017).

Species/sex	TL_{∞}	k	t_0	TL_{50}	A_{50}	Max. age	Max TL	Source
Females								
Dusky flathead	1275	0.08	-2.39	568	4.5	16	985	Gray and Barnes 2015
Dusky flathead east Gippsland				328				Hicks *et al.* 2015
Rock flathead	547	0.17	-2.14	264	1.4	21	540	Koopman *et al.* 2004
Sand flathead PPB	277	0.459	-1.38			23	370	Koopman *et al.* 2004
Sand flathead PPB	269	0.603	-1.11					Hirst *et al.* 2014
Sand flathead Tasmania	404	0.23	-0.52	235	3	16	475	Jordan 1998, Jordan 2001
Males								
Dusky flathead	432	0.71	-0.67	317	1.2	11	615	Gray and Barnes 2015
Rock flathead	520	0.10	-5.79	231	1.8	16	426	Koopman *et al.* 2004
Sand flathead -PPB	260	0.274	-3.79			23	334	Koopman *et al.* 2004
Sand flathead - ppb	250	0.407	-2.73					Hirst *et al.* 2014
Sand flathead Tasmania	366	0.22	-0.79	210	3	17	427	Jordan 1998, Jordan 2001



Growth curves (solid lines) age and size at 50% maturity (dashed lines) for important Victorian flathead species (see Table above for data sources). Females: (a) Rock flathead: 1.4 yrs, 27.7 cm. (b) Sand flathead: 3 yrs, 22.4 cm. (c) Dusky flathead: 4.5 yrs, 54 cm. Males: (d) Dusky flathead: 1.2 yrs, 37.1 cm. (e) Rock flathead: 1.8 yrs, 27.7 cm. (f) Sand flathead: 3 yrs, 20.7 cm.

Appendix IV. Fish hatcheries in south-eastern Australia with the potential to breed flathead

Fish hatcheries in south-eastern Australia with the potential to breed targe flathead species (dusky flathead, sand flathead and rock flathead).

Hatchery	Species in range	Capability (technical expertise)	Capacity	Facilities present					Comments
				Access to seawater/ brackish water	Broodstock holding and spawning	Intensive larval rearing	Intensive/ extensive fry rearing	Live food culture (microalgae, rotifers, *Artemia*)	
VFA – Snobs Creek (VIC)	Nil	✓	×	×	✓	✓	✓	×/✓	
VFA – Queenscliff (VIC)	Sand flathead Rock flathead	×	×	✓	✓	✓	×/✓ (intensive rearing facilities only)	✓	facility leased to the Victorian Shellfish Hatchery Pty Ltd.
Deakin University, Warrnambool (VIC)	Rock flathead Sand flathead	✓	×	✓	✓	✓	×/✓ (intensive rearing facilities only)	×/✓	Intensive rearing facilities only)
SEAMEC, Bullock Island (VIC)	Dusky flathead Rock flathead Sand flathead	×	✓	✓	×/✓	×/✓	×	×/✓	Infrastructure in place but limited facilities. Will require refurbishment. Space limited. Currently no technical expertise on staff.
SARDI (SA)	Rock flathead (Sand flathead)	✓		✓	✓	✓	✓	✓	Has not previously produced flathead.
Port Stephens Fisheries Centre (NSW)	Dusky flathead Rock flathead	✓	×	✓	✓	✓	✓	✓	Currently committed to other species, but is considering production of dusky flathead in future

Hatchery	Species in range	Capability (technical expertise)	Capacity	Facilities present					Comments
				Access to seawater/ brackish water	Broodstock holding and spawning	Intensive larval rearing	Intensive/ extensive fry rearing	Live food culture (microalgae, rotifers, *Artemia*)	
Narooma Aquaculture (NSW)	Dusky flathead Rock flathead (Sand flathead)	✓	✓	✓	✓	✓	×/✓	×	dusky flathead only. relies on food production in fry ponds extensive rearing facilities
Bribie Island Research Centre (BIRC), Woorim (Qld)	Dusky flathead	✓	×	✓	✓	✓	✓	✓	Currently not producing dusky flathead

Appendix V. Estuaries, inlets, bays and coastal lagoons of Victoria, and their potential for stocking with flathead

Water	Region	Water type	Size (ha)	Flathead species present	Flathead stocking interest	Comments
Mallacoota Inlet	Gippsland	Inlet	2,350	Dusky flathead	Yes[1]	Dusty flathead fishery status: Uncertain[3]
Wingan Inlet	Gippsland	Riverine estuary	110	Dusky flathead	Yes[1]	
Tamboon Inlet (Cann River)	Gippsland	Riverine estuary with shallow lagoonal bay	580	Dusky flathead Sand flathead	Yes[1]	
Sydenham Inlet (Bemm River)	Gippsland	Riverine estuary with large shallow lagoonal bay	1000	Dusky flathead	Yes[1]	Dusty flathead fishery status: Limited data[3]
Snowy-Brodribb inlet (including Lake Corringle and Lake Curlip)	Gippsland	riverine estuary and lagoons with substantial expanses of shallow lake	700	Dusky flathead Sand flathead Tiger flathead	Yes[1,2] (Dusky flathead)	Need to assess genetic stock structure and juvenile key habitat for dusky flathead[2]
Lake Tyers	Gippsland	Coastal lagoon	1,200	Dusky flathead	Yes[1,2] (Dusky flathead)	Need to assess genetic stock structure and juvenile key habitat for dusky flathead[2] Dusty flathead fishery status: Sustainable[3]
Gippsland Lakes	Gippsland	Large lagoonal system	36,500	Dusky flathead Sand flathead	Yes[1]	
Corner inlet	Gippsland	Large open bay	38,000	Dusky flathead Rock flathead Sand flathead	Yes[1]	Status of rock flathead is Sustainable[4]
Anderson Inlet	Gippsland	Shallow lagoonal bay with intertidal mudflats	2400	Dusky flathead Rock flathead Sand flathead	Yes[2] (Sand flathead)	
Port Phillip Bay	PPB	Large open bay	193,000	Sand flathead Yank flathead	Yes[1]	Status of sand flathead stock is Environmentally limited[4]

Water	Region	Water type	Size (ha)	Flathead species present	Flathead stocking interest	Comments
Corio Bay	PPB	Part of large bay	5,150			
Swan Bay	PPB	Shallow lagoon, part of large bay	2,100			
Patterson River	PPB	Short highly modified riverine estuary		Flathead		No species recommended for stocking[2]
Werribee River	PPB	Short riverine estuary	75	Sand flathead		No species recommended for stocking[2]
Barwon River, including Lake Connewarre	Barwon	Riverine estuary and lagoon with substantial expanses of shallow lake	950	Sand flathead	Yes[1]	
Anglesea River	Barwon	Short riverine estuary	20		Yes[1]	No species recommended for stocking[2]
Painkalac Creek & Aireys Inlet	Barwon	Short riverine estuary	10		Yes[1]	
Barham River	Barwon	Short shallow riverine estuary	13			No species recommended for stocking[2]
Curdies Inlet and River	South Coast	Riverine estuary with small lagoon	300	Sand flathead	Yes[1,2] (Sand flathead)	
Hopkins River	South Coast	Riverine estuary extending 8.8 km	180		Yes[1]	
Merri River	South coast	Narrow riverine estuary	20		Yes[1]	No species recommended for stocking[2]
Lake Yambuk	South Coast	Small estuarine lagoon	100			No species recommended for stocking[2]

1. Futurefish Foundation (2009). 2. Taylor (2010). 3. Ingram *et al.* (2016). 4. Victorian Fisheries Authority (2017).

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