Victorian Pipi (*Donax deltoides*): Discovery Bay

Assessment Report 2022

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February 2023
Victorian Fisheries Authority Science Report Series No. 35

Printed by VFA

Edited by Simon Conron

ISSN 2203-3122 (print)

ISSN 2204-6933 (online)

ISBN 978-0-6455802-4-2 (print)

ISBN 978-0-6455802-5-9 (pdf/online/MS word)

For more information, contact the Customer Service Centre on 136 186.

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Pipi (Donax deltoides)

Key points

The available information for the Victorian commercial Pipi fishery, which came under quota-management as a stand-alone fishery on 1 April 2020, indicates that –

- Discovery Bay supports the bulk of the commercial fishery, and a small amount of catch occurs sporadically in the Western and Venus Bay zones.
- Since the fishery came under quota management there are now three years of fishery dependent and one year of independent data available. These data are nevertheless insufficient to confidently determine the effectiveness of the change in management, especially as other factors such as the effect of COVID-19 on markets, and the inability to access the fishery, have impacted catches. The data available from the fishery prior to the establishment of quota provide some information indicative of the current relative status of the Pipi resource, but catch data were limited by management controls (i.e., daily catch limits which meant catch was restricted to 150kg per day) during the period of transition to quotas and effort data have been confounded by the prior ability of fishers to use any number of crew.
- Notwithstanding these limitations and caveats, and despite some large fluctuations over 1 and 2-year periods, overall CPUE trends have been increasing over the past decade, including recently by 1.5 times since quotas were introduced. The more than decade-long trends are strongly influenced by low CPUE reported at the start of the series when the fishery operated very differently so do not necessarily indicate a large increase in stock biomass. They neither directly capture signals arising from natural population cycles and changes in environmental conditions, nor do they account for spatial complexity. Nevertheless, there is no compelling indication that the biomass of the stock has declined.
- A change in process was recently approved whereby the TACC for Pipi will be set on a two-yearly basis, informed by detailed assessments aligning with the Status of Australian Fish Stocks (SAFS) national reporting cycle, and a scaled back ‘fishery scan’ during the intervening years. This year’s assessment conducted up to the end of 2022 falls during a ‘non-SAF’s’ year with reporting due at the end of 2023.
- As of 31 December 2022 (with three months of the 2022/23 fishing season remaining), five licence holders have fished in Discovery Bay West. Of the 10 tonne TACC, unlike the previous year only 14% remains uncaught. The previous year’s shortfall was because access to the primary Pipi location at Nobles Rocks was blocked by Parks Victoria. The only fisher who fished in this zone during the 2021/21 fishing season entered via the Glenelg River, far to the west.
- In Discovery Bay East, six of the eight licence holders have fished share of the quota. Of the 40 tonne TACC, 27% remains uncaught.
- There has been no fishing in the Venus Bay commercial zone, so the total 2 tonne TACC remains uncaught. The single licence holder in this zone has concentrated on fishing his scallop licence during the past two years so there is no evidence of a stock issue, although independent surveys revealed biomass was much lower than in Discovery By. This report focusses on exclusively in Discovery Bay for the fishery dependent section of this assessment.

Introduction

Stock Structure and Biology

Genetically, the Victorian Pipi population comprises at least two biological stocks at either end of Bass Strait, centred around Discovery Bay in the west and Venus Bay in the east. This genotypic difference in conjunction with environmental variation would be expected to be expressed as differences in rates of reproduction, growth, maturity, and mortality, but there is no biological parameter information available at present to quantify these rates for Victorian Pipi populations. Future acquisition of these kinds of data may facilitate integrated modelling of the dynamics in population numbers and biomass, as has been done in NSW. More locally e.g., within Discovery Bay, the biological stock delineation of Pipi remains unclear, but new recruits into populations are likely to be self-seeded or to come from nearby, adjacent beaches (Murray-Jones and Ayre 1997). In South Australia, Pipi can live to 3–5 years of age and grow to 61 mm SL (shell length) compared with New South Wales populations, where they live until 1–2 years of age and grow to 75 mm SL i.e., faster growth and more rapid turnover of populations. In South Australia, maturity (50 percent) is reached at 10 months of age and 28 mm SL and in New South Wales maturity is reached at 1 year of age and 37 mm SL reflecting their faster rate of growth. Pipi are highly fecund, and their populations can exhibit large natural fluctuations (Boyd 2017). Their larvae can be widely dispersed geographically, meaning than a population in one area can be a source of recruitment for areas towards which currents flow transporting larvae (Miller et al. 2013). Nevertheless, localised recruitment patterns will be important given the geographically fragmented distribution of this species because suitable habitat is interspersed with extensive areas of rocky reef along much of the Victorian coastline where larvae are unlikely to survive. This at least in part explains observed natural fluctuations in abundance.

Management/Assessment Unit

Victorian Pipi stocks support recreational and commercial fisheries in several main areas along the Victorian coastline from west to east including Discovery Bay, Fairhaven, Venus Bay, and Ninety Mile Beach.

Commercial fisheries occur mainly in Discovery Bay (DB) which as one of five management zones is further divided into areas east and west of Sutton Rocks (DBW, DBE), and to a lesser extent in Venus Bay (VB). The other commercial fishery management zones include the Western Zone (WZ), and Eastern Zone (EZ) which straddles VB (Table 1; see also Appendix I for maps). DBW, DBE, and VB have each had a total allowable commercial catch (TACC) since 2020.

Recreational fisheries occur state-wide including coastal beaches, bays, and inlets, although the predominant recreational harvest areas are also at Venus and Discovery Bays. There is a recreational only area where commercial fishing is prohibited along the coast separating Anderson's Inlet from Bass Strait adjacent to the western boundary of VB (Appendix I).

As DB supports the bulk of the commercial fishery, this management zone (Figure 1) is currently used to assess the state of stocks throughout Victoria. The catch reporting codes for statistical grid blocks in DB are D1 (plus 38 for older data prior to the current fishery) for DBW, and D2, E2 and E3 for DB (Appendix I). Code E1 is only included in zone-wide catch totals as it is offshore, but there was some boundary confusion among operators when this system of grid/block codes were first introduced for catch and effort returns.

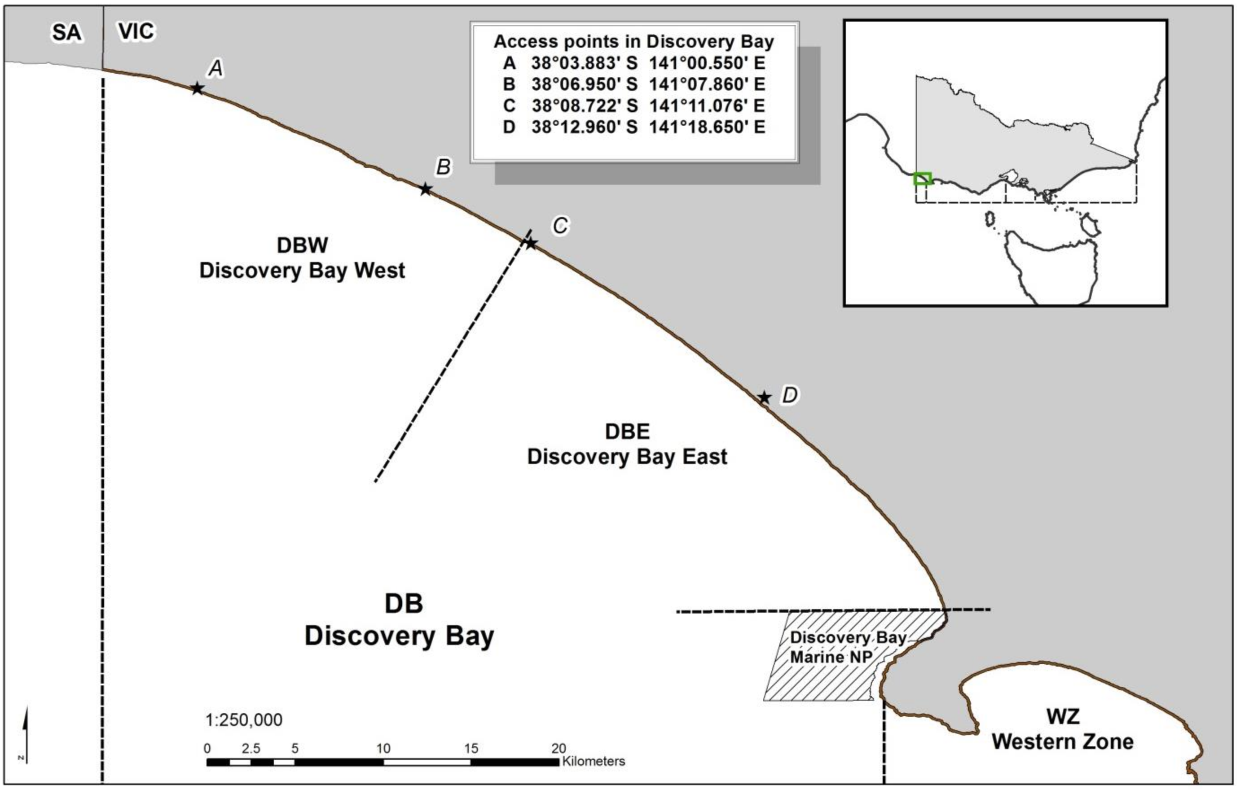


Figure 1. Discovery Bay commercial Pipi zones.

Table 1. Management zones for commercial Pipi and recreational only fishing in Victoria including the two sub-zones in Discovery Bay.

Zone	Description	Coordinates	
DBW	From the South Australian / Victorian border to Sutton Rocks, Discovery Bay.	From To	38° 03.383' S 140° 57.933' E 38° 08.633' S 141° 10.900' E
DBE	From Sutton Rocks, Discovery Bay, to the northern border of Discovery Bay Marine National Park.	From To	38° 08.633' S 141° 10.900' E 38° 20.000' S 141° 23.000' E
WZ	From the southern border of Discovery Bay Marine National Park to the most seaward point of Point Lonsdale	From To	38° 22.748' S 140° 57.933' E 38° 17.535' S 141° 10.900' E
EZ	From the most seaward point of Point Nepean to the New South Wales / Victorian border	From To	38° 18.215' S 141° 10.900' E 38° 30.304' S 141° 23.000' E
VB	From the southern boundary of the 'recreational only' area to the western most point of the entrance to Shallow Inlet	From To	38° 38.866' S 145° 50.000' E 38° 52.550' S 146° 11.600' E
Rec only	Commercial fishing prohibited	From To	38° 38.883' S 145° 43.850' E 38° 43.866' S 145° 50.000' E

Assessment

For this assessment the status of the Pipi stock was evaluated using:

- Nominal CPUE trends for the commercial fishery based in the Discovery Bay area. The performance of the CPUE biomass proxy was assessed in relation to possible reference points consistent with the national harvest strategy guidelines.
- Commercial catch data.
- Fishery independent estimates of biomass from field surveys.

Note: Recreational catch data were unavailable.

This assessment shows:

Fishing pressure –

Most Pipi are taken from Discovery Bay accounting for 94% of the cumulative commercial catch landed since 2009. Infrequent, small, catches of Pipi have been reported since 1990, however it was not until 2011 that the fishery developed and substantial quantities began to be landed. The DB catch during 2013/14 to 2015/16 fishing years was maintained at around 80–90 tonne, but decreased by about 40–50% over the following six years. Some of the reduction in catch arose from the 3-year closure of DBE during the fishing years 2014/15–16/17 followed by catch restrictions when it reopened in September 2017. RestrIctions were a daily catch limit of 150 kg and an effort limit of 8 fishing days per month, imposed by VFA on each licence as the fishery transitioned to quota management which was introduced in 2020/21. Thes restrictions were then revoked. Since fishing resumed in DBE there has been a marked shift in catch away from DBW, as occurred in 2011/12, but for a much smaller (about half) total catch when eight Pipi fishery accesss licences were first issued for Discovery Bay.

Fishing effort increased markedly with the development of the fishery to a peak of 1200 h in 2014/15, then reducing 22% for the next three years before returning to a second slightly higher pear of 1281 h in 2018/19. It must be noted, however, that past inconsistencies in reporting of gears and the number of fishers operating on a given day, largely because the ocean access logbook was poorly designed to record Pipi fishing, means that early fishing effort within this fishery may be inaccurate.

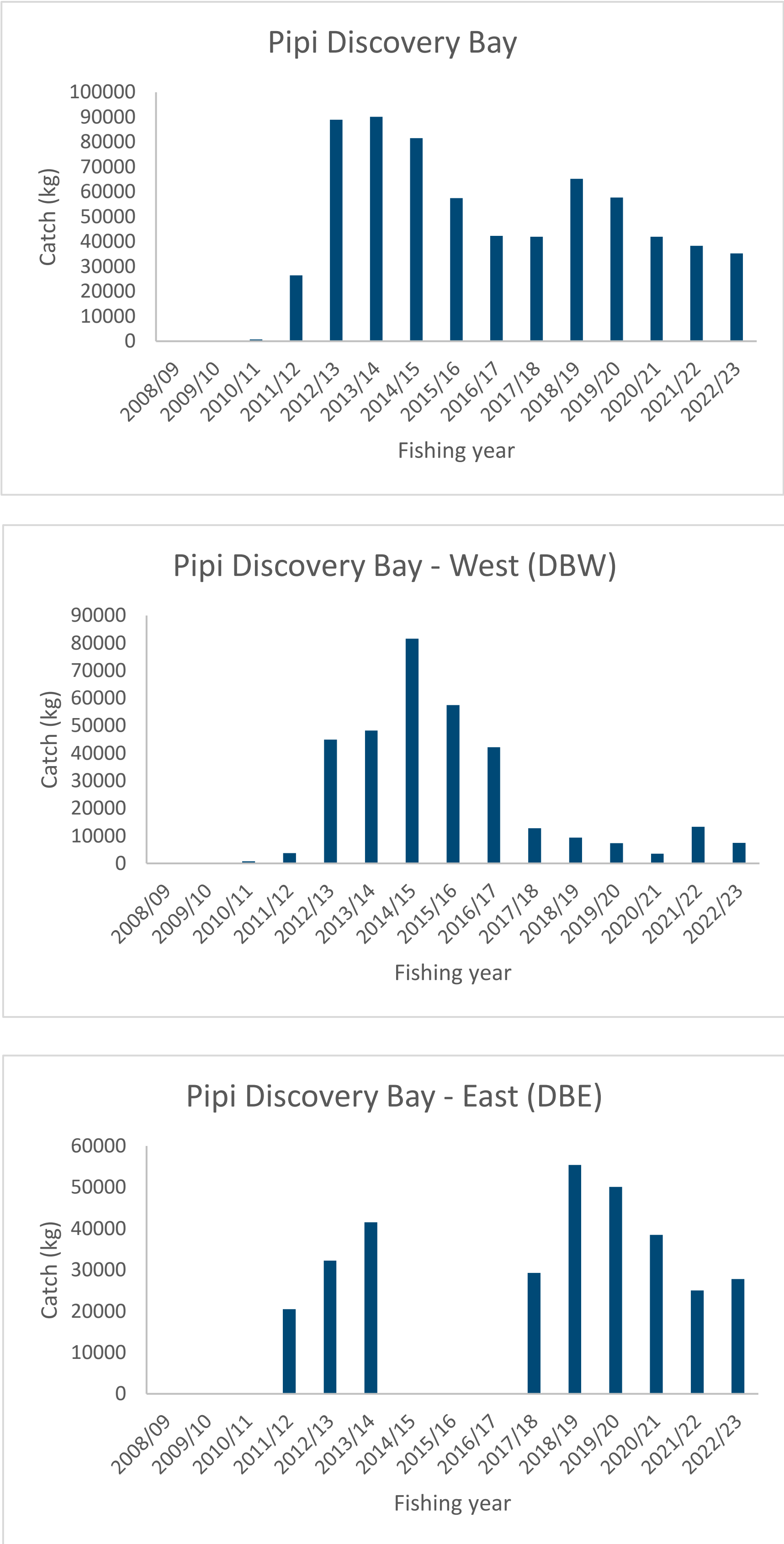


Figure 2. Victorian commercial catches of Pipi from Discovery Bay (total and by area i.e., DBW & DBE) during the fishing years 2008/09–2022/23 plus 2023. Note: the 2022/2023 data points are for only the first 9 months of this fishing year. Area Code E1 catches are only included in total not the zone due to reporting being confounded between West and East zones.

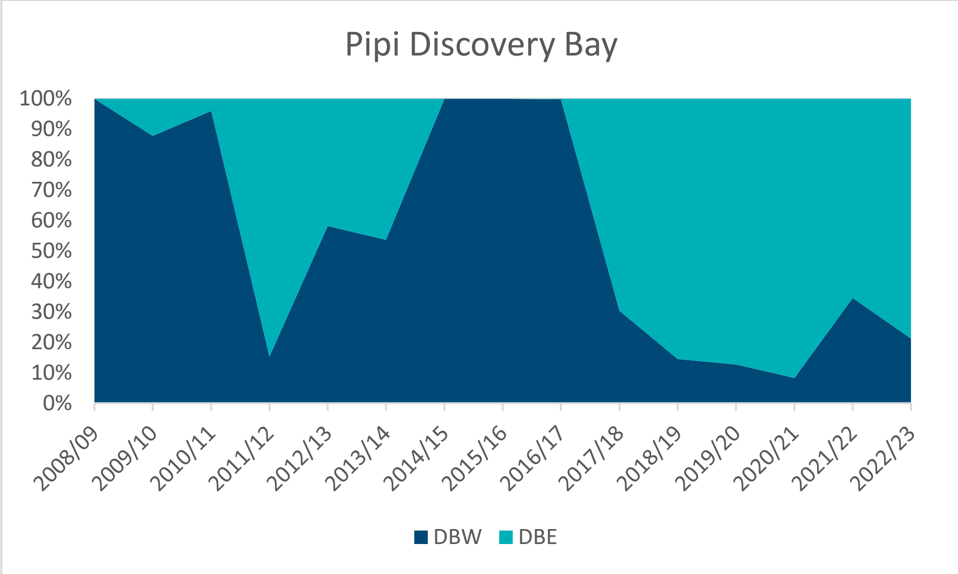


Figure 3. Proportion of catch distributed between the two areas (West = DBW, East = DBE) in Discovery Bay from the 2008/09 fishing year onwards. Note: the 2022/2023 data point is for only the first 9 months of this fishing year.

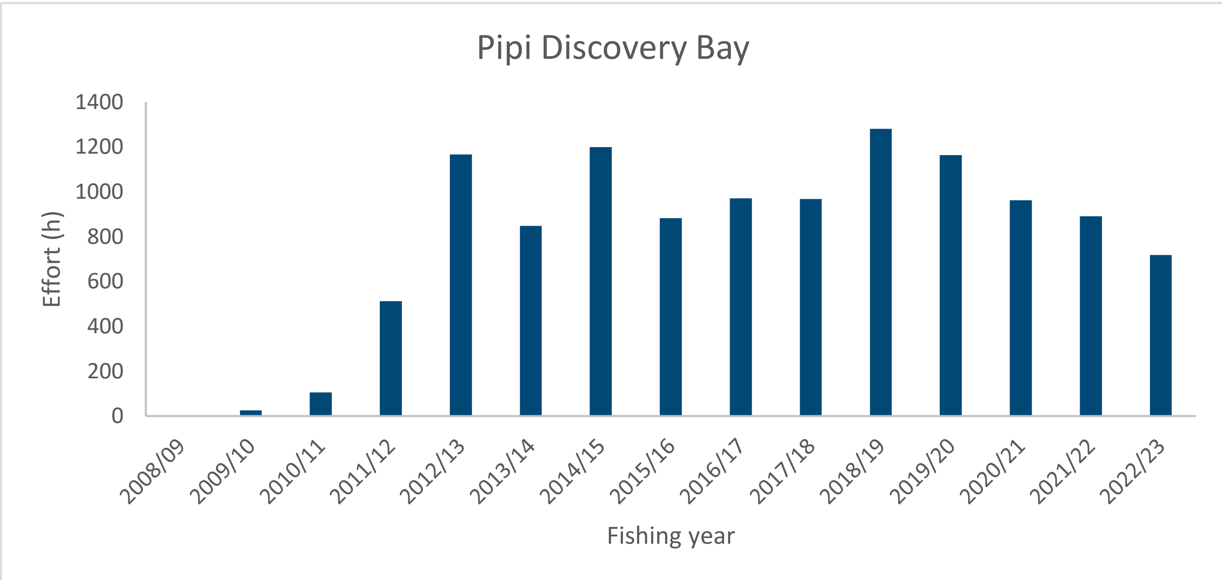


Figure 4. Total effort reported for Pipi fishing in Discovery Bay from the 2008/09 fishing year onwards. Note: the 2022/2023 data point is for only the first 9 months of this fishing year.

Biomass –

Fishery dependent

During the brief period that this fishery has been operating on a stand-alone basis under quota management there have been relatively large shifts in CPUE from typically as low as 10 kg/hr to up to the vicinity of 40+ kg/hr, with the fitted surves from a generalised additive model (GAM) indicating that there have either been large increases in the biomass of Pipi in Discovery Bay, or that fishing practices have changed (Figure 5). Either hypothesis is plausible, especially when considring that Pipi being a short-lived species could be expected to exhibit large natural variation in their abundance depending on recent, presumably localised recruitment; and the reporting of effort for this fishery has varied through time with fishers not initially required to report the number of participants per licence involved in fishing operations, which may have changed through time thereby confounding the interpretation of the standardisd CPUE from generalised linear mixed modelling (GLMM, see Appendix II for modelling details) in terms the explanatory variables of fisher (PFN), month (as a proxy for seasonal differences), area code, and their interactions (Figure 6). In DBE the 3-year closure caused sufficient disruption in the data time series to preclude its standardization, but the GAM output for the past three years shows an increase during the past year (Figure 5), and nominal (raw) CPUE has been relatively consistent and high during the past six years (Figure 7).

CPUE is showing a clear overall positive trend in the DB zone, with standarised values increasing by about 1.5 times (54% more DB zonewide & 46% DBW) since TACCs were introduced (Figure 6), Nothwsothdtadign this result, there may be masking of different localised patterns caused by spatial shifts in effort. In the end, the data that are available limit the interpretation and even for a short-lived species like Pipi, 13 years is not a lot of time for detecting trends when as a higly fecund species producing sporadic but large numbers of larvae the stock will be affected by natural cycles of population recruitment with large amplitudes. Apart from CPUE being a biomass proxy vulnerable to influence from non-biological factors, it is challenging to differentiate between the impact of fishing mortality and effects of environmental changes, be they trends or cycles. In both instances these can cause fluctuating patterns, although this may be more likely with environmental effects, especially if fishing patterns remain consistent as may occur with quota management. It can certainly be the case that environmentally driven alternating peaks and troughs obscure trends in either direction due to fishing mortality that would otherwise be evident if the environmental effects were less variable. The reverse can also apply where patterns in fishing practices and distribution of effort can obscure the effects of biological and environmental drivers. In the absence of monitoring in areas that are similar to the main exploited areas of the fishery but are not subject to fishing, such as marine protected areas, and comparing the patterns between fished and unfished areas, the effects of natural fluctuations will remain confounded with those from fishing and any interpretation will be subjective and prone to error. As time series develop, these kinds of errors should diminish to provide a clearer picture of stock status. The standardised trends allow for the effects of differences among fishers and season but not necessarily changes in the collective fishing practices of operators. Variation in the CPUE for DBW is larger than for DB as a whole, consistent with the 3-year hiatus in fishing in DBE and spatial shifts between the two sub-zones after fishing resumed. These statistical differences may have little to do with stock biomass and more likely reflect the management and operation of the fishery, including beach access issues.

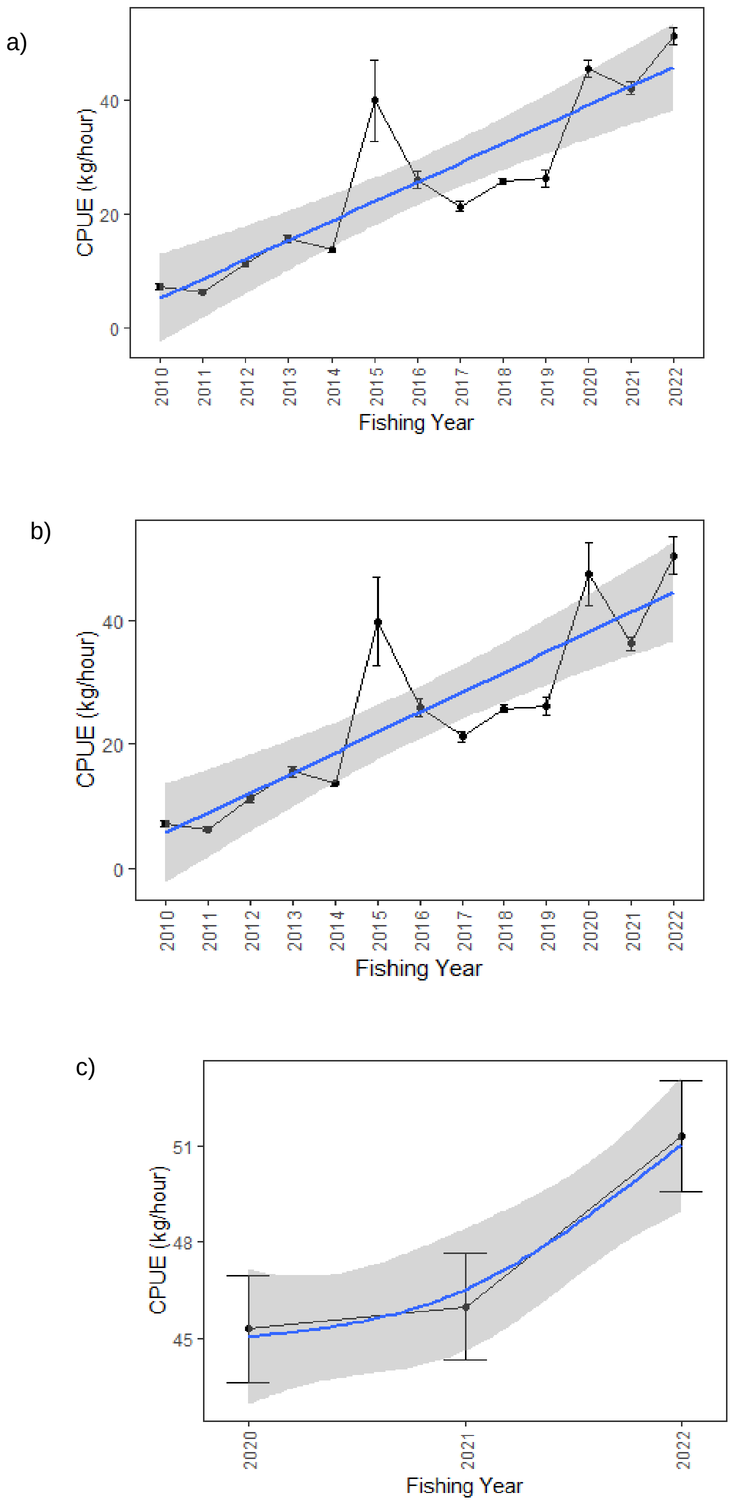


Figure 5. Pipi catch-per-unit-effort for the a) Discovery Bay overall, b) West (DBW), and c) East (DBE) plotted from filtered raw data with standard errors (in black) and smoothed fitted curves (blue lines from a generalised additive model or GAM) showing 95% confidence intervals (grey shading). Note: In DBE only the last three years are displayed because of the 3-year closure of this zone limiting analysis of the series; and the 2022/2023 data point is for only the first 9 months of this fishing year.

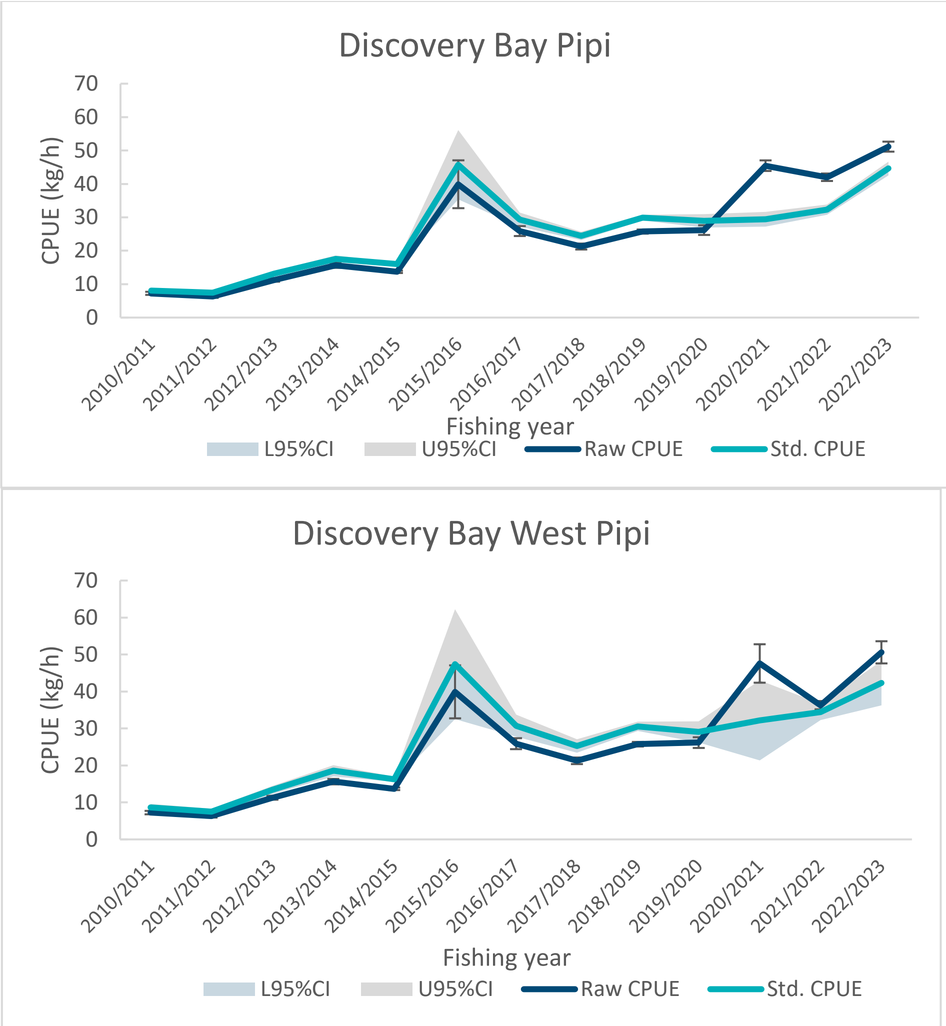
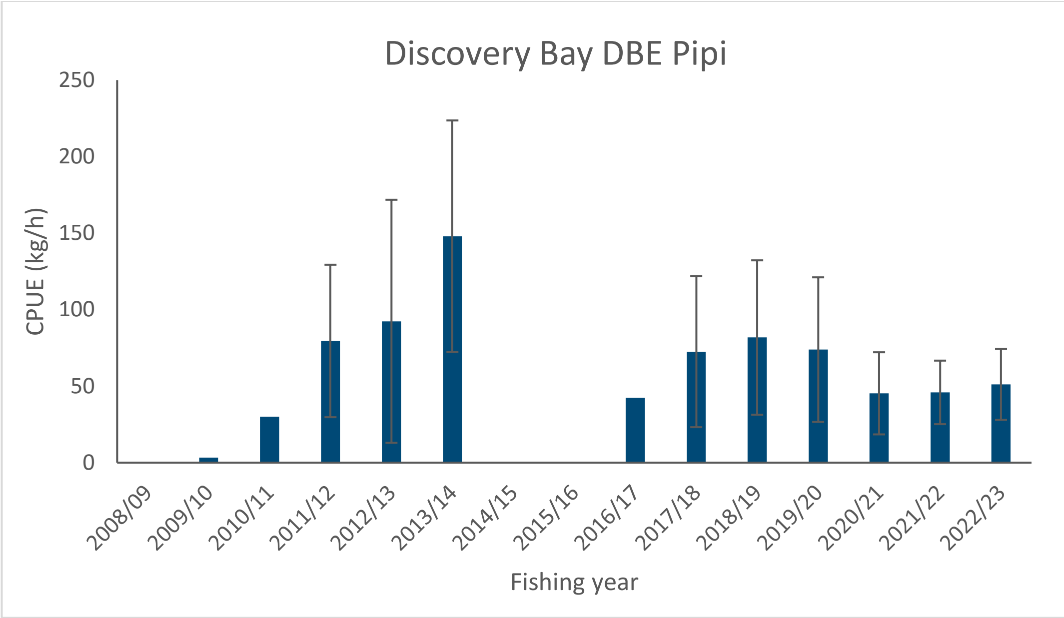


Figure 6. Catch-per-unit-effort (CPUE) in Discovery Bay overall and the western zone only, during 2010–2022 fishing years. Dark blue line is nominal CPUE (±SE), teal line is the standardised series (generalised linear mixed model or GLMM) with year as a fixed explanatory factor and differences among fishers, months and how fishers' catching efficiency in different zones and years affects the CPUE trend at random. The shaded grey area around the CPUE trend is the 95% confidence interval of the estimates predicted by the model. Note: i) although there was a small catch of Pipi by trawl/seine fishers prior to 2010, a targeted fishery only began to develop in 2009 in Discovery Bay and during this year there was minimal effort that was not reflective of catch rates in later years, so it was omitted from the time series, ii) the 2022/2023 data points are for only the first nine months of this fishing year.



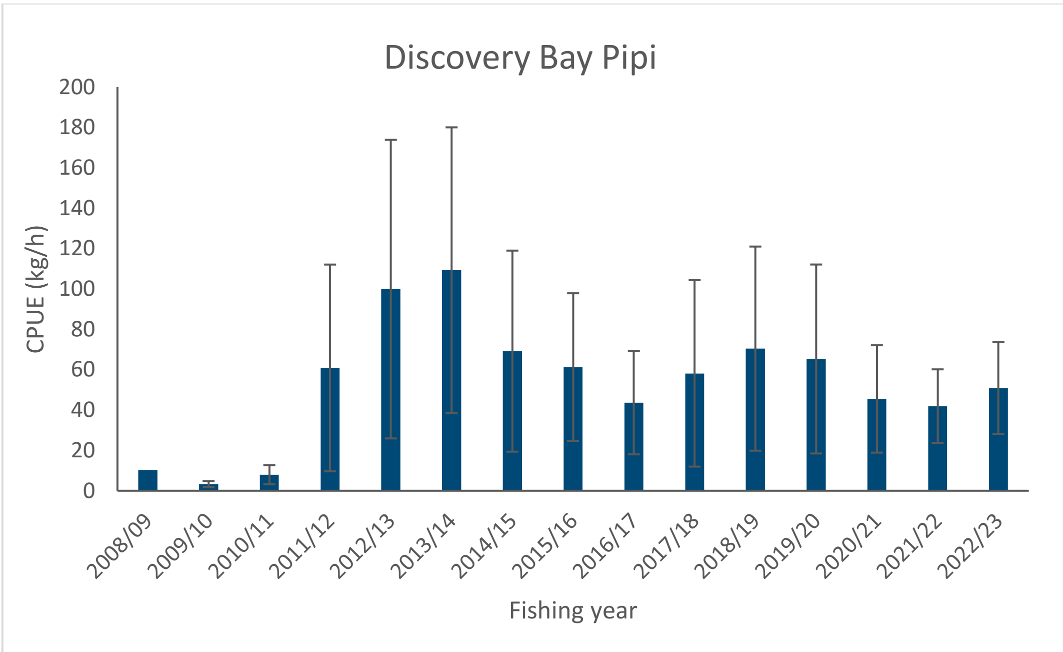


Figure 7. Average CPUE for raw data for the Discovery Bay East (DBE) and the Bay (DB) as a whole. Error bars represent one standard deviation either side of the mean value. The three missing years while DBE was closed preclude standardization and statistical analysis of trends.

Fishery independent

- As only one independent survey has been completed and in the absence of any historic benchmark the data must be treated as stand-alone which limits analysis and interpretation.

  In the absence of estimates prior to the inception of the fishery, pre-fished biomass B_{zero} has been estimated as the maximum density observed for each area surveyed, expressed as kilograms per linear kilometre. The respective maxima were then multiplied by 0.48, 0.4, and 0.2 to obtain target B_{48}, trigger B_{40} and limit B_{20} reference points that invoke yet to be determined harvest control rules which can be used to determine TAC adjustments &/or changes in other management parameters.
- Comparison with potential reference points indicates that the current level is between the limit value and trigger, implying that some form of management intervention is warranted. Currently the average abundance or biomass is 1.91 kg/h or 1.24 kg/100m in Discovery Bay West which are well above the respective limits for these measures of 1.59 kg/h and 1.05 kg/100m but substantially below, at only half, the the target reference point values of 3.80 kg/h and 2.51 kg/100m. In Discovery Bay East biomass was estimated to be substantially larger at 3.94 kg/h or 2.72 kg/100m but nevertheless lie between the limit and trigger referent points (2.24–4.48 kg/h, and 2.24–4.48 kg/100m.

Table 2. Estimates of relative biomass (kg/h) and potential stock biomass performance measures based on national harvest strategy guidelines. All values other than % are expressed in kg/h of survey transect.

Area	$B_{current}$	SD	B_{zero}	B/B_{zero}	B_{20}	B_{40}	B_{48}
Discovery Bay West	1.91	2.26	7.93	50%	1.59	3.17	3.80
Discovery Bay East	3.94	4.06	11.19	55%	2.24	4.48	5.37
Fairhaven	0.10	0.13	0.38	44%	0.08	0.15	0.18
Venus Bay	0.05	0.10	0.37	41%	0.07	0.15	0.18
90-Mile Beach	0.12	0.19	0.53	37%	0.11	0.21	0.25

Estimates from surveys for other locations in Victoria are presented to illustrate how much the biomas can vary spatially, although more replication in terms of additional sampling sites would be needed to refine these estimates which were an order of magnitude lower than those for Discovery Bay. It does, at least, explain why the commercial fishery is centred on Discovery Bay with much lower quantities, sufficient perhaps to satisfy the expectations of recreational fishers. Venus Bay, a recreational only area, is the only instance for the kg/h meaure that was below the limit reference point whereas both Venus Bay and 90-Mile Beach (where commercial hsrvesting is permitted) were at or below the limit for the kg/100m measure.

Table 3. Estimates of relative biomass (kg/100m) and potential stock biomass performance measures based on national harvest strategy guidelines (Appendix II – Generic harvest strategy approach consistent with national guidelines in Australia). All values other % are expressed in kg/100m of survey transect.

Area	$B_{current}$	SD	B_{zero}	B/B_{zero}	B_{20}	B_{40}	B_{48}
Discovery Bay West	1.24	1.48	5.23	50%	1.05	2.09	2.51
Discovery Bay East	2.72	2.78	7.42	55%	1.48	2.97	3.56
Fairhaven	0.06	0.07	0.20	45%	0.04	0.08	0.10
Venus Bay	0.03	0.06	0.20	42%	0.04	0.08	0.10
90-Mile Beach	0.06	0.10	0.29	36%	0.06	0.12	0.14

The fishery independent surveys conducted in Discovery Bay had marginally acceptable levels of sampling precision (replication) as demonstrated by their coefficients of variation (CV) being mostly less than 50%, which is a measure of uncertainty (standard error) divided by the average value (mean), with lower uncertainty relative to average biomass providing greater confidence in the biomass as estimated and the sensitivity of the estimate to change. Typically, values of 25% or less are considered acceptable in terms of the probability of detecting significant changes from year to year. Venus Bay and 90-Mile Beach had CVs > 50% indicating greater replication (cost) would be required to use them in a quantitative assessment, but they are included here more for illustration of how much lower the biomass was among them compared with Discovery Bay. All size classes were included in the estimates presented because confining the analysis to those with shells larger than 34 mm showed negligible difference.

It is unclear if the larger biomass in DBE compared with the DBW of Discovery Bay has arisen from the 3-year moratorium, but aside from natural variation this could be one possible explanation. It is important to note that the inclusion of this analysis in the absence of any time series is to illustrate how a harvest strategy could be applied to assist with managing the fishery, specifically to inform TAC decisions. The performance measures, chosen reference point values for those measures, and the harvest control rules linked with them, would need to be subjected to a formal management strategy evaluation (MSE) prior to implementation and this is not a trivial undertaking, especially in a data limited situation. Notwithstanding this caveat, application of the fishery independent survey estimates in the absence of a formal harvest strategy framework would be highly subjective and difficult to defend from a scientific perspective.

Summary

Encouragingly, CPUE is showing both long and short-term trends, the latter with a 1.5 times increase since quota introduction in 2010/11. Boh trends are strongly influenced by the most recent data point which accounts for catch and effort reporting for three-quarters of the 2022/23 fishing year, yet by the end of March 2023 it is possible that this value could be lower thereby affecting the trend. The postive slope of the long-term trend since 2010/11 is stongly influenced by low CPUE values as the fishery developed. Clearly catch and effort have been quite changeable as th fshery hs prpgressed through different developmental phases and more time is needed under quota for the fishery to settle into a more stable situation to allow confidence in apparent trends in CPUE as a stock biomass proxy. Spatial considerations are important and serial depetion is an ever-present risk that can be best addressed by spatially explicit data. One advantage of commencing fishery independent biomass surveys is that there is a possibility that effort, and hence CPUE, is inaccurate due to differences over time in what has been reported. This implies there is a possibility that changing fishing practices e.g., additional people catching Pipi under the same licence could be masking changes in biomass. Now that the number of fishers is reported in logbooks it will be important to continue monitoring CPUE into the future in conjunction with industry consultation to ascertain whether fishing practices have changed through time. This will assist with determining whether historic CPUE are likely to be biased and can be discounted as more years pass and there is more confidence in the contemporary CPUE, which will increase in its information value. Nevertheless, there is nothing in the CPUE data that would suggest that the stock biomass is undergoing any overall decline in Discovery Bay.

Additionally, a sizeable recreational fishery exists, particularly in Venus Bay, and yet recreational catches remain unknown and current creel surveys are restricted geographically to bays and estuaries so do cover the Victorian Pipi resource. Fishery independent biomass estimates based on a single survey show that the current value of 2.92 kg/m is close but somewhat below a conservatively estimated potential trigger reference point of 3.32 and it would be desirable if the biomass could be managed for improvement so that this estimate increased by about 30% i.e. towards 4 kg/m. One caveat on this conclusion is that interannual variability in these estimates is unknown but is likely to fluctuate naturally especially as climate change will be a persistent driver of reduced productivity among many species, as has recently been demonstrated for abalone populations in this region. Pipi are filter feeders so the availability of nutirents and associated densities of suitable phytoplankton that are sensitive to water temperature and hydrodynamics will mediate future Pipi productivity.

Given the uncertainty and relative brevity of the CPUE series and that independent surveys have only recenltly commenced, and much more work would be required to develop a formal harvest startegy, the current status of the Victorian Pipi stock remains uncertain although it appears unlikely to be depleted. Biomass from the fishery independent surveys will require more years of data and and the harvest startegy results are included more for illustrative purposes and ongoing discussion not for management action. It is advisable that harvest strategies be subject to a comprehensive management strategy evaluation (MSE) via testing prior to implementation. Nevertheless, uncertainy is no reason to avoid management intervention if there is compelling subjective evidence that fishing mortality in some areas might be too high for biomass levels to persist in the medium to longer term. There is no such evidence at present. Improvements in knowledge about Pipi popualtion biology and ecological interactions will also influence approaches to managing for sustainable outcomes and stakeholders harvesting from dyanmical systems need to be receptive to change in this regard.

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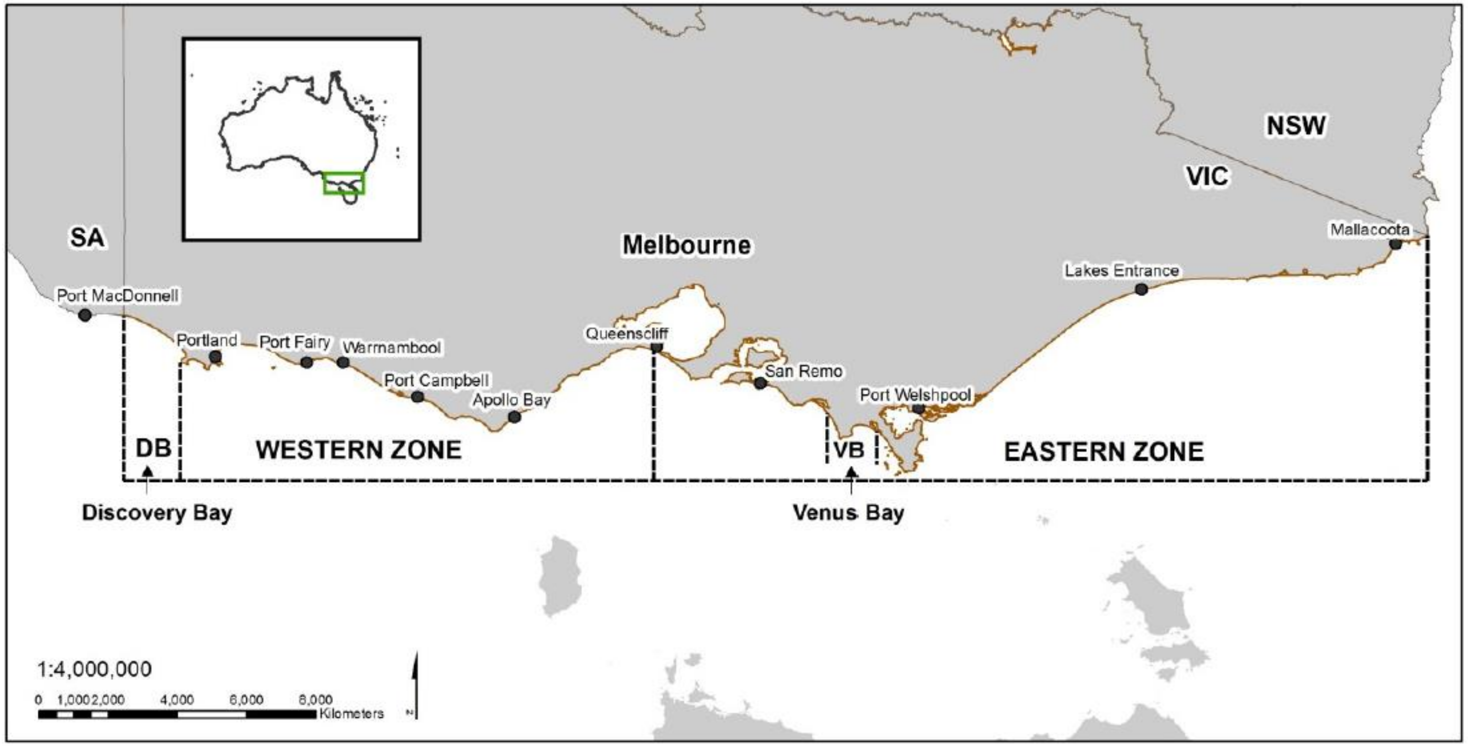
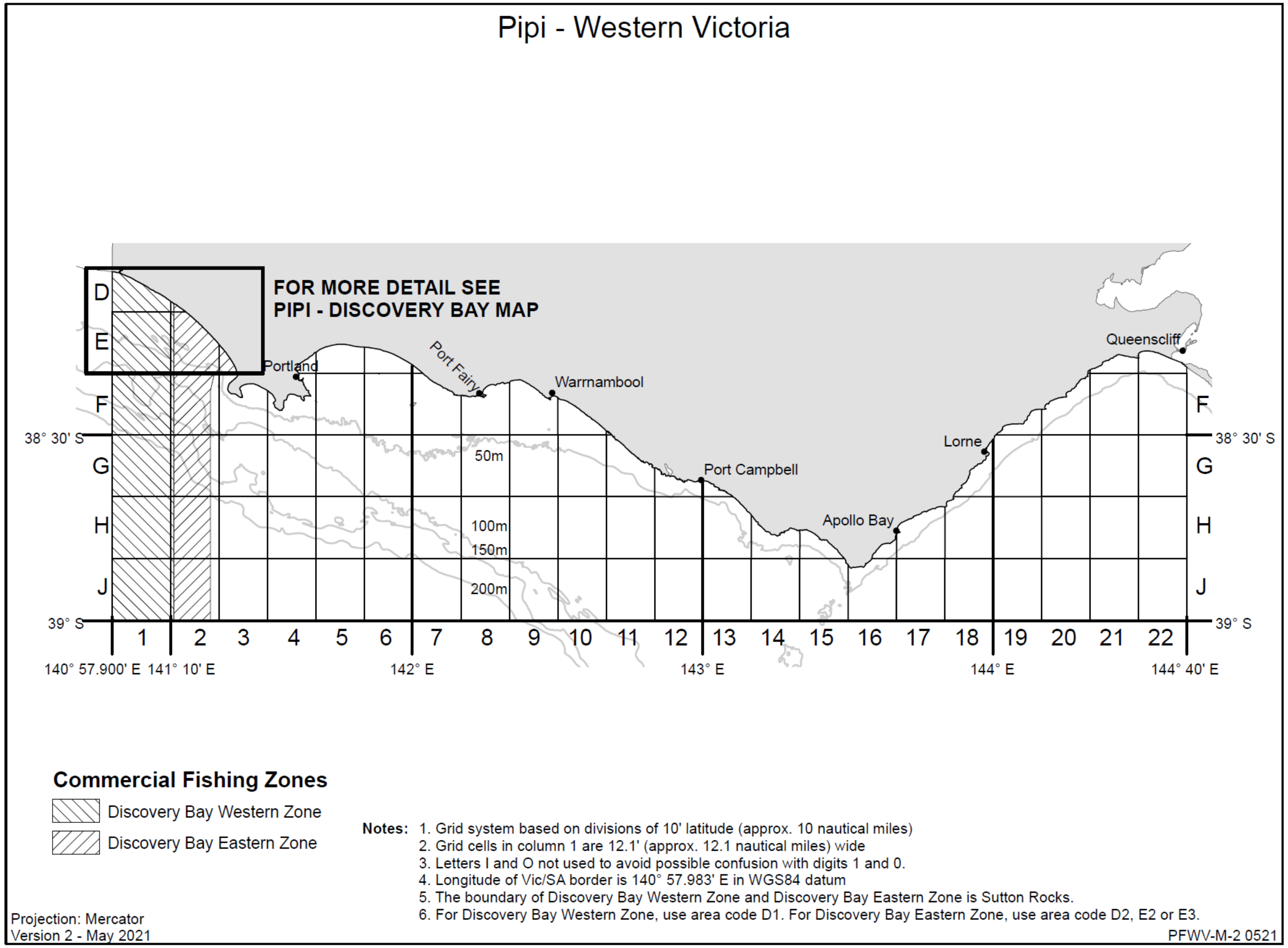
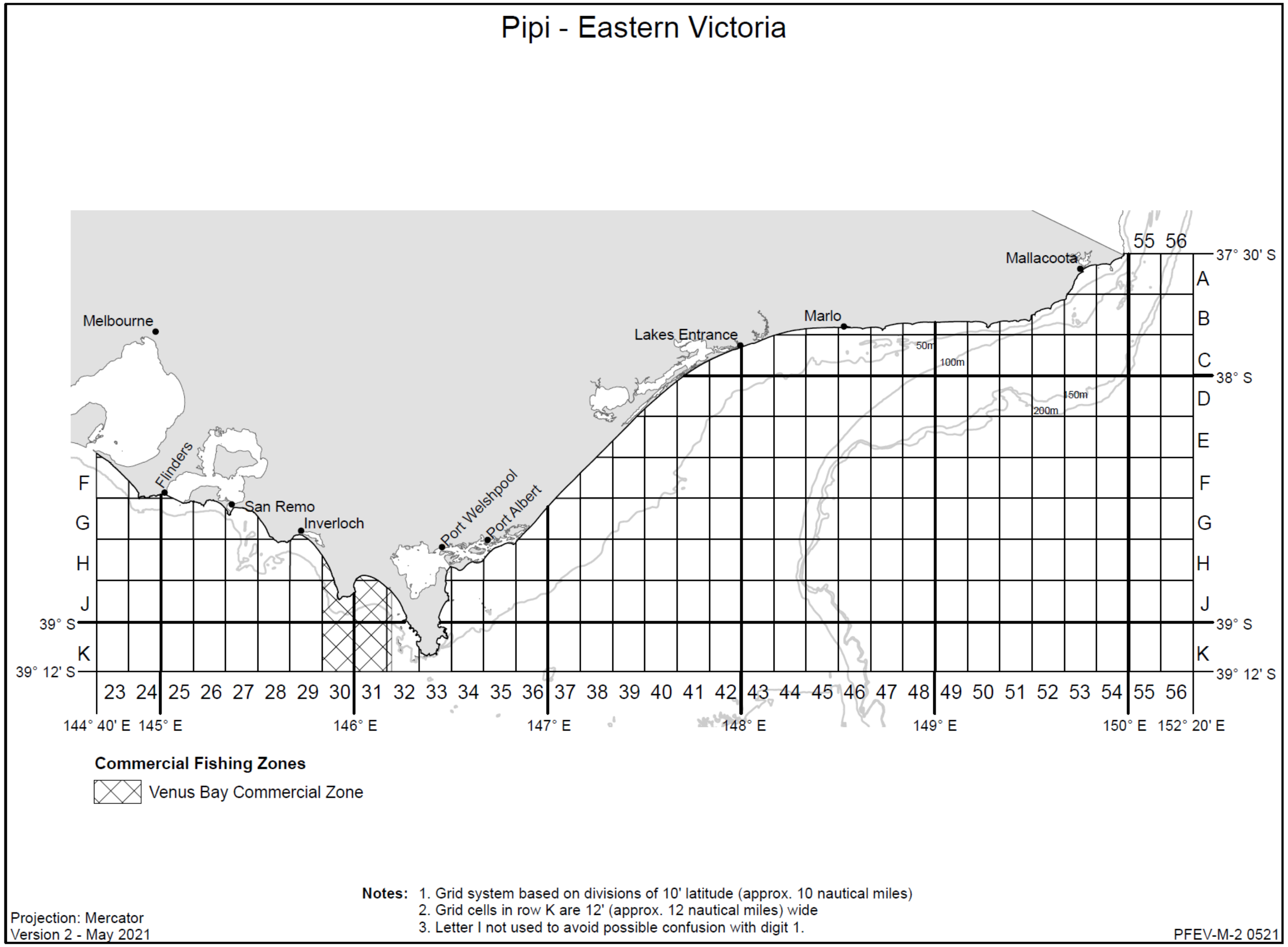
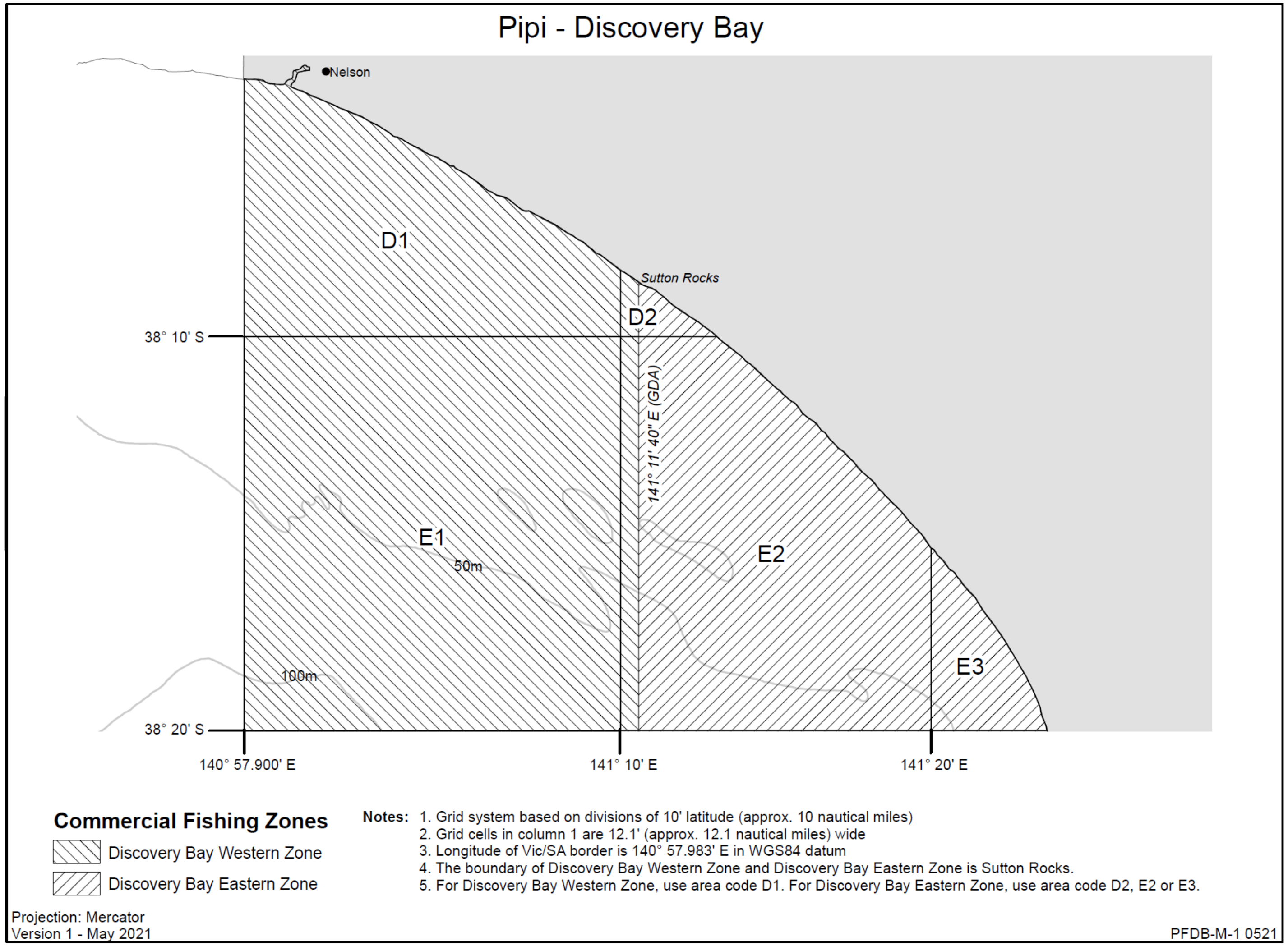
Murray-Jones SE and Ayre, DJ (1997), High levels of gene flow in the surf bivalve *Donax deltoides* (Bivalvia: Donacidae) on the east coast of Australia, *Marine Biology*, 1(128): 83–89. DOI: 10.1007/s002270050071.

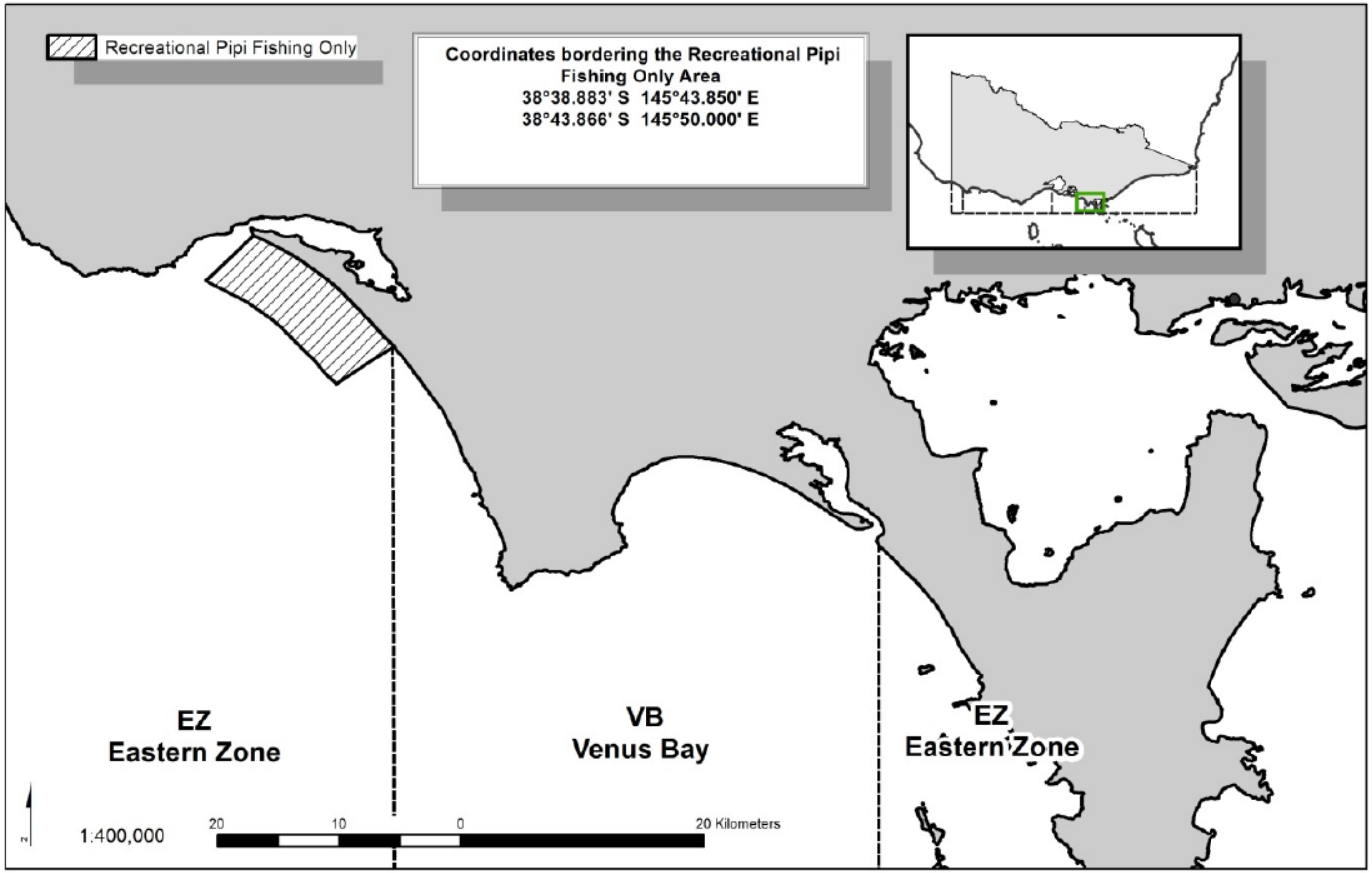
Appendix I – Victorian Pipi fishery maps for management & commercial catch reporting




Pipi - Western Victoria
FOR MORE DETAIL SEE
PIPI - DISCOVERY BAY MAP
Portland
Port Fairy
Warrnambool
Port Campbell
Apollo Bay
Lorne
Queenscliff
50m
100m
150m
200m
D
E
F
G
H
J
38° 30' S
39° S
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
140° 57.900' E
141° 10' E
142° E
143° E
144° E
144° 40' E
Commercial Fishing Zones
Discovery Bay Western Zone
Discovery Bay Eastern Zone
Notes: 1. Grid system based on divisions of 10' latitude (approx. 10 nautical miles)
2. Grid cells in column 1 are 12.1' (approx. 12.1 nautical miles) wide
3. Letters I and O not used to avoid possible confusion with digits 1 and 0.
4. Longitude of Vic/SA border is 140° 57.983' E in WGS84 datum
5. The boundary of Discovery Bay Western Zone and Discovery Bay Eastern Zone is Sutton Rocks.
6. For Discovery Bay Western Zone, use area code D1. For Discovery Bay Eastern Zone, use area code D2, E2 or E3.
Projection: Mercator
Version 2 - May 2021
PFWV-M-2 0521


Pipi - Eastern Victoria
Melbourne
Flinders
San Remo
Inverloch
Port Welshpool
Port Albert
Lakes Entrance
Marlo
Mallacoota
50m
100m
150m
200m
A
B
C
D
E
F
G
H
J
K
37° 30' S
38° S
39° S
39° 12' S
23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
144° 40' E 145° E 146° E 147° E 148° E 149° E 150° E 152° 20' E
Commercial Fishing Zones
Venus Bay Commercial Zone
Notes: 1. Grid system based on divisions of 10' latitude (approx. 10 nautical miles)
2. Grid cells in row K are 12' (approx. 12 nautical miles) wide
3. Letter I not used to avoid possible confusion with digit 1.
Projection: Mercator
Version 2 - May 2021
PFEV-M-2 0521


Pipi - Discovery Bay
Nelson
D1
Sutton Rocks
D2
38° 10' S
141° 11' 40" E (GDA)
E1
50m
E2
E3
100m
38° 20' S
140° 57.900' E
141° 10' E
141° 20' E
Commercial Fishing Zones
Discovery Bay Western Zone
Discovery Bay Eastern Zone
Notes: 1. Grid system based on divisions of 10' latitude (approx. 10 nautical miles)
2. Grid cells in column 1 are 12.1' (approx. 12.1 nautical miles) wide
3. Longitude of Vic/SA border is 140° 57.983' E in WGS84 datum
4. The boundary of Discovery Bay Western Zone and Discovery Bay Eastern Zone is Sutton Rocks.
5. For Discovery Bay Western Zone, use area code D1. For Discovery Bay Eastern Zone, use area code D2, E2 or E3.
Projection: Mercator
Version 1 - May 2021
PFDB-M-1 0521


Recreational Pipi Fishing Only
Coordinates bordering the Recreational Pipi Fishing Only Area
38°38.883' S 145°43.850' E
38°43.866' S 145°50.000' E
EZ
Eastern Zone
VB
Venus Bay
EZ
Eastern Zone
1:400,000
20
10
0
20 Kilometers

Appendix II – analytical methods for CPUE data

CPUE data were standardised using a Generalised Linear Mixed Model (GLMM) which allows for fixed and random factors to be included to separate out the overall trend in changes from one fishing year to the next from the influence of seasonal (month) and operational (pfn) factors. The GLMM analysis used the open-source statistical software R [version 4.1.1 (2021-08-10), R Core Team, 2021, The R Foundation for Statistical Computing https://www.r-project.org) to run the statistical package glmmTMB (Brooks et al, 2017).

The distribution of CPUE values in the dataset was firstly plotted and the gamma distribution chosen due to the heavy right tail (Figure 8).

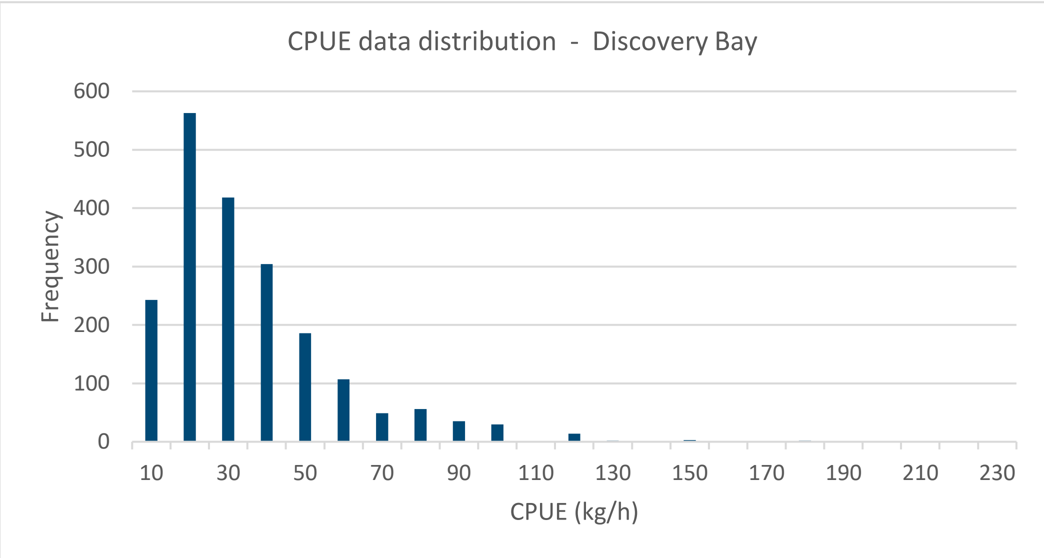


Figure 8. Frequency distribution of CPUE values input to the standardisation model showing a moderately heavy right tail that warrants specification of the Gamma distribution in the model statement.

Standardisation model code in R:

DB_model_5 <- glmmTMB(cpue+0.01 ~ Fishing_Year + (1|pfn) + (1|ShortMonthName) + (1|AreaCode) + (1|pfn:AreaCode)+ (1|Fishing_Year:pfn),

data = tempw3, family = Gamma(link="log")) #Model selected as best fit for Discovery Bay as a whole

DW_model_3 <- glmmTMB(cpue+0.01 ~ Fishing_Year + (1|pfn) + (1|AreaCode),

data = tempw3, family = Gamma(link="log")) #Model selected as best fit for Discovery Bay West (DBW)

Family: Gamma (log)

Formula:

cpue + 0.01 ~ Fishing_Year + (1 | pfn) + (1 | ShortMonthName) + (1 | AreaCode) + (1 | pfn:AreaCode) + (1 | Fishing_Year:pfn)

Example DB Model 5

Model	df	AIC
m1	18	9864.273
m5	**19**	**9851.592**
m3	16	9930.314
m4	16	9881.319

Model performance:

AIC	BIC	logLik	deviance	df.resid
9851.6	9949.1	-4906.8	9813.6	1233

Random effects:

Conditional model:

Groups	Name	Variance	Std.Dev.
pfn	(Intercept)	0.089172	0.29862
ShortMonthName	(Intercept)	0.022472	0.14991
AreaCode	(Intercept)	0.151894	0.38974
pfn:AreaCode	(Intercept)	0.002586	0.05085
Fishing_Year:pfn	(Intercept)	0.005957	0.07718

Number of obs: 2017. Groups: pfn, 6; ShortMonthName, 12; AreaCode, 5; pfn:AreaCode, 17; Fishing_Year:pfn, 50.

Dispersion estimate for Gamma family (sigma^2): 0.162

Conditional model: Estimate Std. Error z value Pr(>|z|)

(Intercept)	1.99146	0.38573	5.163	2.43e-07	***
Fishing_Year2011	-0.07457	0.14679	-0.508	0.611481	‘ ‘
Fishing_Year2012	0.49672	0.15257	3.256	0.001132	**
Fishing_Year2013	0.78357	0.15244	5.140	2.74e-07	***
Fishing_Year2014	0.69201	0.13971	4.953	7.30e-07	***
Fishing_Year2015	1.74014	0.15589	11.163	< 2e-16	***
Fishing_Year2016	1.29639	0.14404	9.000	< 2e-16	***
Fishing_Year2017	1.11367	0.14031	7.937	2.07e-15	***
Fishing_Year2018	1.31481	0.13870	9.479	< 2e-16	***
Fishing_Year2019	1.28167	0.14028	9.137	< 2e-16	***
Fishing_Year2020	1.29936	0.36823	3.529	0.000418	***
Fishing_Year2021	1.39360	0.36747	4.122	0.000149	***
Fishing_Year2022	1.71609	0.36802	4.663	3.12e-06	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

DBW Model 3 Output

Model	df	AIC
m1	18	4684.954
m5	19	4686.954
m3	**16**	**4683.170**
m4	16	4693.776

Model performance:

AIC	BIC	logLik	deviance	df.resid
4683.2	4755.1	-2325.6	4651.2	647

Random effects:

Conditional model:

Groups	Name	Variance	Std.Dev.
pfn	(Intercept)	0.07447	0.2729
AreaCode	(Intercept)	0.06148	0.2480
pfn:AreaCode	(Intercept)	0.002586	0.05085
Fishing_Year:pfn	(Intercept)	0.005957	0.07718

Number of obs: 2017. Groups: pfn, 6; ShortMonthName, 12; AreaCode, 5; pfn:AreaCode, 17; Fishing_Year:pfn, 50.

Dispersion estimate for Gamma family (sigma^2): 0.139

Conditional model: Estimate Std. Error z value Pr(>|z|)

(Intercept)	2.20598	0.33819	5.341	6.90e-11	***
Fishing_Year2011	-0.13907	0.09025	-1.541	0.123337	‘ ‘
Fishing_Year2012	0.44008	0.09817	4.483	7.36e-06	***
Fishing_Year2013	0.76662	0.09817	7.809	5.75e-15	***
Fishing_Year2014	0.63380	0.08028	7.895	2.91e-15	***
Fishing_Year2015	1.70380	0.10263	16.602	< 2e-16	***
Fishing_Year2016	1.27126	0.08666	14.670	< 2e-16	***
Fishing_Year2017	1.07447	0.08140	13.200	< 2e-16	***
Fishing_Year2018	1.26554	0.07890	16.041	< 2e-16	***
Fishing_Year2019	1.21551	0.08128	14.955	0.001217	***
Fishing_Year2020	1.31674	0.34662	3.799	0.000145	***
Fishing_Year2021	1.38526	0.33605	4.122	3.75e-05	***
Fishing_Year2022	1.58945	0.33480	4.747	2.06e-06	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

<u>Software reference</u>:

Brooks, ME, Kristensen, K, van Benthem, KJ, Magnusson, A, Berg, CW, Nielsen, A, Skaug, HJ, Maechler, M and Bolker, BM (2017), glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal, 9(2), 378–400.
see R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Appendix III – Generic harvest strategy approach consistent with national guidelines in Australia

Harvest strategies provide formal and structured frameworks that guide fishery management decision-making processes and assist in achieving fisheries management objectives by ensuring that managers, fishers, and other stakeholders understand and document how they will respond to various desirable and undesirable fishery conditions before they occur and therefore avoid ad-hoc decision-making. They bring together all the key elements and management functions used to make decisions about the level of fishing activity that should be applied to a fish stock or a management unit to maximize the likelihood of achieving ecological, economic, and social sustainability.

Harvest strategies are widely used internationally and throughout Australian fisheries management jurisdictions and represent a best-practice approach to fisheries management decision-making (Sloan *et al* 2014).

Effective fisheries harvest strategies are comprised of three key components that guide fishery managers and stakeholders in ensuring the sustainability of the fishery:

- *Objectives*: clearly stated policy and/or management objectives often related to ensuring biological sustainability, security of access and/or socio-economic benefits;

- *Performance indicators*: one or more indicators used to track performance of each of the objectives; their values are linked to defined reference points or benchmarks called targets (where we want the fishery to be), triggers (early warnings that the fishery has deteriorated to a point where action should be taken) and limits (where we do not want the fishery to be (Figure 9); and

- *Harvest control rules*: predetermined management responses, usually controls on harvest or effort, which are invoked when a performance indicator is above, below or between specific reference points.

To reduce the risk of reaching the limit reference, it is necessary to establish trigger levels that provide early warning to management and industry that the fishery status has deteriorated to a point where management action can be taken in a timely manner to prevent the limit being breached and therefore reduce the risk of a fishery collapse.

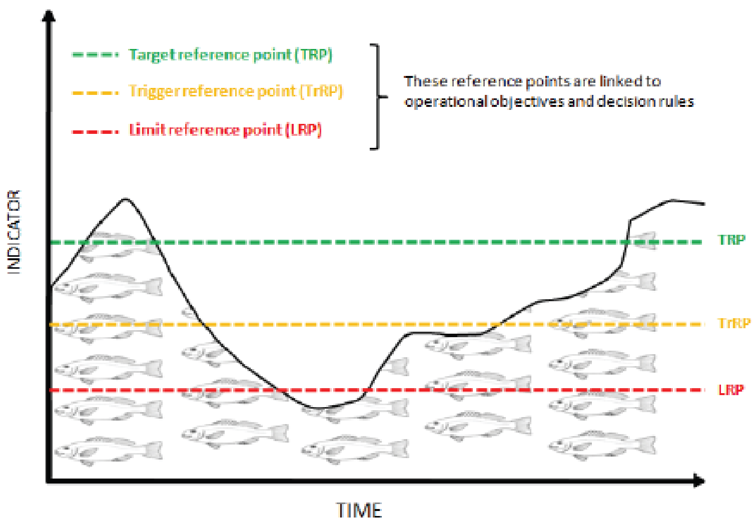


Figure 9. Graphical representation of the relationship between a stock performance indicator and the reference points (Sloan et al 2014). Note that the indicator data used in this graph is for illustration purposes and does not reflect the performance of the Victorian commercial Pipi fishery.

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