2014-2024 Macquarie Harbour Maugean skate population status and monitoring report

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This report highlights the critical need for continued monitoring of the Maugean skate (*Zearaja maugeana*) population. The sampling method facilitates a measure of catch per unit effort (CPUE) which serves as a proxy for relative abundance. Previous reporting on CPUE demonstrated a significant decline in CPUE between 2014 and 2022 within the harbour. Regional differences in CPUE were also evident, with significant declines in relative abundance at Table Head/Liberty Point and Swan Basin from 2014 to 2021/22, while the relative abundance in the World Heritage did not differ significantly over this period. These declines were likely driven by a combination of supressed spawning, limited hatching success and reduced juvenile survival beginning in 2009/2010 and two high impact environmental events that occurred in 2019.

Recent surveys, however, suggest a significant increase in relative abundance from 2022, with current estimates now not significantly different to 2014. This increase was observed at all three sampling sites, with estimates in 2024 not significantly different from 2014 at Table Head/Liberty Point and Swan Basin and significantly greater in the World Heritage Area.

This timing aligns with an improvement in environmental conditions within the harbour, in particular an increase in dissolved oxygen levels. Noting, that while CPUE has increased in 2023 and 2024, the standard error estimates are larger than previous years, indicating an increase in seasonal variability of catches. This may be at least partially due to changes in skate behaviour affecting catchability. Planned research on skate habitat utilisation in the harbour, combined with ongoing analysis of within-year sampling variability, will offer deeper insights into its implications.

Following an initial decline in 2009/2010, juvenile births and subsequent 'recruitment' – defined as juveniles progressing to the adult population – have generally shown a trend of year-on-year improvements up to at least 2019, with size selectivity of the sampling method influencing data interpretation beyond this point. This will be resolved as future net sampling is conducted and supporting research methodologies implemented to determine juvenile survival rates and habitat utilisation of individuals across a range of ages. Some degree of spawning success and juvenile survival, however, appears to have persisted until at least 2020, based on the capture in both 2022 and 2023 of young individuals that were likely hatched in 2020 or 2021 based on age and size cohort progression. The capture of these small animals in the nets was unusual and it is not clear at this stage whether the captures were due to availability (a disproportionate number in the harbour increasing the rate of capture) or catchability (their behaviour or location in the harbour made them more susceptible to capture). Further net sampling and possibly complementary methods to identify juveniles prior to them becoming catchable in nets is needed to assess the magnitude of this event and its eventual contribution to the breeding population.

Developing Robust Population Estimates

The deployment of 214 dart tags on released skate caught during the netting surveys since 2021 and recapture of four individuals provides a dataset to facilitate a Capture Mark Recapture (CMR) total population estimate model. A Schnabel closed population, multiple census CMR model provided a population estimate of 4,102 individuals (CI: 1,602–15,055). However, it is important to note this estimate is not directly comparable to the 3,177 individuals (CI: 1,827–6,247) estimated in 2014 reported by Bell et al. (2016) due to differences in modelling approaches and the wide confidence intervals, driven by a low number of recaptures. As highlighted in prior research, these estimates should be interpreted with caution.

Despite indications of recovery to 2014 levels, the Maugean skate population remains a species of conservation concern due to its limited distribution and susceptibility to environmental extremes. For example, the significant mortality event inferred in 2019 (Moreno et al) was driven by extreme weather that affected environmental conditions and potentially exacerbated by low oxygen levels within the harbour. Developing a robust population estimate is a key priority and understanding the populations susceptibility to these events is critical to inform recovery action. Current biological data and abundance trends provide a foundation for parameterising various population modelling approaches. Further, the exploration of novel assessment methods, integration of acoustic, sonar-based, and genetic approaches will provide a more comprehensive understanding of population dynamics, supporting effective conservation planning.

New information presented in this report provides an updated understanding of recent demographic trends in the population. Therefore, incorporating this knowledge into a revised Population Viability Analysis (PVA) framework and development of associated population models should be considered a priority. Previous versions of the PVA model and related population estimates were based on a now outdated dataset, with some previous assumptions in the framework now invalidated. Updating the PVA model will in turn result in a better characterisation of the extinction risk for the species, improve clarification of research priorities, help monitor the efficacy of current conservation actions and guide the implementation of management actions. This recommendation aligns with conservation priorities emphasising fine-tuning the PVA model to assess extinction risk and guide management strategies.

Female juvenile Maugean skate in Swan Basin. (Jane Ruckert IMAS).

Introduction

The endangered micro-endemic Maugean skate (*Zearaja maugeana*) is only known from two isolated estuarine systems located on the west coast of Tasmania, Australia, Bathurst and Macquarie Harbours, representing one of most restricted distributions of any elasmobranch (Last and Gledhill, 2007). A recent environmental DNA study (Moreno et al., 2022) has demonstrated that the vast majority, if not all, of the current population of Maugean skate live only in Macquarie Harbour. Monitoring the population of Maugean skate in Macquarie Harbour is critical to ensure the most contemporary information is available to determine population viability and apply appropriate conservation action as required. Dedicated netting surveys targeting Maugean skate in Macquarie Harbour to accommodate a range of research objectives first commenced in 2012 through to 2019, funded by FRDC, additional surveys were funded by the Sustainable Marine Research Collaboration Agreement (SMRCA) from 2021 to 2023 and the Department of Natural Resources and Environment Tasmania from 2024 to September 2025.

The first interim report in this series reported on data from the 2021 survey and a reanalysis of the survey dataset from 2012 to 2019 (Moreno and Semmens, 2023). Findings identified that the median size of females had significantly increased between 2014 and 2021, while there was no significant change in the median size of males. The proportion of juvenile and sub-adults relative to adults caught declined significantly from ~17-21% in the 2012 and 2013-2014 surveys to 2.2% in 2021. In 2014, catch per unit of effort (CPUE) was 0.17 skate caught per metre of net per hour (N/m/hr) for all sites combined. In 2021, CPUE was 0.06[1] N/m/hr. This represented a 64%[1] decline in estimated relative abundance across the harbour, this declined further in 2022 to 0.04 N/m/hr representing a 77% decline relative to 2014.

The second interim report in this series reported on the current dataset up until September 2024, including the dataset from 2012 to 2019, the 2021-2023 net surveys, and the data collected at the time from the 2024 surveys (August and September 2024). The updated relative abundance data showed an increase in CPUE to 0.11 N/m/hr and 0.13 N/m/hr respectively. This represented a relative abundance 35% and 23% below the 2014 baseline, suggesting that no further declines in adult relative abundance had occurred since 2021/22, leading to the population trend being reported as stabilised. Additionally, following a lack of juveniles or sub-adults observed in the net sampling in 2021, there were indications of limited hatchling success, juvenile survival and recruitment in the 2022, 2023 and 2024 sampling periods.

Here we report on the current full dataset from 2012 to 2024.

Objectives

The objectives addressed in this report are:

- Compare catch per unit effort (CPUE) changes through time within Macquarie Harbour to describe changes in relative abundance.

- Assess the size and age (estimated) composition of Maugean skate catches as an indicator of population change, in particular recruitment variability.

- Provide a Capture Mark Recapture (CMR) model estimate of total abundance of Maugean Skate within Macquarie Harbour.

[1] See Erratum in Moreno et al. (2024) and Moreno and Semmens (2023)

Methods

Sampling methodology and historical data

Gillnet surveys were conducted in Macquarie Harbour, Tasmania at roughly three-month intervals between February 2021 and December 2023 to coincide with the austral seasons, noting that previous analysis demonstrated that CPUE was consistent across seasons (Bell et al., 2016). In 2024, sampling was conducted in August (five days), September (four days) and October (6 days). Sampling was not conducted earlier in 2024 due to a prioritisation for the research team to secure an ex-situ population of Maugean skate at the IMAS Taroona facility in the first half of the year, and then adverse weather through June and July was unsuitable for sampling. This does not affect analysis as the capture rate is of relevance, not the total number of netting events or skate caught.

Since 2021, surveys have primarily been conducted in three core areas within the harbour based on previous knowledge of skate movement and distribution as determined by acoustic telemetry, and areas of higher skate abundance identified through earlier systematic random sampling across the harbour (Bell & Lyle, 2016; Bell et al., 2016; Moreno et al., 2020, Treloar et al., 2016). Importantly, these three areas were comparable with the survey design in 2014 in terms of geographic location and fishing intensity, allowing 2014 to be considered a baseline for the post-2020 population monitoring program (Noting that historical population baseline data prior to this period does not exist). These sites were (A) the Table Head / Liberty Point area, (B) the World Heritage Area, and (C) the Swan Basin area, which includes Pine Cove and Long Bay and Swan Basin (Figure 1).

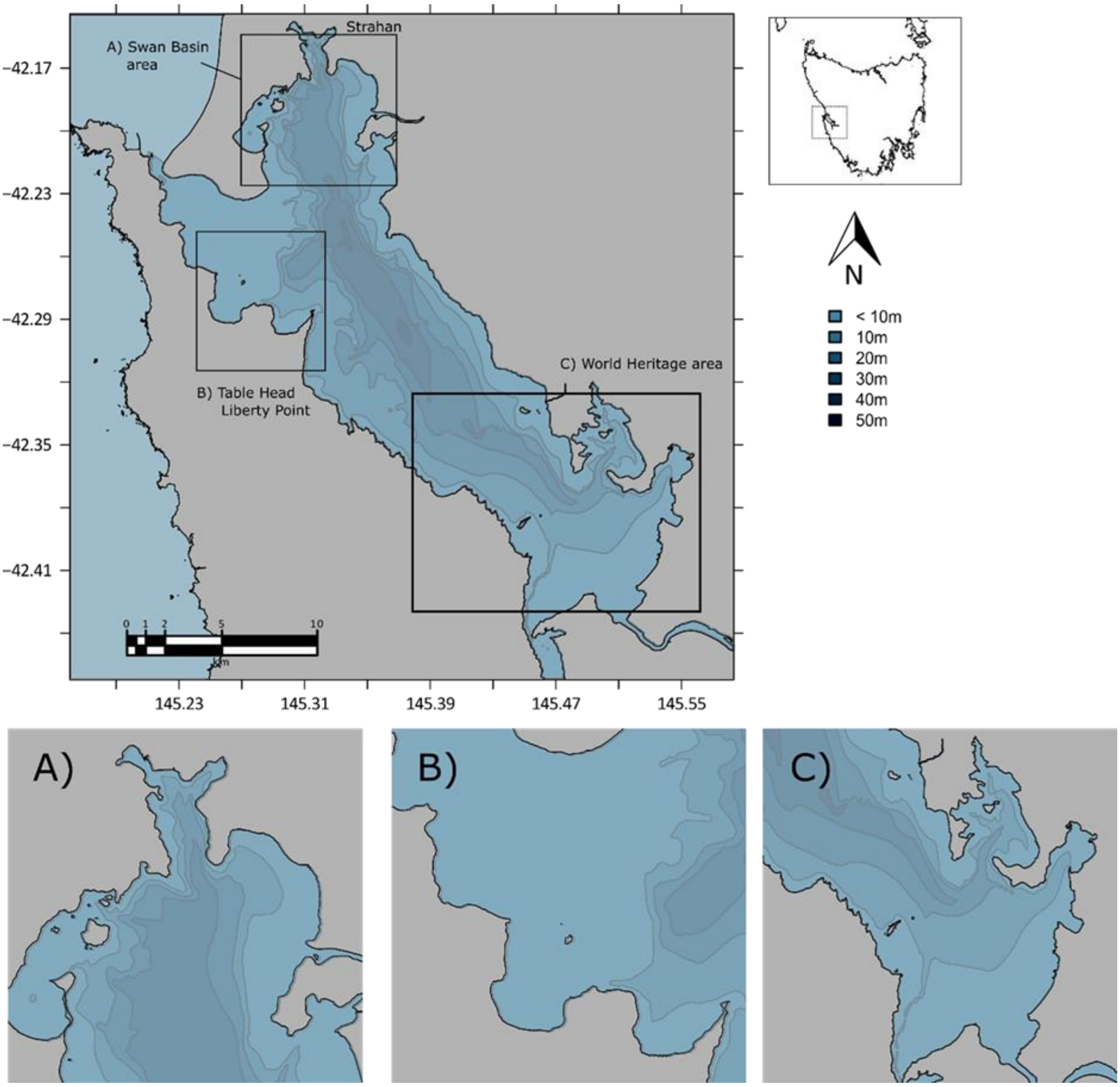

Figure 1. The primary sampling areas for Maugean skate population monitoring with inserts showing the complex bathymetry of (A) Swan Basin, (B) Table Head, and (C) and the World heritage Area.

Maugean skate were captured using standard monofilament graball nets (50 m long by 33 mesh drops with a 114 mm stretched mesh size). In 2014, and from 2021 nets were only set during daytime and soak times were restricted to under 2 hrs (with a couple of exceptions in 2014 which were excluded from subsequent analysis to avoid confounding effects of extended soak times). All Maugean skate captured from 2021 onwards were measured (total length (TL)), sexed, tagged, tissue samples collected, sexual maturity determined for females using ultrasonography, body condition assessed using a biometric impedance analysis (BIA) unit, 0.5 -1.0 ml of blood extracted via a caudal venipuncture, and a photograph taken before being released at the capture location. Skate were submerged in a recirculating processing tub throughout the procedure (except for length measurement), with the dissolved oxygen levels kept at 100% through supplementary oxygen. The processing of each individual was completed in less than 10 minutes. Only one skate mortality has occurred between 2021 to 2024, which was due to a lice event while the animal was in the gillnet. Noting that the net deployment method has been designed to minimise lice mortality events by reduced set times and not netting at night.

All animal handling and processing procedures were conducted under University of Tasmania Animal Ethics approvals (A23857 & A30685). The research was conducted under NRET Permits to Take

Threatened Fauna for Scientific Purposes: TFA20167; TFA22271; TFA23014; TFA24130 and TFA23035 and NRET Living Marine Resources Management Act Scientific Research Permits: 20075; 21080; 22018; 22091; 24056 and 23087.

Summary of available data

The sampling gear (gillnets) and broad methodology used throughout the current and previous studies has not changed. However, the distribution, intensity and timing of sampling has varied due to different project objectives (i.e. assessing the impacts of gillnetting in the harbour, sampling to deploy acoustic tags, etc). An essential component of estimating CPUE is that the net sets are deployed in a randomised design. Some of the project objectives listed above relied on targeted, repeated sampling and therefore are not suitable for use in population comparisons. Further, netting involves logistic and ethical considerations such as limiting deployment time to avoid bycatch or limit risk of predation. Finally, all fishing methods are generally accompanied by size selective catchability bias. The implication of this bias is discussed in the context of results below.

Despite the caveats listed above the time series available from the netting surveys provides the best longer-term cost-effective option to assess changes in the population through time.

Specifically, this dataset can provide information on:

1. Changes to relative abundance through time

2. Changes in the relative importance of key skate habitat utilisation through time

3. Changes in the size / age structure of the population

4. Provide biological and reproduction parameters and samples for comparison (not included here).

5. Total population size facilitated through attachment of dart tags on released individuals and subsequent recaptures.

To minimise the introduction of bias, only catch data from sampling years that could be standardised to represent catch per unit effort (CPUE) through time are used in this report, based on the following criteria:

1. Total fishing effort per year: > 300 net deployments to meet a sufficient sample size for comparison to the 2014 data.

2. Spatial distribution of effort: Conducted in the three historical areas of high skate abundance informed by early broad fishing surveys and knowledge of movement and space use from acoustic tracking.

3. Temporal distribution of effort: The effort must be distributed across a comparable temporal distribution (more than three sampling trips spread across at least three different months and two different seasons).

4. Purpose of sampling: Randomised design for purpose of estimating relative abundance.

Sampling in 2014, 2021, 2022, 2023 and 2024 met the criteria listed above and were used for subsequent CPUE and length frequency analyses (Table 1).

Data analysis

Maugean skate in Macquarie Harbour constitute a single homogeneous population (Weltz et al., 2018; Moreno et al., *In review*). There are no site-specific differences in sex or size frequency distribution (Bell et al., 2016). Therefore, analysis of size frequency data was conducted for total catch across the three reference sites combined for the years 2014 and 2021-2024. Sex specific size dimorphism is a feature of Maugean Skate (Bell et al., 2016), as such, size frequency composition (total length; TL) was reported by sex. Individual skate with missing sex or size data (n = 13) were not included in size frequency composition analysis.

A Kruskal Wallace (KW) test was used to test for Rank (~median) differences in size by year. A post hoc planned comparison of rank differences (~median) using a Dunn test with a Bonferroni correction was used to test for significant differences for each sampling year from 2021 against the baseline year (2014). A post hoc planned comparison of mean size differences using a Wilcox test with a Bonferroni correction was used to test for significant differences for each sampling year from 2021 against the baseline year (2014). Significant differences in size frequency distribution for each sampling year from 2021 against the baseline year (2014) were tested using a bootstrapped Kolmogorov-Smirnov test with a Bonferroni correction.

The parameters of the Von Bertalanffy growth model (VBGM) were used to estimate the age of each animal caught based on their measured length (van Werven et al., 2025). The estimated ages of skate caught were then used to back-calculate the estimated birth year of each individual.

Relative abundance

To explore changes in relative abundance through time, data from 2014 and 2021-2024 were analysed from all areas combined and the three areas separately. Sampling in these years was restricted to daytime only and had a similar spatial and temporal design (four seasonal surveys targeting the same sites), meeting the criteria outlined above. An exception was 2024, where seasonal sampling did not occur, due to reasons outlined previously. There were 13 longer duration deployments in 2014, where soak times were greater than 5 hrs. These deployments were excluded from CPUE calculations to account for potential effects of being significantly longer than all other sets assessed. A further eight individual deployments (less than 0.1% of all net sets) that had incorrect or missing metadata records were excluded as it was not possible to calculate CPUE (2014 = 1, 2021 = 1, 2022 = 4, 2023 = 2).

CPUE was estimated as the number of Maugean skate caught per net metre per hour (N/m/hr) for each of the included sampling years. Standard error was calculated based on CPUE per trip within a year to show inter-seasonal variability in catch rates.

Tagging and mark-recapture population estimation

From 2012 to 2014, 275 individuals were tagged with passive integrated transponder (PIT) tags placed under the skin and included in a Capture Mark-Recapture (CMR) model. Absolute population abundance from based on the total number tagged and recaptured was estimated at 3177 (CI: 1827 – 6247) (Bell et al., 2016). It was noted, however, that due to the low number of recaptures, many closed population models failed to converge. The best fitting model that did converge, based on the Akaike Information Criterion, was the Chao Lower Bound model (Mth), which accounts for both time-dependent variation in capture probability and behavioural responses to capture.

Since 2021, 206 individuals have been tagged with dart tags, including 99 that were double-tagged in 2024. Double-tagging has been introduced to determine tag loss, which is an important component of mark-recapture modelling. Further, genetic identification of recaptures, where tag loss has occurred has also proven successful.

A suite of closed population tag-recapture models were applied to the dart tag data collected since 2021 using the R packages Rcapture v1.4-2 (Baillargeon and Rivest, 2007) and RMark version v.2.1.12

(Laake, 2013) that acts as an interface with program MARK v.6.2 (White and Burnham, 1999). Due to the low recapture number all models failed to converge, including the Chao Lower Bound model.

A simpler closed population model for multiple census data, that does not account for time-dependent variation in capture probability and behavioural responses to capture was applied using the FSA v0.9.6 (Ogle et al., 2025) in R. The Schnabel method (Schabel, 1938), without the Chapman correction (due to the CMR data being derived over multiple events rather than a single census event) was fitted using the 'mrClosed' function. Confidence intervals were fitted using a Posson distribution (Ogle, 2016).

Results and Discussion

Catch summary

There were a total of 2583 individual gillnet deployments in Macquarie Harbour from 2012 to October 2024 (Table 1). A total of 666 individual skate have been captured since 2012 (female = 320, male = 331, not recorded=15; < 600mm = 97, > 600mm = 509, not recorded=60). The smallest individual captured was 215 mm TL and the largest was 870 mm TL.

The filtered dataset analysed in this report based on the criteria outlined above (years 2014, 2021, 2022, 2023 and 2024) consisted of 1734 individual gillnet deployments in Macquarie Harbour and a total of 386 captured skate (female = 189, male = 193, not recorded = 4, < 600mm = 51, > 600mm = 322, not recorded = 13) (Table 1). The smallest individual captured was 296 mm TL and the largest was 840 mm TL.

Table 1. Summary of all gillnet survey effort by year. 2014 and 2021 - 2024 meet the criteria for subsequent CPUE and length frequency analyses. Deployments are the total number of net deployments in the year, Total caught is the number of skate caught in each year inclusive of recaptures, LF data is the number of skate used in size frequency analysis (showing how many skate were removed due to missing or incomplete data) and Areas is the number of areas sampled (3 key skate habitat areas are used for monitoring and any additional sampling areas that occur away from these 3 key areas are indicated by the + symbol). The temporal distribution of effort (days, months and seasons) are also shown, as well as the number of adults (>600mm) and juveniles (< 600mm) and the number of skate tagged each year, with the numbers in parentheses showing the days at liberty – in 2014 this is shown as the range of days at liberty.

Year	Days fished	Net deployments	Mean soak time (hours)	Total caught	LF data	Areas	Months	Seasons	Total caught >600mm	Total caught <600mm	Skate tagged	Recaptures
2012	9	202	2.6	113	108	3 +1	3	3	84	28	84[1]	
2013	7	167	2.7	68	66	3 + 1	3	2	46	11	62[1]	
2014	18	342	2.7	163	161	3 + 2	4	4	130	26	151[1]	10* (2-733)
2015	3	76	2.6	10	10	3	1	1	7	3	9[1]	
2017	1	18	1.8	9	9	1	1	1	7	2	0	
2018	5	107	2.3	46	45	1	2	2	43	2	0	
2019	9	212	1.5	17	0	3 +1	1	1	0	0	0	
2021	17	395	1.9	45	44	3 + 1	5	4	43	1	44[2]	1 (64)
2022	18	455	1.6	25	24	3 + 1	5	3	17	6	22[2]	
2023	14	302	1.8	57	50	3 + 1	4	3	40	10	50[2]	1* (651)
2024	15	307	1.6	102	100	3 + 1	3	2	92	8	98[3]	2 (301,380)

[1] PIT tag
[2] Single Dart Tag
[3] Double Dart tag
*Denotes tag loss from a single individual but genetically identified

Catch per unit effort (CPUE)

In 2014, CPUE in the harbour was 0.17 N/m/hr (Figure 2). In 2021, CPUE declined to 0.06 N/m/hr (Figure 2). In 2022, CPUE decreased further to 0.04 N/m/hr (Figure 2). This translates to a point-to-point decline against the baseline year of 2014 to 2021 of 64%, and 77% in 2022. The observed decline in relative abundance was likely driven by limited hatching success and juvenile survival beginning in 2009/2010 (see Figure 6) and two high impact environmental events that occurred in 2019 (Moreno et al., 2020). A direct measure of the impact of these two events supporting the interpretation of the decline in relative abundance identified through CPUE was the unusually high inferred mortality (~44%) over a short time period of individuals being electronically tracked at the time (Moreno et al., 2020).

In 2023 and 2024, CPUE increased to 0.11 N/m/hr and 0.21 N/m/hr respectively (Figure 2). This translates to a 35% decline in 2023 relative to 2014 and a 23% relative increase in 2024. With consideration of the standard errors, the declines in relative abundance reported in 2021 and 2022 were significantly different (lower) to the baseline year (2014), while in 2023 and 2024, the relative abundance had increased to a point where the errors around the mean overlaps with the baseline year (2014). This timing aligns with an improvement in environmental conditions within the harbour, in particular an increase in dissolved oxygen levels (EPA, 2024).

While CPUE in 2024 was higher than 2014, standard error estimates in 2023 and 2024 are larger than previous years (Figure 2). This is likely linked to a change in behaviour that affects catchability, for example a change in the depth distribution in which skate are found or movement around the harbour. This result highlights the importance of the stratified random sampling design, which includes multiple areas within the harbour. Reduction in the variance within year may be achieved with increased sampling intensity and consideration of additional sampling areas. The latter would be best informed with updated tracking information to further increase knowledge on habitat utilisation within the harbour.

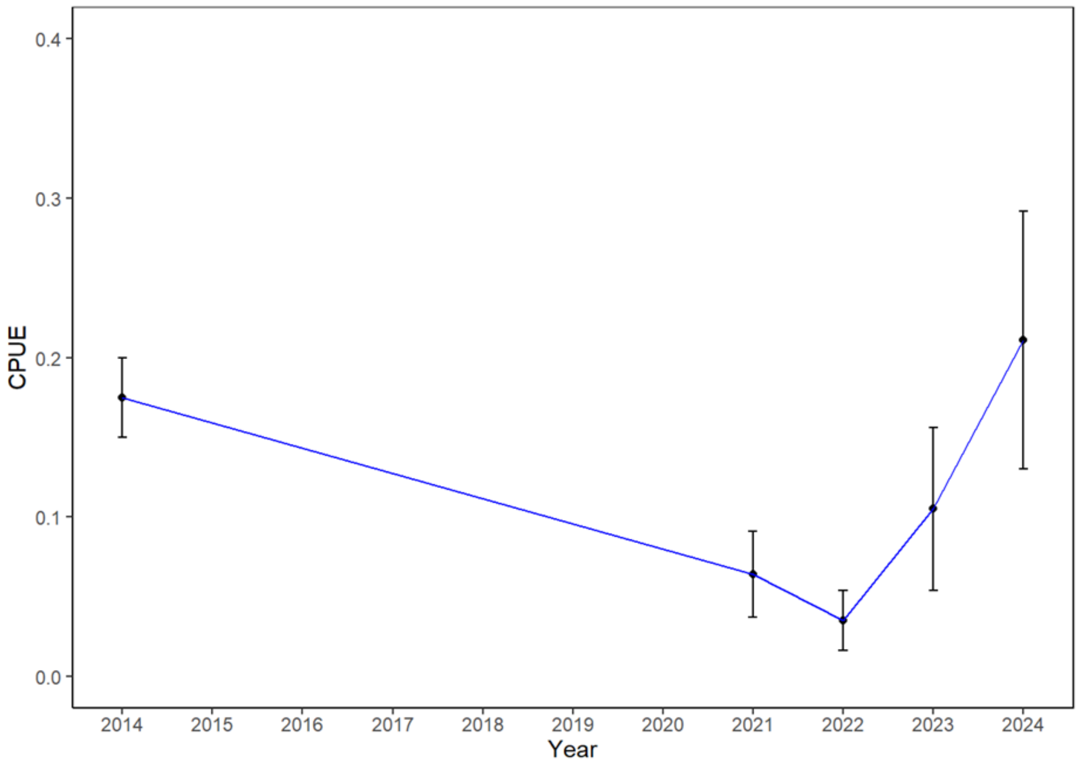

Figure 2. Catch Per Unit of Effort (CPUE) of Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments.

The absence/presence of juveniles and subadults (less than 600 mm TL) in net catches was an important contributor to the decrease (along with the reported inferred mortality events discussed above) and subsequent increase in relative abundance. It is known that the selectivity of the sampling method underrepresents these cohorts, as such, CPUE is sensitive to their abundance. This is explored further below in the size composition and back-calculated age analysis.

Site specific CPUE

Previous investigations into the distribution, movement, and habitat use of the Maugean skate show that Table Head/Liberty Point (THLP) is a notable known habitat for the species within the harbour (Moreno et al., 2020). As such it is a focal sampling site with over 57% of all skate sampled from the area.

In 2014, CPUE was reported at 0.25 N/m/hr for the THLP area (Figure 3) In 2021, CPUE decreased to 0.11[1] N/m/hr representing a decline in relative abundance of 56%[1] at the site. In 2022, CPUE decreased further to 0.02 N/m/hr before increasing to 0.11 N/m/hr in 2023, and 0.24 N/m/hr in 2024, a level not significantly different from 2014 (Figure 3).

The decline in relative abundance was also evident in CPUE at the Swan Basin site. In 2014, CPUE was reported at 0.12 N/m/hr decreasing to 0.02[1] N/m/hr in 2021 and 0.04 N/m/hr in 2022 and 2023, before slightly increasing in 2024 to 0.05 N/m/hr (Figure 3). Comparatively, an increase in relative abundance in the World Heritage area compared to 2014 (0.09 N/m/hr) was observed in 2023 (0.16 N/m/hr) and 2024 (0.23 N/m/hr) resulting in a 77% and 155% increase when the baseline year is compared to 2023 and 2024 respectively, with 2024 resulting in a significant increase relative to 2014 (Figure 3).

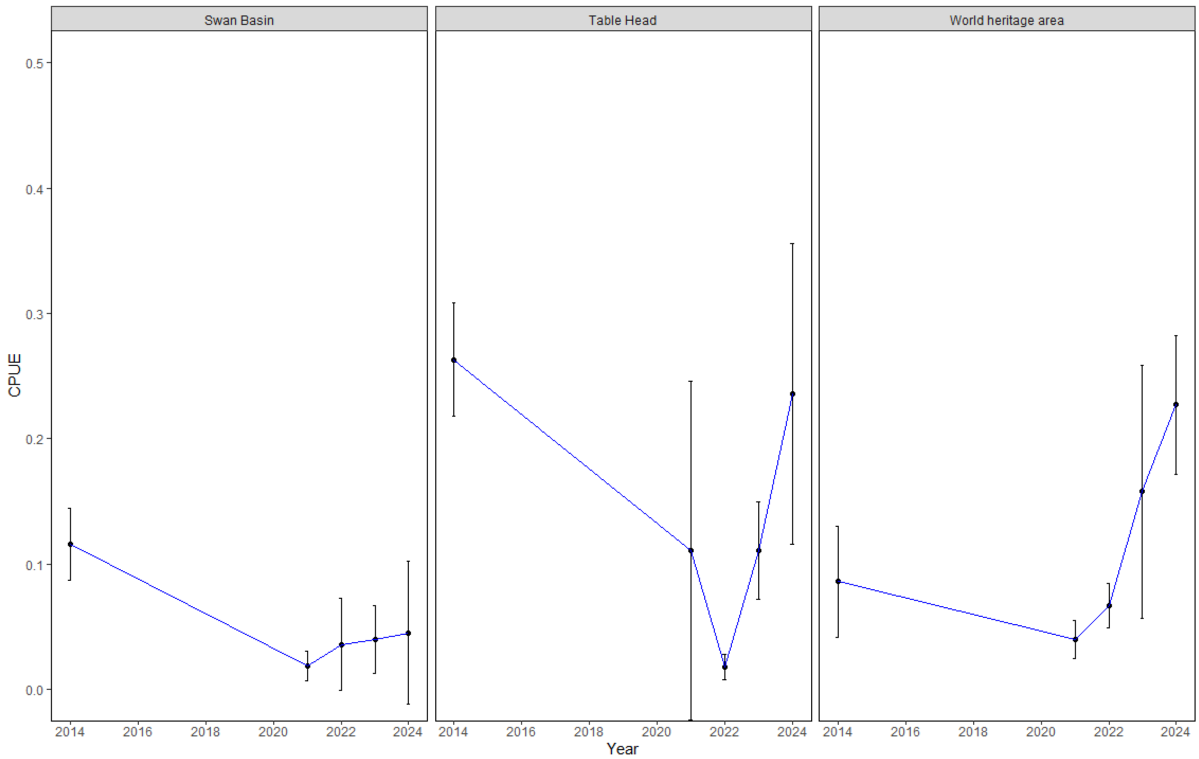

Figure 3. Catch Per Unit of Effort (CPUE) of Maugean skate caught from the three reference sites in Macquarie Harbour. The error bars represent an approximate standard error calculated based on variability in skate per net hour caught between individual deployments.

[1] See Erratum in Moreno et al. (2024) and Moreno and Semmens (2023)

Size and age structure

The size of females differed significantly by year ($\chi^2 = 9.45$, $p = 0.05$) (Figure 4). Compared to the 2014 baseline, median female size was significantly larger in 2021 (D = 38.3, $p = 0.02$) but not in subsequent years (Figure 4). Mean female size was significantly larger relative to the baseline in 2021 ($p < 0.01$), 2022 ($p = 0.03$) and 2024 ($p = 0.01$) but not in 2023 ($p = 0.14$), with the mean size in 2023 influenced by the capture of several juveniles which were absent in the net samples in the other years (Figure 4). Size frequency distribution of females differed significantly from the baseline in 2021 (D = 0.32, p = 0.02), 2022 (D = 0.34, $p = 0.02$) and 2024 (D = 0.20, $p = 0.03$) but not in 2023 ($p = 0.07$), again influenced by the capture of juveniles in this year (Figure 4).

The size of males differed significantly by year ($\chi^2 = 9.11$, $p = 0.05$). Compared to the 2014 baseline, median male size was significantly lower in 2022 (D = -39.7, $p = 0.04$), influenced by the capture of juveniles, but not in other years (Figure 4). Mean male size was significantly different to the baseline in 2022 ($p < 0.01$), again influenced by the capture of juveniles but not in other years (Figure 4). Size frequency distribution of males differed significantly from the baseline in 2021 (D = 0.22, $p = 0.05$), 2022 (D = 0.36, $p = 0.02$), 2023 (D = 0.26, $p = 0.04$) and 2024 (D = 0.18, $p = 0.04$) (Figure 4).

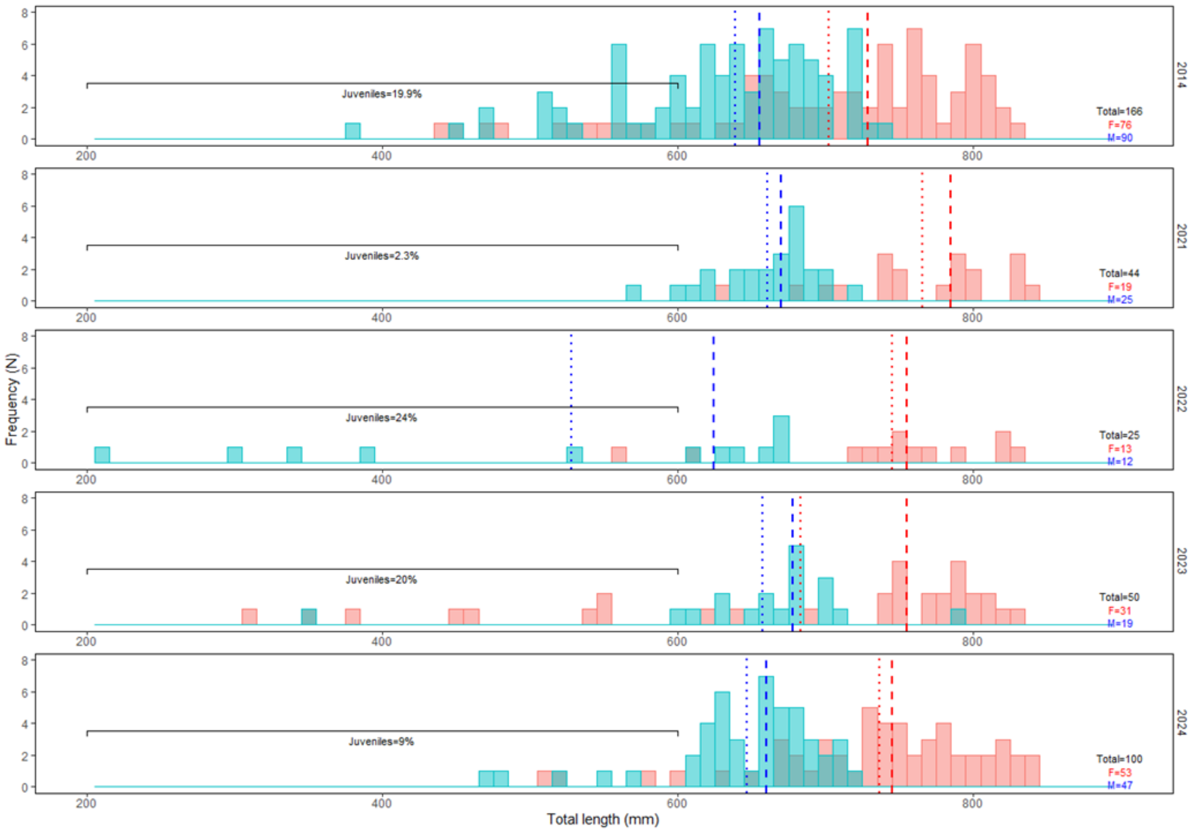

Figure 4. Size distribution of male (blue) and female (red) Maugean skate sampled from all sites during 2014 (top panel; FRDC 2013-008), 2021-2023 (second to fourth panels; SMRCA study), and 2024 (bottom panel; current NRE study). Vertical dashed and dotted lines indicate median and mean lengths of males (blue) and females (red), respectively. Sample sizes are indicated (Total = sexes combined, M = males, F = females). Values below the horizontal bracket indicates the proportion of individuals < 600 mm (juveniles and sub-adults) present in each sample. Note some individuals were released without length measurements.

In 2021, the relative percentage of juveniles/sub-adults reported across the harbour was the lowest of all sampling years accounting for 2.3% of the total skate caught. The relative lack of juveniles in the net sampling raised significant concern for the species, indicating a potential absence of successful hatching, juvenile survival or recruitment for a period of approximately eight years. It is recognised however, that the net sampling method imparts a size selective bias with smaller individuals under-represented in the nets (although this sampling method bias is consistent across years as the same gear and same capture methodologies were used throughout).

Net sampling in 2022 identified the first evidence of juveniles since sampling in 2014 (also see Moreno et al., 2023). Although the total number of skate caught in this year was low, the percentage of recruits relative to adults sampled was 24%, slightly higher than the percentage reported in 2014. Juvenile and sub-adults continued to appear in sampling in 2023 and 2024 at 20% and 9% respectively of the total population structure reported (Figure 4).

Age structure

The median female age has remained relatively consistent from 2012 (7.12 years) to 2024 (7.38 years). Similarly, the median age of male skates has remained almost identical from 2012 (5.5 years) to 2024 (5.57 years) (Figure 5). A slight shift towards older age groups is evident, in 2021, due to the lack of smaller skate being caught in that year. However, juvenile and sub-adult individuals can be seen from 2022-2024 (Figure 5), indicating again that at least one successful hatching event with relatively successful juvenile survival has occurred. Based on the back-calculated ages, this event most likely occurred in 2020 or 2021. Noting it takes approximately four years after birth for juveniles to become broadly represented in net sampling, a more robust understanding of the magnitude of recruitment from this cohort will become more evident in 2025 and beyond sampling events.

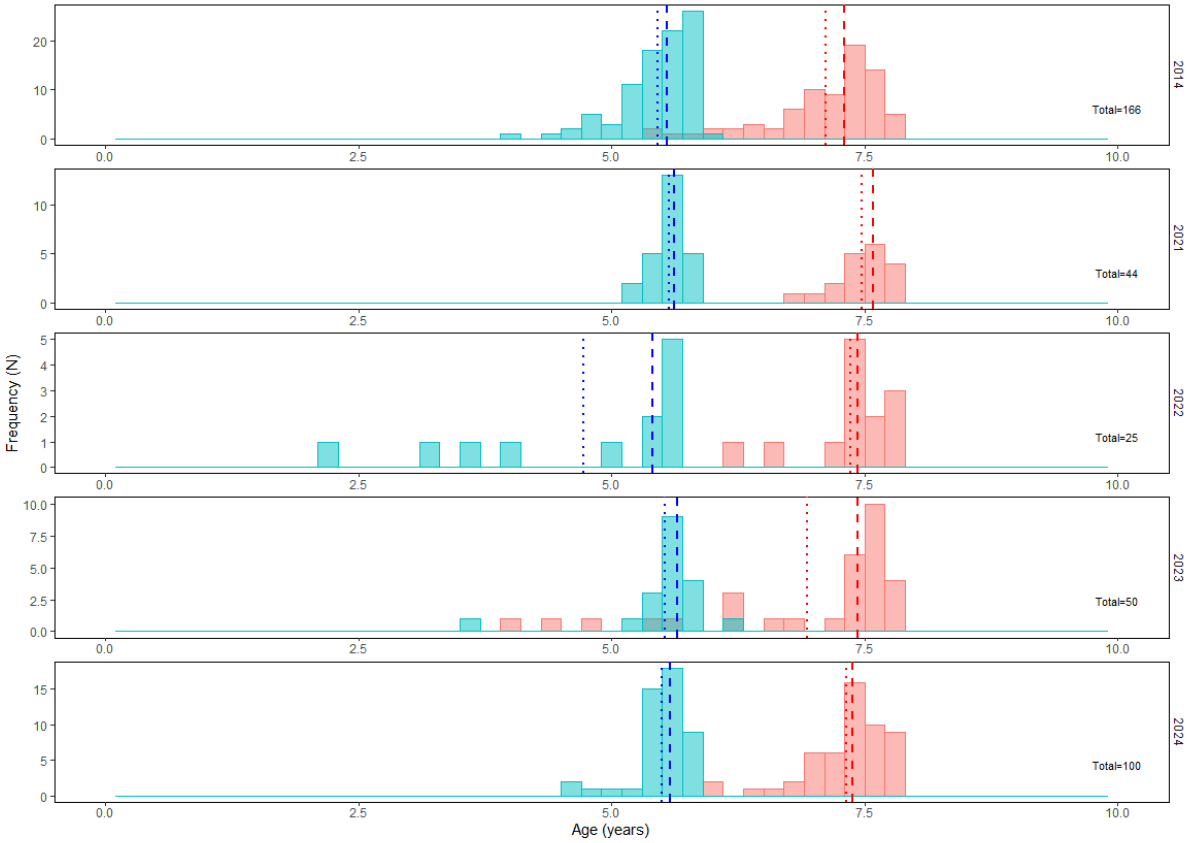

Figure 5. Calculated age frequency distribution of male (blue) and female (red) Maugean skate sampled from all sites during 2014 (top panel; FRDC 2013-008), 2021-2023 (second to fourth panels; SMRCA study), and 2024 (bottom panel; current NRE study). Vertical dashed and dotted lines indicate median and mean ages of males (blue) and females (red), respectively. Sample sizes are indicated (Total = sexes combined). Note that there are differences in the scope of the y-axis, this is to highlight the relative variation in age structure rather than the magnitude of different age classes represented across sampling years.

An analysis of back-calculated birth year of skate caught was conducted to assess recruitment patterns, noting that the net sampling method has a known size selectivity bias and under-represents smaller individuals, this method can identify recruits to the adult size composition that may have been under-represented or absent in net sampling.

Contributions of skate hatched in 2006 and 2007 was relatively consistent and at the highest levels identified (Figure 6). Contributions from 2008 declined slightly and then in 2009 the number of contributing hatchings had declined by approximately half relative to 2006 (Figure 6). In 2010, there was a dramatic drop in hatchlings contributing to the population, which corresponds with the downward trend in dissolved oxygen (DO) levels observed in Macquarie Harbour between 2009 and mid-2014 (Bell et al., 2016).

From 2011 to 2017 the number of contributing hatchlings steadily increased returning to approximately half of the numbers identified in 2006 and 2007 (Figure 6). A significant recharge event occurred in late 2014, resulting in an increase in DO levels (Bell et al., 2016), which may have contributed to the increasing trend of hatchlings contributing to the population.

From 2017 the numbers of contributing hatchlings vary until 2020 (Figure 6). It is difficult to interpret this as the size selective artefact of net sampling will influence the number of juveniles caught but there were also two high impact environmental events in 2019 leading to significant inferred mortality of acoustically tagged skate (Moreno et al., 2020). These events may have contributed to the decline in recruitment observed as the altered environmental conditions potentially impacted the reproductive success of adult skate or affected the survivorship of juvenile skate, decreasing the number of breeding skate available. This will become clearer through future sampling as individuals from these years become fully selected by the net sampling, given it takes at least four years for skate to be fully selected by netting.

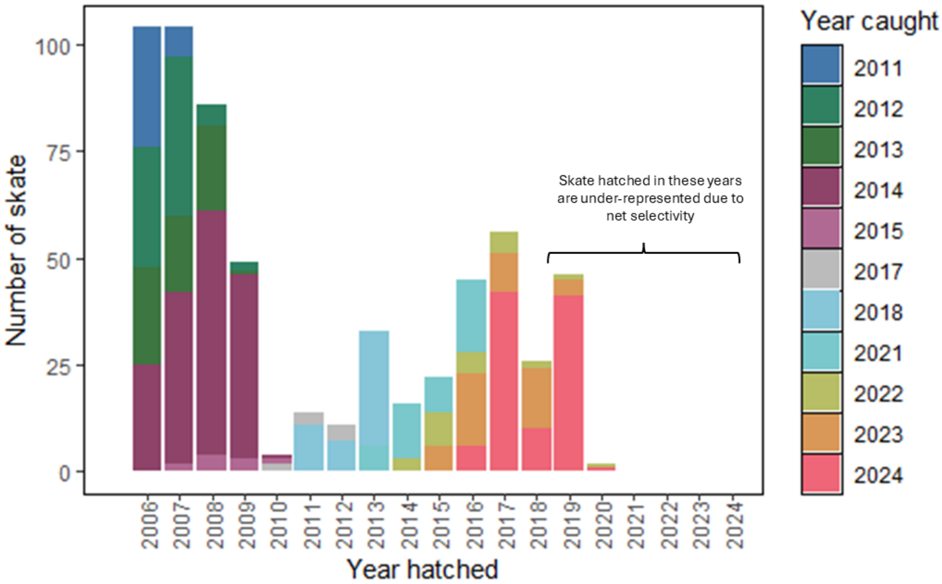

Figure 6. Abundance of skate individuals per birth year from all catch data based on back calculated ages. The colour indicates the year individuals in each birth cohort were caught. Individuals hatched in 2020 and possibly 2019 are likely not of a size where they are fully catchable by the nets, hence data from those years are possibly under-represented. The skate caught in 2011 were from a netting study in the harbour not related to targeting skate (Lyle et al., 2014)[1].

[1] Lyle, Jeremy M., et al., (2014). Assessing the impacts of gillnetting in Tasmania: implications for by-catch and biodiversity. Institute for Marine and Antarctic Studies, University of Tasmania, 2014.

Tagging and mark-recapture population estimation

A total of 214 skate have been tagged since 2021, of these four have been recaptured thus far (Table 1). The first recaptured animal caught in October 2021 was at liberty for 64 days, the second recaptured animal (a genetic recapture detected using the single nucleotide polymorphism (SNP) data provided by diversity array technology (DArT)) caught in June 2021 was at liberty for 651 days, the third recaptured animal caught in September 2024 was at liberty for 301 days and the fourth recaptured animal caught in October 2024 was at liberty for 380 days. Three recaptures of two animals occurred soon after release in September 2024 at the THLP site (at liberty <1 day). Based on the numbers presented in Table 1, the Schanbel population estimate is 4102 (1602 – 15055).

Conclusion

This report identifies the importance of continued stratified random design monitoring of the Maugean skate population in Macquarie Harbour. While there was evidence of a significant decline in the relative abundance of the Maugean skate population between 2014 and 2022, likely a result of a significant decline in hatching success, juvenile survival or a combination of both from 2009/2010 and the effect of two high impact environmental events that occurred in 2019, the most recent surveys indicate the relative abundance has increased since 2022. While relative abundance has increased in 2023 and 2024, the standard error estimates are larger than previous years. This is likely due to changes in behaviour affecting catchability. This variance will be further clarified through continued net sampling and an improved understanding of the habitat utilisation in the harbour, assessed by acoustic telemetry, to determine how spatial habitat use impacts catchability. Back calculation of birth year indicates a general trend of improvements in hatching success, juvenile survival or a combination of both year on year from 2010 through to at least 2019, with size selectivity from that point confounding interpretation of these results. However, small juveniles have been identified in the net sampling in the last three years, which based on consideration of cohort progression, likely hatched in 2020/2021, suggesting that successful hatching has continued to occur up until at least this time. The contribution of this event will become more evident with future net sampling. Alternate methods of identifying juvenile skate that may not be selected by nets are also being explored. A recently tested sonar-based method has shown promise for detecting Maugean skate, including juveniles (Moreno et al., In Review). This technique could be employed in a random stratified transect design to provide additional population size estimates, offering a complementary approach to model-based assessments. Such an approach aligns with the first listed priority, '*Continued population monitoring to include the development of a robust, non-harmful, and logistically feasible sampling method to effectively assess the Maugean skate population size, structure, status and trend…including through techniques such as video sonar (ARIS)',* under the 'Medium-term actions' category of the 'Survey and monitoring priorities' in the *Zearaja maugeana* (Maugean skate) Conservation Advice (DCCEEW, 2024).

Ongoing monitoring of the Maugean skate population is essential to understand contemporary status and trends, support the substantial body of work being undertaken to determine causative links to factors that influencing these trends, and inform appropriate conservation action. This advice is consistent with the first listed priority, '*Continued population monitoring of the Maugean skate to support evaluating effectiveness of conservation actions and to underpin conservation planning decisions',* under the 'Urgent action' category of the 'Survey and monitoring priorities' in the *Zearaja maugeana* (Maugean skate) Conservation Advice (DCCEEW, 2024).

Furthermore, previous IMAS studies have routinely used acoustic monitoring to examine Maugean skate behaviour in relation to environmental variables (temperature and dissolved oxygen) and changes in these variables (see Bell et al., 2016; Moreno et al., 2020). As such, this method provides a useful tool to examine potential changes in behaviour that may be influencing catchability and CPUE and new acoustic monitoring studies will be commenced in 2025. A research focus going forward should include an extensive acoustic monitoring program within the harbour to ensure that the sampling areas are still appropriate and broader area use and behaviour within the harbour is well understood. With the addition of tags that facilitate recording of environmental data, deep insight into the environmental habitat preferences of the skate including the influence of the halocline and low DO areas can be elicited (e.g., Moreno et al. 2020). This data will also be instrumental for progressing necessary research on how to successfully re-introduce captive-reared skate to the harbour.

While the data now suggests signs of recovery relative to population estimates in 2014, the Maugean skate population is still at low levels and potentially subject to major environmental events leading to mortality, as inferred in 2019. An immediate focus should be the development of a robust population estimate as well as refined estimates of the likelihood and consequence of major environmental events. There is now a relatively good understanding of the biological parameters and relative abundance through time to parameterise a range of abundance modelling approaches.

Due to the low number of recaptures, all closed population capture-mark-recapture models (CMR) tested with the 'MARK' program (White and Burnham, 1999) failed to converge based on the dart tag data collected since 2021. The same issue was identified by Bell et al., (2016) where only a limited number of models converged for the PIT data collected in 2013/2014. The models provided in 'MARK' allow for consideration of time-dependent variation in capture probability and behavioural responses to capture. The assumptions underlying these models align with acoustic tagging data, which indicate that skate exhibit unusual behaviour following release (Bell et al., 2016). Additionally, some individuals have been observed relocating over time. Therefore, if sampling repeatedly occurred in the same areas, as is the case in this study, such movement likely influenced recapture probability over time. Furthermore, acoustic telemetry data indicate that most skate exhibit strong site fidelity (Bell et al. 2016; Moreno et al., 2020). Because sampling occurred in the same locations repeatedly, tagged individuals are more likely to be recaptured, potentially leading to an underestimation of population size. On the other hand, potential tag loss could have led to an overestimation, although recent genetic recapture techniques are minimising on this potential bias and future recaptures of double tagged individuals will aid in clarifying this bias further.

The updated Schanbel population estimate based on dart tag deployments and recaptures since 2021 is 4,102 (CI: 1,602 – 15,055). It is important to note that this estimate is not comparable to the abundance estimate produced by Bell et al. (2016) of 3,177 individuals (CI: 1,827–6,247). The models used to report these estimates differ and in both cases, but particularly in the most recent case, the confidence intervals are extreme. As such, and as identified by Bell et al., (2016), these population estimates should be interpreted with extreme caution. Ongoing genetic analyses will provide alternative population estimates based on genetic tag-recapture data, which may offer greater accuracy than the estimates presented here.

A promising research direction enabled by repeated tissue sampling for molecular assessment is a variation of the mark-recapture population estimation model, using each skate's DNA as a unique identifier. With ongoing sampling, if the same skate is caught again, its distinct genetic signature will confirm it as a recapture. Recently, we have identified genetic recaptures of individuals previously tagged with both PIT and dart tags (see Table 1). An extension of this approach is the close-kin mark-recapture model (Bravington et al., 2016), which CSIRO will apply to the IMAS genetic samples collected thus far (National Environmental Science Program Project No: EP4.25).

In summary, there is now sufficient data to execute a number of total population estimate approaches. These can be considered together to provide confidence through multiple lines of evidence. Critically, the Population Viability Assessment (PVA) model, and particularly the population estimate component, presented in Grant and Simpfendorfer (2023) will require updating as no further declines have been detected and abundance trends have improved, requiring a revision of some of the assumptions made in the first iteration of the model. This recommendation is consistent with the first listed priority, '*Fine tune the PVA to assess extinction risk and assist with prioritising management, conservation and* *research actions'* under the 'Urgent action' category of the 'Information and research priorities' in the *Zearaja maugeana* (Maugean skate) Conservations Advice (DCCEEW, 2024).

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