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PRIMARY RESEARCH PAPER

Trophy fish heads are a source of body size information for historical and contemporary ecology

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Abstract This study investigated whether trophy taxidermy specimens of Australia's largest freshwater fish, Murray cod (*Maccullochella peelii*), can provide accurate records of historical body size. Taxidermy mounts came mostly from informal collections in hotels from across the Murray–Darling Basin, south-eastern Australia, comprising 20% whole-body and 80% head forms. We compared the morphology of mounts to live Murray cod, collected from the mid–Murray River in 2018, and identified the head morphometrics that most accurately described length and weight of whole mounts and live fish. Eight morphological characters were analysed for 60 whole mounts, 172 head mounts and 51 live fish. We found that inter-orbital distance, inter-nare width and upper jaw length were relatively robust to taxidermy processes and were reliable features for predicting fish total length and total weight. Shrinkage in head morphometrics due to taxidermy was evident, however, and we recommend that this be considered when reconstructing length and weight measures. We discuss how estimated body length and weight from head morphometrics of trophy fish, coupled with analysis of the accompanying remaining tissue and hard parts, opens up opportunities to explore patterns in genetics, life history, movement and trophic ecology of historical fish populations and of past environments.

Keywords Taxidermy fish mounts · Head morphometrics · Historical ecology · Environmental history · Murray cod · Maccullochella peelii

Introduction

Knowledge of past environmental conditions can help to establish more realistic baselines, put current states into longer-term context and add legitimacy to policy and management objectives (McClenachan et al., 2012; Beller et al., 2020). Historical research can also be used to improve our understanding of the human influences on ecosystems, and through those insights, mitigate future impacts (Millien et al., 2006;

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Schwerdtner Máñez et al., 2014). There are a number of applications of historical ecology that have highlighted long-term changes in diversity and structure of animal populations (McClenachan, 2009; Bellquist et al., 2016; Boon et al., 2024), and while some have fundamentally altered management priorities and strategies (McClenachan et al., 2015), such studies are still relatively rare in the literature (Beller et al., 2020).

Formal collections of animal specimens (e.g. museums) are typically considered high-value sources of historical evidence, because they tend to be accessibly registered, come with provenance records (Hebert et al., 2013), are maintained in good condition, persist over long time periods, and can be actively used by researchers (Pyke and Ehrlich, 2010; Schnalke, 2011). The features of the form, tissues and other parts of animal specimens are conducive to multiple analytical applications (e.g. taphonomy, morphometry, genetics and microchemistry) and can provide historical data on an individual animal's life (e.g. occurrence, size, condition and age), on a species (e.g. genetics), or on the relationship between an animal and its environment (e.g. diet) (Pyke and Ehrlich, 2010; Izzo et al., 2016; McLean et al., 2016; Beck, 2018). However, formal collections only capture a fraction of the spatial, temporal and taxonomic diversity that exists within most species (Sikes and Paul, 2013; Izzo et al., 2016). Moreover, the use of specimens in these collections, in particular for invasive or destructive sampling, is severely restricted. Given these gaps and constraints, it would be advantageous to expand the range of data sources and archives to informal collections, especially ones that may not have as many restrictions of use on them.

Informal collections of taxidermy mounts, often referred to as trophies, are one type of informal collection with scientific potential for providing historical records and insight (O'Connell et al., 2025; Wueringer et al., 2023). Taxidermy is the preservation of an animal that generally involves the whole, or part of the animal being skinned, then preserved, positioned and mounted (Morris, 2010). The preparation and preservation of an animal through taxidermy effectively forms a biological archive that has the potential to provide much high-value information for the historical ecologist and environmental historian. To date, taxidermy preparations have been used as scientific study specimens in a range of research contexts, including: determining the most appropriate populations from which to reintroduce fish (Worthington et al., 2016); understanding genetic diversity within extant populations of goats (Cassidy et al., 2017); describing the taxonomy of endangered cats (Bahuguna, 2018) and fish (Mayden and Kuhajda 1996); and defining the adult and juvenile forms of extinct marsupial carnivores (Sleightholme and Campbell, 2018). Informal sources of taxidermy have been used as a supplementary record with unique provenance (e.g. Seitz and Waters, 2018) and as a source of biological tissue (e.g. Casas-Marce et al., 2012).

Taxidermy fish are regularly curated outside of formal collections and could be a source of invaluable point-in-time data to fill scientific knowledge gaps. In a world where animals are increasingly represented in non-biological ways (e.g. digital), and the collection, preservation and curation of animal specimens in formal institutions is past its peak (Vernon, 1993), the existence of taxidermy outside formal collections, including trophy animal records, is a unique legacy and opportunity to expand animal-based archives (Smith, 1965).

The quality of a taxidermy mount is commonly assessed by the lifelike form, realism, natural posture and replication of the original animal's morphology (Morris, 2010; Kalshoven, 2018). Morphometrics of preserved animal specimens are common for taxonomic identifications and have been used to identify new species (e.g. Seitz and Hoover, 2017) and help to fill gaps in specimens with missing parts (e.g. Larkin and Porro, 2016). The relationships between the preserved features of taxidermy to their lifelike size have the potential to be used to validate the size of the specimens (Izzo et al., 2016). For fish, this would be useful, because length is a fundamental metric used in estimating growth, age, weight, and in assessments of life history more generally (Jellyman et al., 2013). Given the many features of taxidermy that make a 'mount' conducive for use as a study specimen to understand past biological and environmental conditions, it is surprising how few examples of mounts used as an ecological record occur in the literature (Morris, 2010).

For a non-traditional form of evidence, like taxidermy fish, to be considered a reliable data source, there is a need to validate its features and accessibility as a scientific record. Because fish taxidermy mounts are typically created for trophies, we need to know the selection and persistence biases in collections to properly understand how they can be used as historical scientific specimens that represent populations, the species and the environment in which they were caught (Beller et al., 2017). Even after a specimen is accessed, there may then be biases associated with the removal of original tissues (Migdalski, 1981) and the shrinkage (Radtke, 1989) that occurs during the preservation and curation process, which will influence morphological measurements.

Traits like length and weight of fish are fundamental biological metrics used for fisheries science, and they provide ecological and biological insights on the populations, species and environment they came from (Froese, 2006). Similar to understanding the biases in the record, the application of morphometry to the form of the taxidermy can be used to validate fish size at capture (Izzo et al., 2016). To our knowledge, this study is one of the few to examine if length-based relationships involving head morphometrics (HM) of taxidermy fish mounts are comparable to those of live fish.

Australia's largest freshwater fish, the Murray cod, *Maccullochella peelii* (Mitchell, 1838)*,* is a species of high conservation status throughout its range and commonly features in informal taxidermy collections as a trophy; as either head or whole mounts (Humphries, 2023; O'Connell et al., 2025). Trophy Murray cod present a useful case study for exploring the utility of taxidermy mounts for inferring historical ecological changes in length and weight. The aim of this paper is to describe how head morphometrics of the taxidermy mounts relate to those of live fish. Specifically, we apply morphometric analysis to: 1) identify the head morphometrics that most accurately reflect live length and weight of fish at capture; and 2) calculate shrinkage-correction factors to facilitate predicting the live length and weight of fish at capture from taxidermy mounts. We then discuss the potential uses of trophy fish, such as Murray cod, for investigating historical and contemporary ecology.

Materials and methods

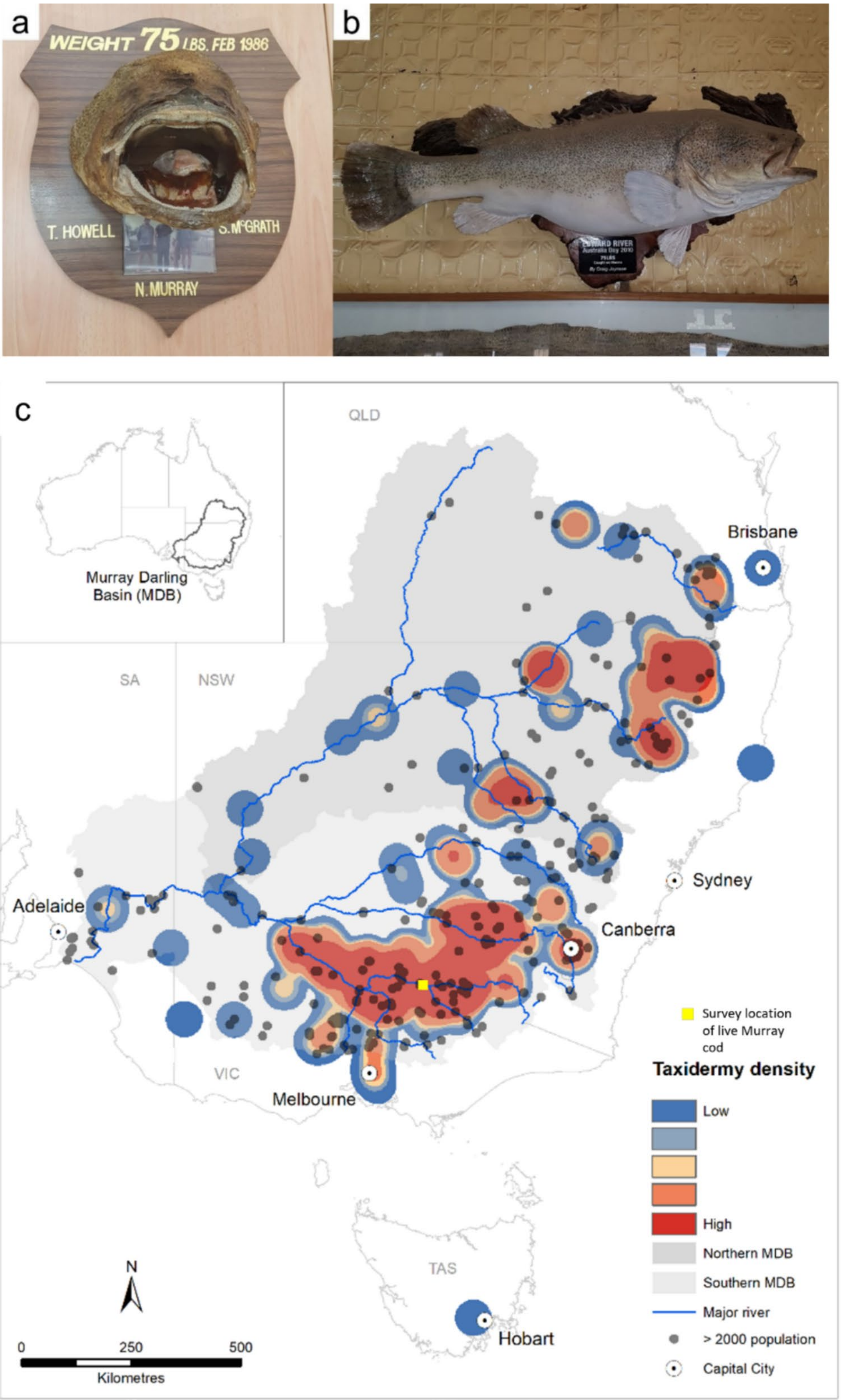
Murray cod

The Murray cod is Australia's largest freshwater fish, living up to 49 years of age and growing to 1.8 m (Allen et al., 2002; Humphries, 2023). Distributed throughout most of the Murray-Darling Basin (MDB), south-eastern Australia (Lintermans, 2023), it once supported an important commercial fishery and continues to support a popular recreational fishery (Doyle et al., 2023). Its current populations are estimated to be well below historical levels (Ye et al., 2021) and consequently, the species has been listed under the Commonwealth of Australia's Environment Protection and Biodiversity Conservation Act of 2003 as 'vulnerable', as 'threatened' in the state of Victoria (2021), 'endangered' in South Australia (2009) but it is not listed in New South Wales. The IUCN's Red List classified Murray cod as 'critically endangered' in 1996, but now considers the species as 'least concern' based on unpublished data from the New South Wales Department of Primary Industries. Claims of recent increases in population size appear minor in comparison to the severe historical declines in abundance (Humphries, 2023). The conservation and management of Murray cod is typically given priority in the MDB, and the species is considered ecologically and culturally important (Ebner et al., 2016; Humphries, 2023; Murray and Humphries, 2023).

Collection of taxidermy Murray cod

We adopt the Morris (2010) definition of taxidermy, by which preservation involves the whole or part of the animal being skinned, then preserved, positioned and mounted in a near lifelike state. At the commencement of the study, we were unaware of how many Murray cod mounts were held in informal collections. Information on the location of taxidermy Murray cod mounts, type of mount (head or whole), location, steward, and presence of accompanying interpretive records (e.g., date of capture, size, location caught etc.) were collected via a broad-scale citizen science survey in 2018–19, as described in O'Connell et al. (2025). A total of 363 head and 96 whole forms of taxidermy Murray cod from informal curatorial origins were verified as accessible to use for this study and usable as biological records, as their stewards were open to registrations of the features, interpretations of location, timing and size at harvest (O'Connell et al., 2025).

Two forms of taxidermy Murray cod were assessed for their life-like shape: head mounts (the severed head) and whole mounts (the entire body). The


a
WEIGHT 75 LBS. FEB 1986
T. HOWELL
S. McGRATH
N. MURRAY
b
c
Murray Darling Basin (MDB)
QLD
SA
NSW
VIC
TAS
Brisbane
Sydney
Canberra
Adelaide
Melbourne
Hobart
Survey location of live Murray cod
Taxidermy density
Low
High
Northern MDB
Southern MDB
Major river
> 2000 population
Capital City
N
0
250
500
Kilometres

◂**Fig. 1** Examples of taxidermy Murray cod **a** head mount and **b** whole mount, with co-located interpretations of provenance on backing boards, and **c** density map of verified Murray cod taxidermy specimens held in Australia ($n=459$) across their 189 steward locations plotted against major rivers and population centres of > 2000 people in the Murray-Darling Basin (MDB)

taxidermy Murray cod were mounted in a trophy style (Fig. 1a, b), which typically involved the mounts fixed onto a backing board in a position to emphasise the fish's mouth or body size, with interpretations of provenance transcribed on the board, and then hung on display. While the preservation techniques applied to the fish and the curatorial history for the mounts were generally incomplete or unknown, commonly applied preservation technique for fish mounts involves using a combination of alcohol and formalin (Kabir and Hawkeswood, 2020).

Each of the taxidermy mounts was photographed *in-situ* and had its curatorial circumstances, condition and interpretative records copied and transcribed. The available interpretative information relevant to the assessment of biological features and provenance were recorded, including the date of capture, location, weight and length. This information was used with the morphological features to help evaluate potential biases in the taxidermy presentations and utility of the fish as biologically meaningful historical records. Of the full record of mounts identified and verified to exist, the morphological features of the mounts were measured for 172 head mounts and 60 whole mounts (see below, Morphological measurements). Mounts were verified as Murray cod using Allen et al., (2002) and distinguished from the closely related *Maccullochella macquariensis* based on their jaw alignment and provenance records.

Collection of live Murray cod

To determine if head morphometrics from taxidermy forms of Murray cod were correlated with live Murray cod, live Murray cod were collected from the Murray River, near Yarrawonga, in the southern MDB, in June 2018. Live Murray cod were measured here, as it is in the same region of the MDB where the highest density of taxidermy Murray cod had been captured (Fig. 1c). Live Murray cod were collected from the Murray River using a boat electrofisher (Smith Root Inc., Portland, Washington, USA), and collected over approximately 10 km of river downstream of Yarrawonga. Murray cod were distinguished from trout cod (*M. macquariensis*) based on jaw alignment, pigmentation patterns and from descriptions in Allen et al., (2002). Morphological measurements (see below) and weights of all Murray cod captured ($n=51$) were taken, with fish then returned to the river. Fish were collected under Animal Ethics Committee, Australia (AEC 14/04) permit by the Department of Environment, Land Water and Planning with researchers from Arthur Rylah Institute for Environmental Research.

Morphological measurements

We tested if head morphometrics (HM) could provide an accurate estimate of the lifelike length and weight of Murray cod. Head (skull) features were used because of: their potential robustness to taxidermy; the relatively common occurrence of the head taxidermy form; their previous use in the taxonomic description of the genus *Maccullochella* (Berra and Weatherley, 1972); the existing knowledge on the length–based features of the species (Anderson et al., 1992; Rowland, 1998); and their likelihood to be related to a biologically-relevant metrics, total length (TL) and total weight (TW) (Froese, 2006).

Head morphometric features were measured on 172 head mounts, 60 whole mounts and 51 live Murray cod. The head morphometric features selected for measurement were chosen based on: 1) their potential to be robustly obtained from the three types of study specimens; 2) if they had been used in previous studies investigating Murray cod morphology and length-based growth characteristics; 3) if they had been used in previous studies investigating preserved forms of fish as morphological records; and 4) their likelihood of being related to TL and total weight (TW).

From these criteria, seven head morphometrics were identified for measurement: minimum inter-orbital distance (IO), minimum inter-nare width (IN), upper jaw length (UJ), maximum eye diameter (ED), maximum mouth width (MW), maximum head width (HW), and maximum mouth height (MH) (see Supplementary Information 1 and 2 for diagram and definitions). IO and IN were chosen because they are the least-fleshy point-to-point measurements associated with the skull. Furthermore, previous Murray cod studies have found them to be robust to the typical influences of preservation and curation (e.g., weathering, shrinkage and distortions) (Berra and Weatherley, 1972; Rowland, 1993). ED and HW were measured, as they have successfully been used for detecting allometric growth (Berra and Weatherley, 1972; Rowland, 1993) and isometric growth (Stuart et al., 2008) in Murray cod. The UJ was included due to it being previously assessed in Murray cod without its morphometric relationship details (Berra and Weatherley, 1972) and its potential relationship to TL (Lawton et al., 2010). The MW and MH were likely to be influenced by preservation, but were still included because of their potential relationship to Murray cod TL (Ebner, 2006). All head morphometrics were measured as point-to-point straight line lengths that followed standard protocols (Strauss and Bond, 1990).

To establish relationships between head morphometrics (HM) and TL and TW, TL (mm) was measured for whole mounts and live fish (TL_m), and TW (g) was measured on the live fish (TW_m). Due to the availability of specimens, this resulted in mostly larger living individuals (e.g., > 600 mm TL) and small whole mounts (e.g., < 600 mm TL) measured.

Where available, interpretive records of total length (TL_r) and total weight (TW_r) were recorded from head and whole mounts. These records were used to examine how interpretive records of length and weight compared with the estimates of length and weight derived from the HM–TL and HM–TW relationships. Observations on the influence of preservation on the taxidermy fish morphology were also recorded, including where mounts appeared to display shrinkage, included foreign objects (e.g., moulds); and/or deformities (e.g., mouth dislocated).

Data analysis

We examined relationships between i) head morphometrics and total length (HM–TL), ii) head morphometrics and total weight (HM–TW) and iii) total length and total weight (TL–TW) for head and whole mounts and compared them to the analogous relationships for live Murray cod. Patterns and interactions among the HM, TL and TW were visualised, and models tested for significant differences between the head mounts, whole mounts and live fish. For each test, only live fish and taxidermy forms with a similar size range were analysed and compared.

HM–TL relationships for taxidermy mounts and live fish

To assess the relationships of HM–TL for live fish, whole mounts and head mounts, a Pearsons correlation matrix was used to determine the strength of associations for the seven HM metrics and TL. For this exercise we used TL_m for live fish and whole mounts and excluded TL as a metric for head mounts. Positive correlations > 0.95 between two metrics were considered to be very strong associations. Measurement data from live Murray cod and whole mounts were clipped so that the two forms of Murray cod analysed were within a similar TL range of each other (590–1195 mm TL) (Supplementary Information 3a). This resulted in 20 live Murray cod, 32 whole mounts and 172 head mounts used in their respective correlation matrices. The strength of the correlations within a form were used to identify the most robust head morphometrics for predicting TL and used for subsequent analyses thereafter.

Using the robust head morphometrics identified from the correlation matrix, we then fitted linear regressions to compare how HM–TL relationships differed from whole mounts to live Murray cod. HM–TL relationships were determined by the method of least squares to fit a simple linear regression:

$$TL = a + bHM.$$

where TL = total length of fish (mm), HM = a head morphometric measurement (mm), a = intercept and coefficient related to body form (proportionality constant) and b = exponent coefficient. Linear regression lines of best fit were plotted with 95% CI overlaid, to visually assess how HM–TL relationships differed from whole mounts compared to live fish.

For each of the robust HM–TL relationships identified from the correlations, we ran an analysis of covariance (ANCOVA) to test if the HM–TL relationships of whole mount taxidermy fish was different to live fish. Here, TL_m was the dependent variable, the HM was the continuous covariate, and 'Form' was a categorical covariate with two levels (live fish, whole mount). Exploratory plots of the data and residuals showed that assumptions of linearity, homogeneity of variances, independence and normality of error terms were upheld, and so a Gaussian distribution was used to fit the models. We tested for significance of the interaction and main effect terms of HM and Form.

Reported vs measured total length

We examined the relationship between the measured total lengths (TL_m) of whole mount Murray cod with the reported live length at capture (TL_r) using a simple linear regression. The data set was limited to Murray cod whole mounts that had records of live length at capture (size range 860–1500 mm TL_r), which reduced the number of records from 60 whole mounts to 16.

HM–TW relationships for taxidermy mounts and live fish

HM–TW relationships for whole mounts, head mounts and live fish were examined using ANCOVA. For this, the HM with the strongest associations with TL were analysed, using TW_r at capture for whole and head mounts, and TW_m for live fish for the response variable. The HM was the continuous covariate and 'Form' was a categorical covariate with three levels (live fish, whole mounts, head mounts). HM and TW were $\log_e$ transformed prior to analysis. For the ANCOVA, we reduced the effect of allometric and isometric growth, by subsetting the available fish to those within a similar HM range to each other (IN = 30.2–86.7 mm, See Supplementary Information 3a). This resulted in 120, 45 and 28 specimens included for head mounts, whole mounts and live fish, respectively. The HM-TW relationship was considered isometric (proportions stay relatively the same) when (*b*) (exponent coefficient) = 3. Departures from 3 were considered allometric growth (Crook and Gillanders, 2013). High values of 3 for (*b)* are termed positive allometric growth and occur in fishes that become progressively fatter as they grow. Conversely, (*b)* can be less than 3 (negative allometric) when larger specimens become more elongated, or smaller specimens are in better condition (Froese, 2006).

TL–TW relationships on whole mounts and live fish

To assess the differences in the ln transformed TL–TW relationships between the whole and living specimens, the data was clipped to analogous TL range (590–1195 mm), which resulted in a TW range of 2.6–37.2 kg.

Predicting live fish length and weight from taxidermy mounts

To estimate live fish length and/or weight at capture from taxidermy Murray cod mounts, corrections for the shrinkage of the taxidermy form were applied. The correction factor (Ć) was calculated by: 1) assessing which length feature (e.g. TL or HM) was contributing to the difference; 2) deriving Ć algebraically (Supplementary Information 4) that describes the difference between the living and taxidermy forms; and 3) incorporating the Ć into the benchmark living form regression that uses the intercept (*a*) and the slope (*b*) from the analogous living form. The resulting linear regression was:

$$Y_L = a_L + b_L\left(X_T + \acute{C}\right).$$

where $\acute{C} = \left(b_T/b_L\right)X_T + \left(a_T - a_L/b_L\right) - X_T.$

And Y_L = lifelike size of fish (e.g., TW (kg) or TL (mm)), X = head morphometric measurement (e.g., IN) (mm), (*a*) = is the coefficient related to body form (proportionality constant), (*b*) = exponent coefficient and (Ć) = correction factor. The derivation of the Ć for shrinkage on the various length–weight relationships occurred on the natural log-transformed data. This regression includes the Ć for shrinkage and uses the subscript '$_T$' to refer to the parameter that relates to the taxidermy form, and subscript '$_L$' to refer to the benchmark living form.

All statistics and graphics were undertaken with R freeware (R Core Team, 2013). Pearson's Correlations, linear regressions and ANCOVAs were run with the 'stats' package (R Core Team 2022), and figures were created with'ggplot2' (Wickham, 2016). Statistical significance was defined as $P < 0.05$, and adjusted R^2 values are reported as R^2.

Results

Provenance features

The taxidermy specimens came in two forms, head mounts and whole mounts (Fig. 1a, b), with three times more heads assessed as morphological records (Table 1). Total weight was the most commonly-recorded attribute with the mounts, followed by the year of harvest and then the location of harvest.

Based on the capture locations recorded on the mounts, the taxidermy Murray cod were caught from locations covering an area over 250 000 km^2 of south-eastern Australia. More Murray cod were caught from the southern than the northern MDB (Fig. 1c). The mounts were hosted by 189 stewards and were almost exclusively informally-curated, with only 3% curated in formal collections. Most mounts were curated within, but some were also found outside, of the MDB (Fig. 1c). Mounts of both forms were more commonly stewarded in the southern part of the MDB, with pub hotels in that part of the MDB stewarding 51% of the head mounts and 33% of the whole mounts. Most mounts were located within the southern-most section of the Murray River and its major tributaries, and in the more densely populated areas. Only three stewards associated with three mounts were forthcoming from the state of South Australia.

Weight at harvest records

The 260 (57%) verified specimens that came with interpretative records of weight suggest that the mounts of both forms were mostly large, mature and old specimens, with less than 10% of both forms being immature fish (<9 kg, Rowland, 1985) (Fig. 2). For the head mounts, the most common reported weight range was 14–17 kg, and the overall weight distribution was approximately normal. The median and mean weights of the Murray cod preserved as head mounts were 24 kg and 22 kg, respectively. For whole mounts, the most common reported weight at capture range encountered was 36–40 kg, with a median of 24 kg and a mean of 32 kg. The largest reported weight was a whole mount of 56.7 kg.

Year of harvest records

A total of 246 mounts (54%) had their harvest year reported with them. The harvest period range was 121 years, from 1893 to 2014 (Fig. 3) (O'Connell et al., 2025). Apart from a single whole specimen collected in 1893 and stewarded in a formal museum, all other recorded mounts were harvested over a 62-year period from 1952–2014. The harvest date

Table 1 Descriptive morphometric and interpretative metadata of Murray cod taxidermy mounts and live fish

Form	No specimens	Year of capture		Harvest location		Total weight (kg)						Total length (mm)					
						Measured			Reported			Measured			Reported		
		Range	N	Northern MDB	Southern MDB	n	Range	Mean ± SE	n	Range	Mean ± SE	n	Range	Mean ± SE	n	Range	Mean ± SE
Head mount	172	1952–2006*	111	63*	40	0	–	–	125	2.9–48.9	22.2 ± 0.9	0	–	–	11	950–1300	1162 ± 34.7
Whole mount	60	1958–2010*	42	6*	42	0	–	–	48	3.6–56.7	32.4 ± 1.5	60	590–1419	1135 ± 24	16	860–1500	1200 ± 43
Live fish	51	2018	51	0	51	51	0.031–27.1	5.5 ± 1.2				51	148–1180	559 ± 43.2	0	–	–

*Denotes metrics reported in mounts' interpretive records

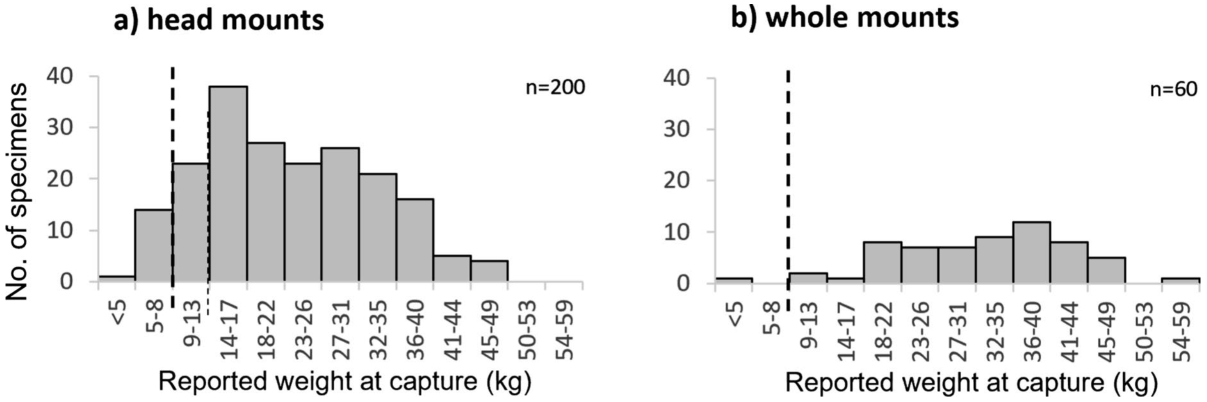


Fig. 2 Frequency of recorded weight at capture for taxidermied Murray cod **a** head mounts and **b** whole mounts. The dashed line is a conservative benchmark weight at maturity of live Murray cod (~ 9 kg) from multiple habitats across their range (Rowland, 1985)

distributions for both forms of taxidermy were negatively skewed, with only 16 specimens coming with a harvest date before 1980. The number of verified mounts for both head and whole mounts showed a peak harvest period during the 1990s. Before 2000, there were many more head mounts ($n = 150$) than whole mounts ($n = 32$). However, after 2000, whereas there were still more heads than whole mounts, the proportion of whole mounts increased, with 44 head and 18 whole mounts. Overall, there were similar temporal trends for both forms, with a sharp increase in the number of mounts from the 1980s and a subsequent decline around the 2000s.

Morphometric features

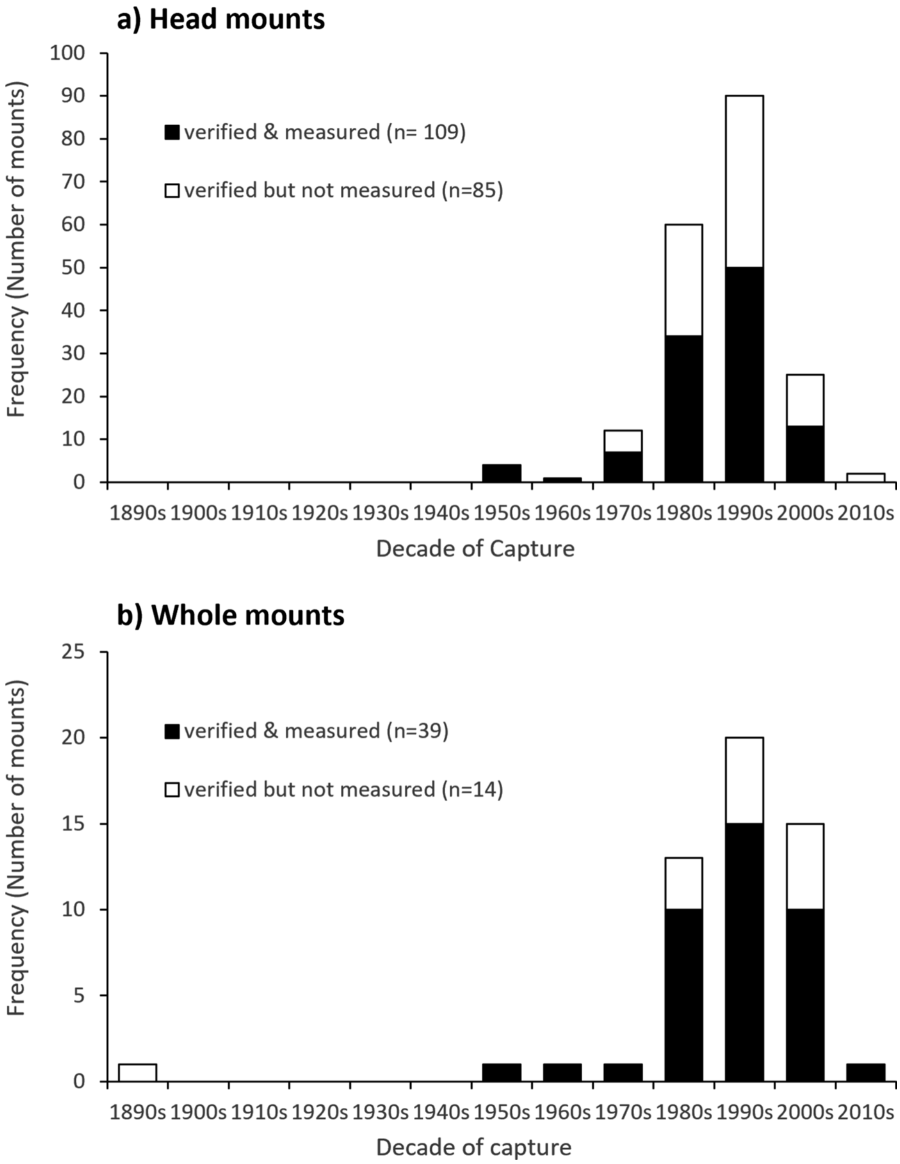
The reported total weight (TW_R) and measured total length (TL_M) indicated that both the head and whole mount taxidermy forms of Murray cod included larger specimens than the live fish caught in the Murray River in 2018 (Table 1).

Of the head morphometric features (HM) measured, three of them, eye diameter (ED), mouth height (MH) and head width (HW), appeared to have been visibly distorted by the taxidermy preparations, particularly for head mounts. An un-lifelike opening of the mouth was common in the head mounts, which unnaturally increased MH, while non-biological glass eyes were a common feature in mounts, which artificially increased ED. Un-lifelike flaring of the gills was also common in head mounts, artificially increasing HW.

HM–TL relationships on taxidermy mounts and live fish

The subset of Murray cod whole mounts ($n = 32$) and live fish (n = 20) used to determine the correlation strength between the suite of HM and TL had an analogous TL range of 590–1195 mm. For the live Murray cod specimens, the correlation between the size of all HM was strong ($r > 0.91$), and all HM were very strongly correlated with TL ($r > 0.98$) (Table 2). The strongest HM correlations with TL for live fish were inter-orbit (IO), inter-nare (IN), upper jaw (UJ) and HW ($r = 0.99$). For the whole mount and head mounts, the strength of HM and TL correlations was more variable (whole mounts: $r = 0.30$–0.98, head mounts: $r = 0.27$–0.99). IO, IN and UJ had a consistently strong correlation with each other across the three forms of fish (live fish, whole mounts and head mounts) ($r > 0.96$) and were also strongly correlated with TL ($r > 0.95$) on both the whole mounts and live fish. As compared to the live fish, whole mounts and head mounts MH and ED had poor intercorrelations with other head morphometrics, indicative of the observations of some mounts having been physically manipulated.

Fig. 3 Frequency of **a** head mounts and **b** whole mounts based on their reported decade of capture, where black bars represent mounts verified to exist (white) and of those, the mounts measured in the present study (black)



Reported vs measured total length

We found a strong, positive relationship between measured and reported TL of the Murray cod whole mounts ($F = 32.36$, df = 1.14, $R^2 = 0.67$, $p < 0.0001$) (Fig. 4). While this was a limited data set (n = 16), and outliers were present, the reported range was large (TL 860–1500 mm). The regression coefficient, 1.129 (95% CI 0.7–1.6), was close to allometric (1:1) indicating that the records of TL that accompanied the mounts are indicative of their lifelike TL.

HM–TL relationships

Total length increased significantly as IN, IO and UJ increased ($p < 0.0001$, Table 3, Fig. 5). Form also had a significant effect, with whole mounts being larger (TL) than live fish for any given HM ($p < 0.001$). There was no significant interaction between IN, IO and UJ and Form ($p > 0.05$).

The largest living Murray cod caught was 1180 mm TL, with an IN of 86.7 mm. The size of a whole mount fish with an equivalent IN was ~ 150 mm TL longer. Using a correction factor (Ć) to account

Table 2 Correlation matrix (r values) for TL and seven head morphometrics (HM) for live fish and whole and head mounts

Form		TL	IO	ED	IN	UJ	MH	MW	HW
Live fish (n = 20)	TL	1							
	IO	**0.99**	1						
	ED	0.98	0.97	1					
	IN	0.99	**0.99**	0.97	1				
	UJ	0.99	**0.98**	0.97	**0.98**	1			
	MH	0.94	0.95	0.91	0.96	0.93	1		
	MW	0.98	0.98	0.97	0.99	0.98	0.94	1	
	HW	0.99	0.98	0.97	0.98	0.98	0.93	0.97	1
Whole mounts (*n* = 32)	TL	1							
	IO	**0.95**	1						
	ED	0.80	0.74	1					
	IN	0.96	**0.98**	0.81	1				
	UJ	0.96	**0.96**	0.84	**0.98**	1			
	MH	0.52	0.38	0.32	0.41	0.41	1		
	MW	0.85	0.89	0.73	0.89	0.88	0.30	1	
	HW	0.84	0.89	0.67	0.87	0.84	0.35	0.94	1
Head mounts (*n* = 172)	TL	–							
	IO	–	1						
	ED	–	0.81	1					
	IN	–	**0.99**	0.84	1				
	UJ	–	**0.96**	0.83	**0.97**	1			
	MH	–	0.31	0.27	0.36	0.39	1		
	MW	–	0.92	0.84	0.93	0.94	0.38	1	
	HW		0.84	0.73	0.85	0.84	0.41	0.90	1

Morphometrics: Total length (TL), inter-orbital distance (IO), eye diameter (ED), inter-nare width (IN), upper jaw length (UJ), mouth height (MH), mouth width (MW) and head width (HW). The consistently significant interrelationships among the robust HMs of IO, IN and UJ are in bold

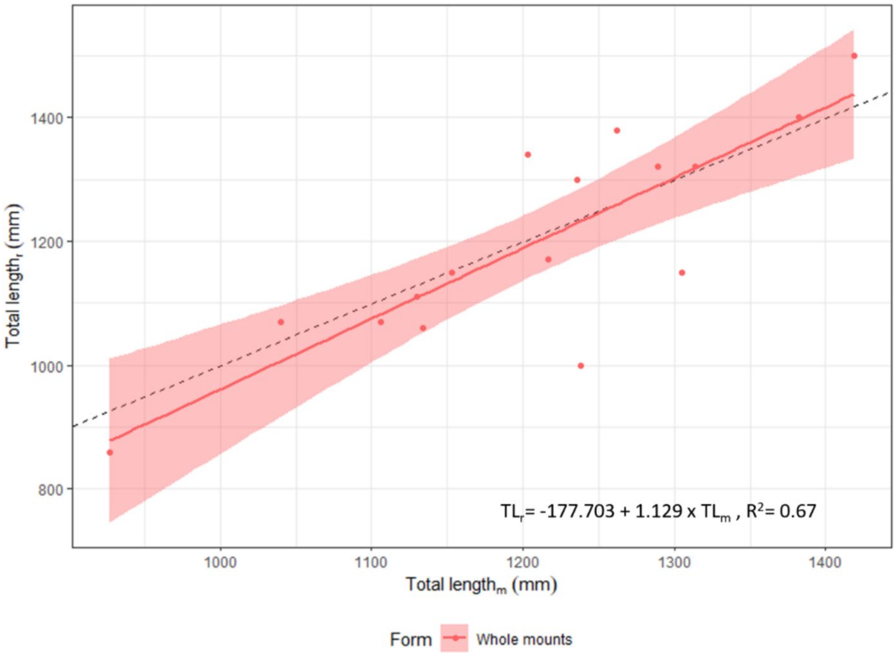


Fig. 4 Scatterplot showing regression fit (with 95% CI) of measured total length (TL_m) and reported total length (TL_r) of whole mount Murray cod (*n* = 16). R^2 = adjusted R^2. Black dashed line represents 1:1 of TL_m:TL_r

for the consistent difference in HM–TL relationships between live Murray cod and whole mounts, life-like TL (TL_L) could be predicted from IN, IO and UJ of taxidermied mounts using the following equations (see Supplementary Information 4 for calculations):

$$IN\text{:}\quad TL_L = 11.211\left(IN_T + \acute{C}\right) + 196.720,\\ where\ \acute{C} = 0.092IN_T + 1.470. \tag{1}$$

$$IO\text{:}TL_L = 9.401\left(IO_T + \acute{C}\right) + 177.700,\\ \text{where } \acute{C} = 0.039IO_T + 7.843. \tag{2}$$

$$UJ\text{:}TL_L = 6.065\left(UJ_T + \acute{C}\right) + 133.107,\\ \text{where } \acute{C} = -0.024UJ_T + 17.402. \tag{3}$$

where IN_T, IO_T, and UJ_T, are the taxidermy measurements of IN, IO and UJ (mm) from whole mounts.

HM–TW relationships

The head morphometrics IN, IO and UJ were all highly significantly and positively related to total weight (TW) for live fish, head mounts and whole mounts (Table 3, Fig. 6). Regression fits for TW against IN, UJ and IO were stronger for live Murray cod ($R^2 = 0.98$, 0.99 and 0.98, respectively) than for head mounts ($R^2 = 0.86$, 0.84, 0.85) and whole mounts ($R^2 = 0.88$, 0.83, 0.89).

Total weight (Ln TW) increased significantly with an increase in IN and IO (IN $p < 0.0001$, IO $p < 0.0001$, Table 3, Fig. 6a, b). Head and whole mounts had a significantly greater Ln TW than live fish for any Ln IN or Ln IO length (Form: $p < 0.0001$). There was no significant difference in head mount and whole mount relationships. There was also no significant effect of the interaction term (IN:Form and IO: Form, $p < 0.05$). The 95% confidence intervals of the IN–TW relationship showed that live fish were between 0.44 and 0.60 smaller (on a log scale) than the head form, and 0.4–0.59 smaller than the whole form regardless of IN length of the fish. The equivalent IN on the taxidermy specimens resulted in a ~ 5 kg heavier fish. For UJ and Ln TW relationships, there was a significant interaction between UJ and Form (Table 3, Fig. 6c).

Table 3 Analysis of covariance (ANCOVA) testing the significance of head morphometrics (inter-orbital (IO), inter-nare (IN), upper jaw (UJ)) and Form (whole mounts, live fish) with i) total length (TL) and ii) total weight (TW). *P*-values (Pr) < 0.05 are considered significant and highlighted in bold

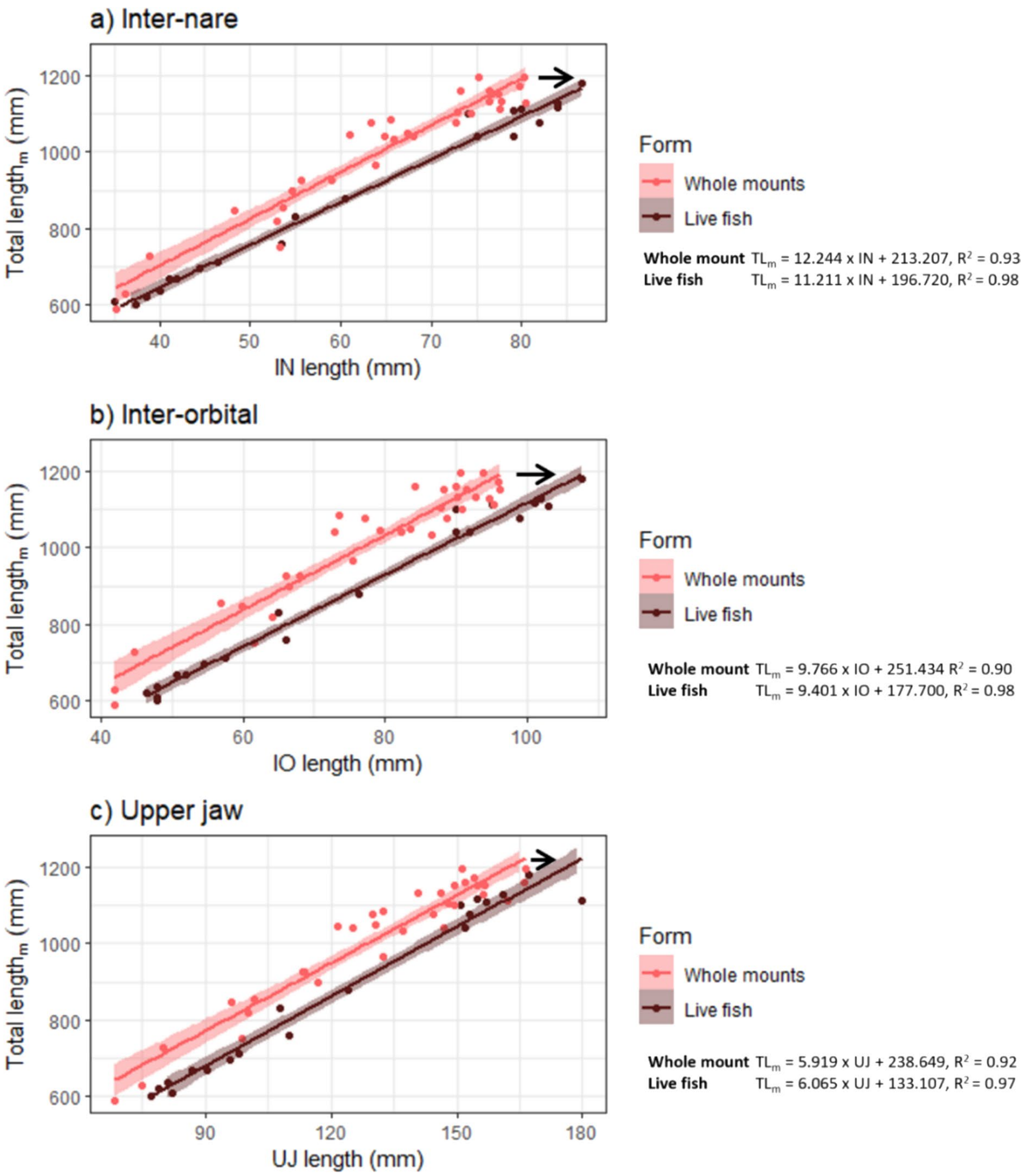
		DF	*F* value	Pr (> F)
Total Length (TL)	*TL ~ IN*			
	IN	1,49	1192.77	**< 0.0001**
	Form	1,49	53.25	**< 0.0001**
	IN x Form	1,49	2.12	0.1512
	TL ~ IO			
	IO	1,49	895.49	**< 0.0001**
	Form	1,49	64.46	**< 0.0001**
	IO x Form	1,49	0.31	0.5827
	TL ~ UJ			
	UJ	1,49	954.14	**< 0.0001**
	Form	1,49	48.78	**< 0.0001**
	UJ x Form	1,49	0.13	0.7181
Total Weight (TW)	*TW ~ IN*			
	IN	1,188	3523.33	**< 0.0001**
	Form	2,188	81.97	**< 0.0001**
	IN x Form	2,188	1.05	0.3508
	TW ~ IO			
	IO	1,187	2798.86	**< 0.0001**
	Form	2,187	111.33	**< 0.0001**
	IO x Form	2,187	2.13	0.1215
	TW ~ UJ			
	UJ	1,185	3211.85	**< 0.0001**
	Form	2,185	82.59	**< 0.0001**
	UJ x Form	2,185	3.95	**0.0208**

Using a correction factor (Ć) to account for the consistent difference in HM–TW relationships between live Murray cod and taxidermy mounts, life-like TW (TW_L) could be predicted from taxidermy IN, UJ and IO using the following equations (see Supplementary Information 4 for calculations). The corrected regressions that relate taxidermy IN, IO and UJ (X_T) to lifelike TW (TW_L) were:

$$IN\text{:}\quad \ln TW_L = 2.789 \times \ln\left(IN_T + \acute{C}\right) — 9.111,\\ \text{where } \acute{C} = e^{(2.631x\ln(IN))/2.789+0.407)} - IN_T. \tag{4}$$

$$IO\text{:}\quad \ln TW_L = 2.679 \times \ln\left(IO_T + \acute{C}\right) - 9.183,\\ \text{where } \acute{C} = e^{(2.490\times\ln(IO))/2.679+0.523)} - IO_T. \tag{5}$$

$$UJ\text{:}\quad \ln TW_L = 2.964 \times \ln\left(UJ_T + \acute{C}\right) - 11.909,\\ \text{where } \acute{C} = e^{(2.570\times\ln(IO))/2.964+0.8205} - UJ_T. \tag{6}$$



Whole mount $TL_m = 12.244 \times IN + 213.207$, $R^2 = 0.93$
Live fish $TL_m = 11.211 \times IN + 196.720$, $R^2 = 0.98$

Whole mount $TL_m = 9.766 \times IO + 251.434$ $R^2 = 0.90$
Live fish $TL_m = 9.401 \times IO + 177.700$, $R^2 = 0.98$

Whole mount $TL_m = 5.919 \times UJ + 238.649$, $R^2 = 0.92$
Live fish $TL_m = 6.065 \times UJ + 133.107$, $R^2 = 0.97$

Fig. 5 Scatterplots showing regression fits (with 95% CI) of head morphometrics: **a** inter-nare width (IN), **b** inter-orbital distance (IO), and **c** upper jaw length (UJ), with total length (TL mm); for whole mounts ($n = 32$) and live Murray cod ($n = 20$). Arrow points to the correction that needs to be applied to the taxidermy head morphometrics to meet the benchmark living form

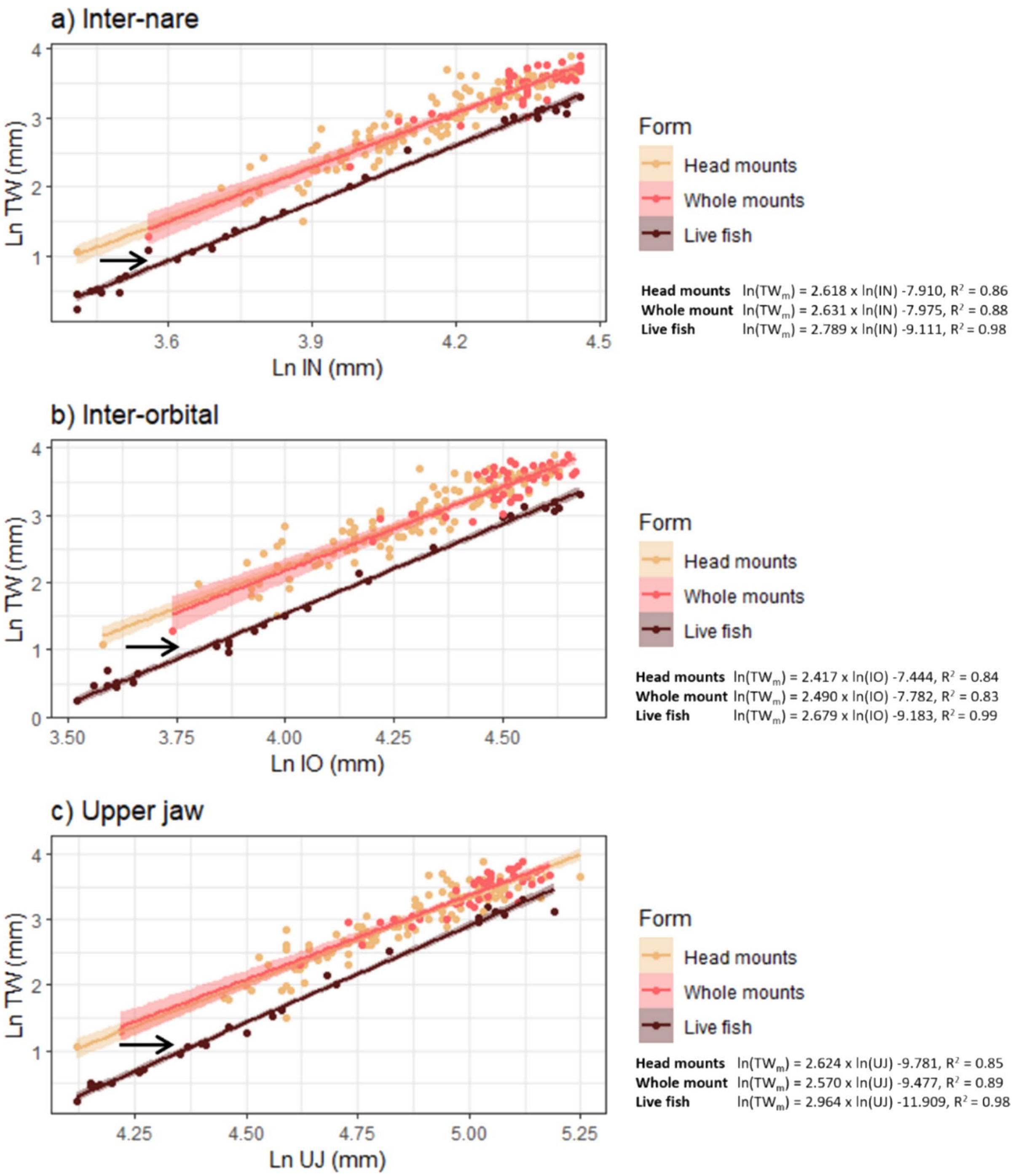


Fig. 6 Scatterplots showing regression fits (with 95% CI) of head morphometrics: **a** Inter-nare width (IN), **b** Inter-orbit distance (IO), and **c** upper jaw length (UJ), with total weight (TW kg); for head mounts ($n = 120$), whole mounts ($n = 45$) and live Murray cod ($n = 28$) sized between 590 and 1195 mm TL. Data ln transformed and subset to specimens with comparable IN length (30.2–86.7 mm). Arrows point to the correction that needs to be applied to the taxidermy HCM to meet the benchmark live form. R^2 = adjusted R^2

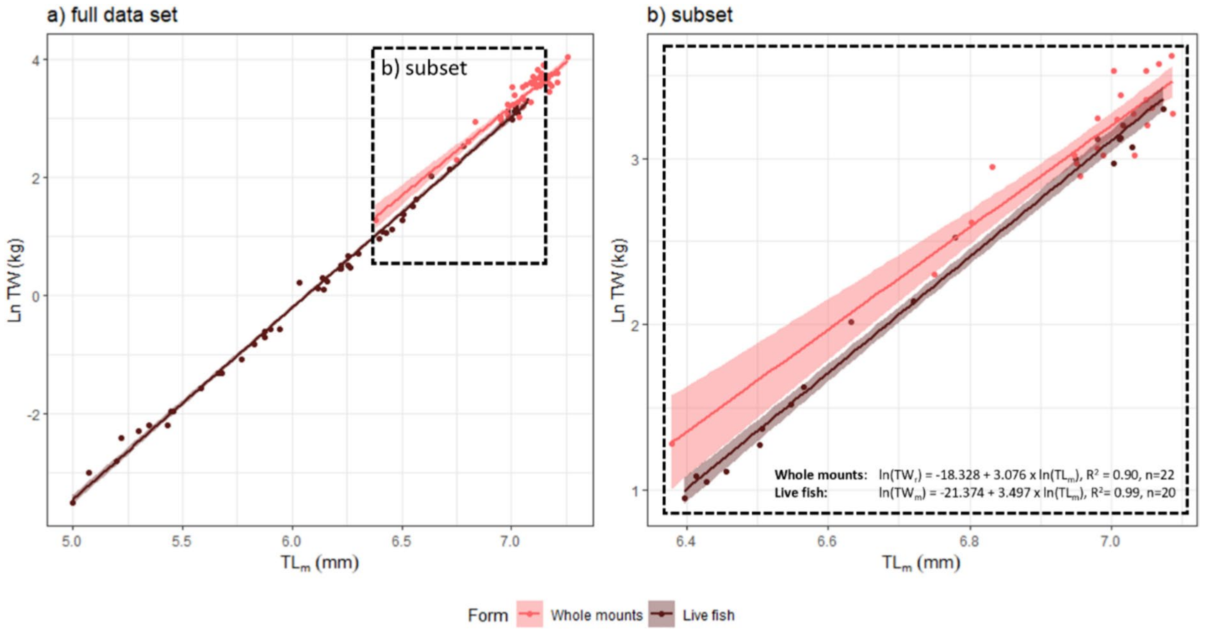


Fig. 7 Scatterplot of ln-transformed TL (mm) and ln-transformed TW (kg) of Murray cod live fish and whole mounts for **a** the full data set and **b** a subset of live fish and whole mount specimens with a comparable TL range (590–1195 mm) and associated TW (2.6–37.2 kg). Linear-regression line of best fit and 95% prediction intervals overlaid. TW_r = reported weight, and TW_m = measured weight. R^2 = adjusted R^2

TL-TW relationships

For fish sized between 590–1195 mm, the relationship between ln TW and ln TL was very strong for whole mounts ($R^2 = 0.90$), and live fish ($R^2 = 0.99$) (Fig. 7). Total weight increased significantly with increasing TL (ANCOVA: df = 1.38, $F = 1505.76$, $p < 0.0001$). There was no significant difference in ln TW among live fish and whole mounts at any given TL (df = 1.38, $F = 3.539$, $p = 0.067$). However, the influence of ln TL was significantly different for live fish and whole mounts (df = 1,38, $F = 8.44$, $p = 0.006$), with whole mounts consistently heavier than live fish for the same measured TL (Fig. 7). When back transformed, the difference in the ln TW predictions for whole mounts and live fish was ~ 1.15 kg for any given size between 590–1195 mm and not considered biologically significant. Thus, TW for the two forms of Murray cod within this TL range could be predicted from TL with the equation:

$$\ln(TW) = 3.497 \times \ln\left(TL + \acute{C}\right) - 21.374, \quad \text{where } \acute{C} = e^{(3.076 \times \ln(TL))/3.497 + 0.871} - TLT \tag{7}$$

Discussion

In this study we found taxidermy Murray cod in the form of head and whole mount specimens to be reliable records of total length and weight. The informally-curated taxidermy Murray cod provided usable head and body features for estimating total length (TL) and total weight (TW). Morphometry identified three head morphometric features (HM), inter-orbital distance (IO), inter-nare width (IN) and upper jaw length (UJ), that had strong and significant correlations with each other and were useful to estimate TL and TW on both live and taxidermy forms. Once the shrinkage for HM is corrected for, the relationships to TL and TW can be used on taxidermy specimens within the TL 590–1195 mm range. Given the trophy origins of the specimens and the predominance of head forms without body size measurements, the ability to predict TL from head morphology expands opportunities for their use as an historical biological record. Validation of the recorded historical TL and TW of the taxidermy specimens supports further exploration of variation in body size and what this means for past and current environmental conditions and population-related metrics.

Provenance features

The application of morphometry and comparison with live Murray cod validated the lengths and weights included with the taxidermy specimens. The provenance records of the taxidermy Murray cod indicated that they include unusually large and rarely-surveyed examples from across the Murray-Darling Basin (MDB) (Rowland 2004). Interpretive records of total length rarely accompanied the taxidermy Murray cod specimens but, when they did occur, they correlated well with the measured total length of the preserved whole mounts. Records of total weight were far more common, and based on the evaluation of length-based relationships, the taxidermy HM–TW relationships were consistent with those of live fish. Other investigations into informally-curated taxidermy specimens have also encountered a richness of temporal and spatial provenance (e.g. Casas-Marce et al., 2012).

The reported harvest period of the informally-curated taxidermy Murray cod coincided with major environmental change in the MDB, especially water resource development, dam building, the spread of the invasive common carp, *Cyprinus carpio* Linnaeus, 1758, and the Millennium drought (Humphries, 2023; Lintermans, 2023). Limitations in recorded size traits and other provenance data with taxidermy specimens and historical records are common (Morris, 2010; Lucas, 2014). As a result of this research, the 459 taxidermy Murray cod registered from across a broad geographic range of the MDB (O'Connell et al., 2025) can effectively have their biological size traits enhanced. Further, any Murray cod mounts that do not come with length and weight interpretations, now have several HM relationships that can be applied to them to produce reliable estimates of size.

Head morphometric–length relationships

To our knowledge, this study is the first to demonstrate that head morphometric - length- relationships of taxidermy mounts are comparable to those of live fish. Further, for live fish, none of the morphometric details associated with the HM relationships (e.g., IN–TL, IO–TL or UJ–TL) have been previously reported for Murray cod. A number of factors are known to influence the length relationships in fishes, including growth phase, season, degree of stomach fullness, gonad maturity, sex, size range, health and general fish condition and preservation techniques (Tesch, 1968), which may have introduced random error into our relationships. The shrinkage to the taxidermy specimens, however, introduced a systematic preservation factor that must be accommodated (Paradis et al., 2007).

The isometric HM–TL relationships were linear for both live and taxidermy fish and explained high percentages of variances on both head and whole-body forms over the assessed size range. All eight of the head morphometrics assessed were highly correlated with TL on the living form. Given that the location and period of harvest for Murray cod are known to increase variability in the species length-based relationships (Anderson et al., 1992), the benchmark relationships derived from the live specimens are likely to be stronger than that of the taxidermy form due to the specimens being purposely sampled from one population at one time up to a maximum TL, and not having taxidermy applied to them.

The comparison between the taxidermy and live forms showed that the length of three head characters, IN, IO and UJ, on the whole taxidermy form, maintained a useable and strong relationship to the life-like TL. While the hard parts, like the bones of animals, tend to be resistant to the processes associated with animal preparations and storage, the post-death shrinkage of bone and inter-bone tissue associated with multiple forms of preservation and preparation is common (e.g. Bancroft and Gamble 2008; Buytaert et al., 2014). The shrinkage of the head morphometrics, however, did not alter the utility of the derived morphologic relationship.

We found that, although the head morphometrics of mouth height (MH), mouth width (MW), eye diameter (ED) and head width (HW) were correlated with TL in live Murray cod, and have been previously used in the taxonomic description of the genus *Maccullochella* (Berra and Weatherley 1972), they correlated poorly with TL in taxidermy whole mounts. Three of the head morphometrics used have been previously identified on Murray cod as having usable length relationships, namely: MH for the trophic position (Ebner 2006); ED for taxonomic differentiation (Berra and Weatherley 1972); and HW for the design of fishways

(Stuart et al., 2008). However, none of these relationships was as strong as IN–TL, IO–TL or UJ–TL on the taxidermy form. Two of the head morphometrics had been directly influenced by the taxidermy preparations, with the placement of the specimen's mouth directly distorting (e.g., overemphasising) MH and the addition of non-biological glass eyes enlarging ED. While MW and HW did not appear to be directly influenced by the taxidermy process and reliably related to TL on the living form, they were a poorer fit to TL than IN, IO and UJ on all forms.

Although both the live fish and whole mount regressions were very strong and able to predict TL from the HM, using the HM from the taxidermy specimens to infer lifelike TL required a correction factor (Ć) to account for the difference. There are several explanations for the difference in TL–HM relationships of live fish and whole mounts: 1) shrinkage (or underestimate of HM on the whole mounts compared with life fish; 2) stretching (or overestimate) of the TL of whole mounts compared with life fish; and/or or 3) that the Murray River live fish sampled population TL–HM relationships were different to past TL-HM relationships of mounted fish. We hypothesise that the difference between forms is most likely a result of the shrinkage of the head morphometrics on the taxidermy due to: 1) the difficulty in stretching a tanned taxidermy skin up to 150 mm; and 2) the consistency between reported TL of the fish at harvest and measured TL of the mount specimens.

Head morphometric–weight relationships

This is the first study to report head morphometric–total weight relationships for taxidermy Murray cod. Similar to the HM–TL relationships, the HM of IN, IO and UJ were strongly correlated with TW on all forms. Also, the TL–TW relationship were strong on the whole and living form specimens. The natural logarithmic length–weight relationships were linear and explained extremely high percentages of variances for all forms. Given that the respective intercepts were significantly different, but not the slope, this suggests that there was consistent shrinkage from the taxidermy of IN, IO and UJ, and the provenance of the fish has limited influence on how these various length–weight relationships can be used to both infer and validate the lifelike weight of taxidermy specimens. The IN on both forms of taxidermy were consistently small for the same weight fish. Due to this, and the correction factor required for the HM–TL regressions, it appears that this HM–TW difference is likely to be due to shrinkage of the head morphometrics rather than consistent over-reporting of 166 taxidermy specimens' weights. Whilst clipping the data was appropriate for the comparison, it included some larger (heavier) taxidermy specimens, due to the likely reduction (shrinkage) of their head morphometrics.

Length–weight relationships

Length–weight relationships vary more when fish are from different habitats and periods, due to different growth rates, and condition levels associated with the timing of their growth (Tesch, 1968). Furthermore, Murray cod become progressively fatter as length increases, and they have consistently been reported to exhibit positively allometric growth, with slope values 3.12–3.26 (Gooley, 1992; Rowland, 1998; Llewellyn, 2011; Robinson, 2012; Forbes et al., 2016). This expected variability is consistent with the positive allometric TL–TW relationships derived in the present study. Without subsampling for length, the slope for the benchmark live form was 3.24 and increased to 3.39 when the data were sub-sampled from an analogous TL range to taxidermy specimens. Also, the analogous slope for the whole mounts over smaller TL range was only 3.02. This data range influence on relationships is a well-understood concept (Jellyman et al., 2013). The goodness of fit (R^2) of the live fish TL–TW regression was 0.996, with that for the analogous relationship on the whole taxidermy specimens was 0.903. The likely reasons for the greater variation in the TL–TW relationship for the taxidermy than that for the live fish are: 1) the live fish were targeted for their size, with limited replication from one population and had a maximum TL of 1180 mm; 2) the whole body mounts included larger specimens (max TL 1419 mm); and/or 3) the taxidermy mounts were from multiple populations and periods and so their TL–TW relationship could be expected to be more variable. In addition to the provenance and range influences, these results could be due to a combination of measurement error (e.g., weight on all forms and length on taxidermy specimens), the taxidermy process stretching TL, and a consistently inaccurate transcription and reporting of taxidermy form TW. The assessment of these factors in the present study and the literature suggests that growth rate differences among locations likely explained the greater variation in the goodness of fit of taxidermy specimens. Irrespective of this, the difference in the TW predictions from TL, from taxidermy and living forms was ± ~1.2 kg, and not considered biologically significant. Thus, for biological assessments that only need TW estimates from Murray cod in the 590–1195 mm TL range, either of the presented TL–TW relationships can provide an estimate of lifelike TW.

The HM–TW relationships showed similar patterns to those of TL–TW, where the taxidermy form had a similar regression slope to live fish (e.g., IN–TW; 2.63 whole, 2.61 head, 2.78 live) and had overall lower R^2 values (e.g., IN–TW; 0.88 whole, 0.87 head) than live fish (0.99). The exceptionally strong R^2 values for the live form are likely due to the specimens' provenance and being targeted for size from a single population. The increased variation in length–weight as fish get larger with different harvest location and period, was consistent with that observed in other Murray cod studies (Anderson et al., 1992; Rowland, 1993). While some may reject fits with R^2 values < 0.9 as seen on the taxidermy form (e.g. Ogle and Winfield, 2009), it is believed the fit observed was a reflection of: 1) the dataset including larger specimens due to shrinkage of the HM observed in the HM–TL assessments; 2) the specimens being measured as available; and 3) the variability in fish condition due to the habitat conditions. The limited sample size for the small mounts and large living form, and the different habitats and periods they were harvested from, are all likely to have contributed to the increased variability (Jellyman et al., 2013). Further, a comparison of the HM–TW relationships showed that the taxidermy forms were consistently heavier than live fish for the equivalent HM length.

Unlike the TL–TW relationship, HM–TW relationships were negatively allometric; where all three of the robust HM (IO, IU and UJ) increased disproportionately with increasing weight. In contrast to the TL–TW relationships, the difference in the predictions of TW from the example HM IN was ± 5 kg, which is of biological significance in smaller specimens (Rowland, 1998). It also could indicate that the TW of the historical specimens was slightly greater (i.e. in better condition) for the same HM length of the benchmark living form (Anderson et al., 1992). Nevertheless, the similar slopes but differing intercepts mean that all the reported HM–TW relationships derived from taxidermy can be used to infer and validate lifelike TW.

Implications for contemporary and historical ecology

The robust head morphometric relationships of taxidermy and live Murray cod provide future research opportunities for contemporary and historical ecology. For example, head morphometrics could be used to estimate length and weight on live fish when time or technical constraints prevent total length and weight from being recorded (e.g., ethical and safe handling of large and dangerous animals). Further morphological and growth investigations across populations of Murray cod and taxidermy techniques is recommended. The population level growth relationships could contribute to the conservation of large forms of the species, given current requirements to release all large individuals (Koehn and Todd, 2012) and associated ethical handling risks for large live fish (Mayden and Kuhajda, 1996). Our results suggest that it should be possible to measure the IN of live fish while they are still in the water using vernier callipers and use IN-TL relationships to estimate TL. This could be especially useful during fishing competitions–or indeed whenever fishers might need or be asked to record catch metrics–allowing fishers to take one measurement to accurately represent the size of their fish. We encourage fisheries managers and fishing competition organisers to adopt routine recording of IN of Murray cod while the fish is still immersed.

The diversity of large and old taxidermy specimens presents advantages to explore the historical trophic processes associated with this apex predator (Ebner, 2006; Humphries and Winemiller, 2009; Humphries, 2023), despite the obvious biases in selection, persistence and availability of such specimens (Holmes et al., 2016). Historical records of large fish could improve our understanding of how the fishery and system productivity changed over time (Izzo et al., 2016). Large specimens can provide key information on maximum size that is often poorly understood in fisheries (Brunell et al., 2013; Winemiller et al., 2016). Museum specimens and records of animal size have been identified as critical evidence sources to improve our understanding of variations in body size, and to assess potential responses to climate change or shifts in species distributions or genetics (Millien et al., 2006). Some of the specimens of Murray cod in the present study were heavier and longer, and by inference potentially older, than those used in previous investigations exploring the growth patterns of the species (Berra and Weatherley, 1972; Rowland, 1985, 1993, 1998; Anderson et al., 1992; Ebner, 2006; Stuart et al., 2008; Llewellyn, 2011; Forbes et al., 2015). The existing knowledge on the variability in size, age, length and associated sexual maturity of Murray cod between systems (Rowland, 1985; Gooley et al., 1995), and associated links to overfishing risk (Forbes et al., 2015), could be investigated. The new archival source of verified size with a targeted effort towards the largest taxidermy specimens from each major population, could help explain some of this variability, provide insights on the historical capacity of the system and inform population level baselines.

Conclusion

The verified body size and accessibly of Murray cod taxidermy mounts, combined with their provenance, represent a new and important biological archive of an apex predator that could be used for contemporary and historical ecology research. The assessment of formally curated, informal, anecdotal and proxy records have been used to inform conservation efforts. In this study, the relatively low level of invasiveness and the associated likelihood of damage to the specimen from the applied technique was an important factor in acquiring the data. Similar non-invasive comparisons between benchmark data or knowledge with other forms of non-traditionally-derived biological records could both discover new evidence sources and build the case for more invasive explorations, such as tissue sub-sampling and otolith extraction and analysis. This could open up opportunities for exploration of the genetics, life history, movement and trophic ecology of historical specimens, which in turn could provide important information about past environments.

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Data availability The data that support the findings of this study are available from the corresponding author, NM, upon reasonable request.

Declarations

Conflict of interest The authors have no competing interests to declare.

Ethics approval Human ethics for the registration of the taxidermy mounts, obtaining copies of interpretive records, undertaking curatorial assessments and surveying their hosts was approved by the Charles Sturt University Human Research Ethics Committee (Protocol No: H400201728). Animal ethics for the collection of morphological features from the catch and release specimens of Murray cod was approved by the Department of Environment, Land Water and Planning Animal Ethics Committee, Australia (AEC 14/04).

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