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ORIGINAL RESEARCH

90 years of catch data reveal changes in catch composition in the Australian east coast recreational marlin fishery

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Abstract Long-term continuous datasets that record fishery catch are key to predicting and managing changes in fisheries. Unfortunately, long-term datasets are rare for recreational fisheries, which hinders our ability to understand long-term changes within these fisheries. Here we use several unconventional long-term datasets, including tournament and tagging program data, to assess changes in catch composition over time in the Australian east coast marlin fishery. We found significant changes to the species and size composition of species within the fishery over time. In the 1930s, catch was solely comprised of striped (*Kajikia audax*) and black (*Istiompax indica*) marlin. Black marlin proportionally dominated the fishery in the 1940s to 1980s, but the proportions of blue (*Makaira nigricans*) and striped marlin increased significantly from the 1980s until present. Currently, the fishery is comprised of primarily striped and black, and to a lesser extent blue marlin. Declines in the mean weight of black and striped marlin were also evident from the 1930s to 1980s. Technological advances improving offshore access may have driven changes in species composition. Our results demonstrate a potential change in technology and gear reshaping species composition within a fishery. This highlights how recreational fisheries, particularly those offshore, have changed with the technology over time, and the potential for future technological to dramatically alter recreational fisheries globally.

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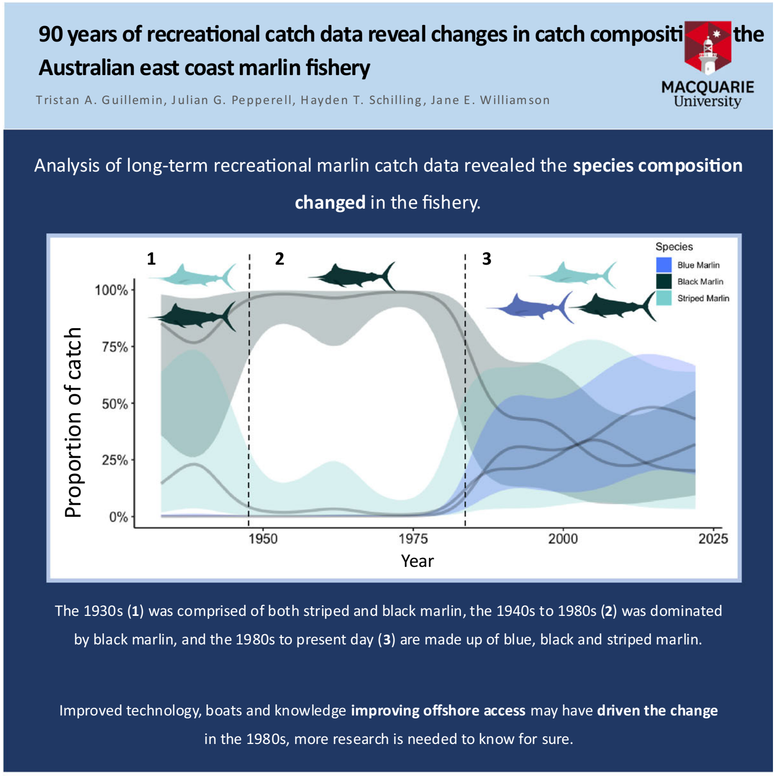
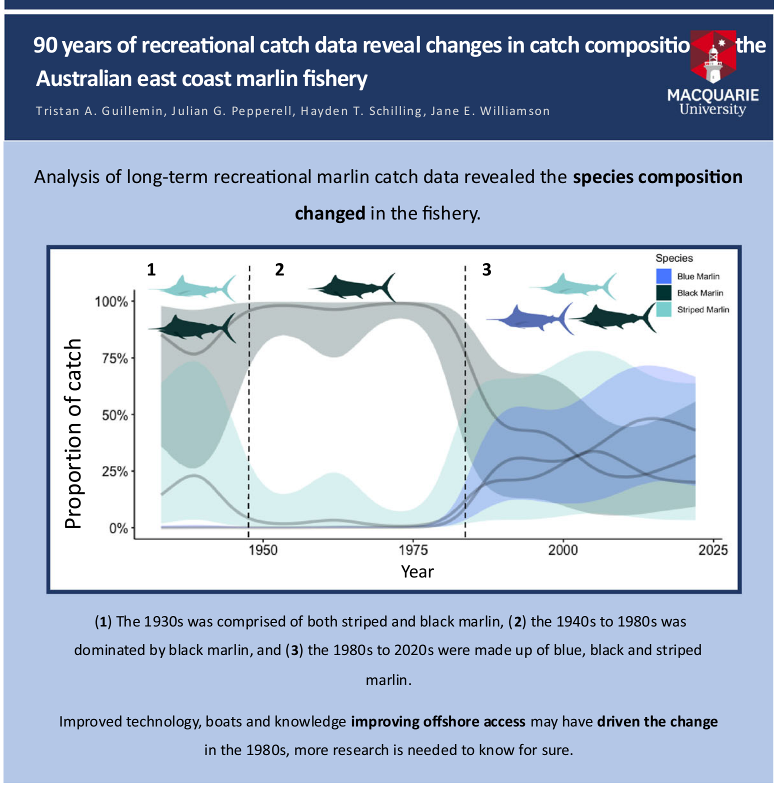
Graphic abstract





Keywords Marlin · Recreational fisheries · Historic · Gamefishing · Catch composition · Billfish

Introduction

Recreational fisheries can play key socio-economic roles in coastal and inland regions and can represent a substantial proportion of total fisheries harvest globally (Arlinghaus et al. 2019, 2015). With the yield and value of recreational fisheries increasing in many areas and in some cases even exceeding that of commercial fisheries (Hyder et al. 2018; Jackson and Moran 2012), there is an increased need for the implementation of effective management strategies that incorporate the recreational sector (Fowler et al. 2023). Unfortunately, most recreational fisheries lack reliable long-term datasets often available for commercial fisheries, greatly limiting our understanding of stock changes through time (Boucek et al. 2023; Gartside et al. 1999; Thurstan et al. 2015). Finding ways to overcome the lack of long-term datasets is key to identifying drivers of change and effectively managing fishery resources.

Where scientific or commercially collected data sources are lacking, alternate historic data have been used to identify long-term change in recreational fisheries. Such sources include: fishing or spearfishing tournament records (Boucek et al. 2023; Gledhill et al. 2015; Pepperell 1992; Pita and Freire 2014); logbooks (Campbell et al. 2003; Conron et al. 2018; Holdsworth et al. 2003); photographs (McClenachan 2009); newspaper articles (Gaynor et al. 2016; Thurstan et al. 2018, 2016); club or fishing association collected records (Boon et al. 2024; Gartside et al. 1999; Pepperell 1992); and surveys or interviews to record local knowledge (Boucek et al. 2023; Thurstan et al. 2018). In many of the above cases, however, the datasets may not be continuous, collection methods may change over time, effort data may be missing, and the alternate data sources can require significant cleaning, all of which can limit utility. With careful framing of research questions specific to the data available, much-needed insights into how recreational fisheries have changed over time can still be gleaned.

Australia is home to one of the oldest recreational marlin fisheries in the world, and their records provide a unique opportunity to study long-term changes in a recreational fishery. The first verified recreationally-caught marlin in Australia was a small black marlin (*Istiompax indica*) caught in 1913 off Port Stephens ($\approx 32.7°$ S) on the east coast of Australia (McGrouther 2020). By the late 1930s, well publicised visits to Australia by legendary angler Zane Grey had greatly popularised marlin fishing in Australia and game fishing clubs had formed at various locations, primarily on the east coast (Kalish et al. 2002). Game fishing in Australia has continued to grow, particularly through the 1960s to 1980s, and now extends to several unique and distinct sectors across Australia: the west coast fishery in Western Australia; the northern fishery in the Northern Territory and Gulf of Carpentaria; the Great Barrier Reef fishery in northern and central Queensland; and the east coast marlin fishery from southern Queensland to southern New South Wales (Kalish et al. 2002; Williams et al. 2015).

The east coast marlin fishery is the oldest marlin fishery within Australia. Three species of marlin—black marlin (*Istiompax indica*), blue marlin (*Makaira nigricans*) and striped marlin (*Kajikia audax*)—are caught on the east coast recreationally. Striped marlin are also commercially landed within this region but commercial take of black and blue marlin has been prohibited since the 1990s, though some are still often caught and released with some mortality (Findlay et al. 2003; Kalish et al. 2002). While commercial catch in the region is limited, marlin movements are wide ranging, placing them in the range of the international pelagic longline fleets which may impact their stocks and therefore availability in the region (Ortiz et al. 2003; Vidal 2023). Marlin in the Australian east coast fishery are seasonally available, typically moving down from the tropics as the East Australia Current (EAC) pushes warm water southwards in Spring (October) and then moving back up to the sub-tropics and tropics in late Autumn (May) as the EAC recedes (Pepperell 1990; Ghosn et al. 2015; Suthers et al. 2011).

Despite the long life of the east coast marlin fishery, little is known about changes the fishery may have undergone, particularly in the last 20 years. Kalish et al. (2002) analysed the composition of the recreational marlin catch across decades from the 1930s to 1990s and identified proportional increases in the catch of blue marlin and striped marlin in the 1980s and 1990s. A study into yellowfin tuna and striped marlin historic catches also showed similar trends in recreational striped marlin catch through time (Campbell et al. 2021). Both reports noted that striped marlin comprised significant proportions of the marlin catch in the 1930s but were scarce in the decades following until the 1980s when the proportional catch of striped marlin increased substantially. Using game fishing tournament data, Ghosn et al. (2012) showed that striped marlin CPUE increased through the 1990s reaching a peak in the early 2000s, this period of increased catch is similar to the period of increased composition in the Kalish et al. (2002) and Campbell et al. (2021) reports. Reports covering shorter durations have shown that marlin total catch and catch-per-unit-effort (CPUE) in the recreational fishery fluctuates annually (Ghosn 2023; Murphy et al. 2002; Ward and Bromhead 2004).

Associated with this century-old recreational fishery are a variety of datasets with potential to increase our understanding of past fishery dynamics (Griffiths and Pepperell 2006). These datasets include club records of captures of individual fish, fishing tournament catch and CPUE data, tag-release data and progressive lists of record sized fish. By integrating these sources, it may be possible to increase our understanding of past changes and therefore our ability to understand future changes in this fishery. Additionally, by providing a unique insight into how the east coast recreational fishery for marlin has changed over time, this study will aid the global understanding and management of recreational fisheries. This study integrates disparate data sources from the east coast marlin fishery with a view to better understanding variations in species composition and size of harvested fish over the long history of the fishery.

Methods

This study assessed data from the sources identified by Griffiths and Pepperell (2006) to analyse historic changes in the recreational east Australian marlin fishery. These were: (1) records and annual reports of captured fish from game fishing clubs affiliated with the New South Wales Game Fishing Association (NSWGFA); (2) data on marlin tagged and released as part the New South Wales Department of Primary Industries (NSW DPI) Game Fish Tagging Program (GFTP); (3) the Game Fishing Association of Australia's (GFAA) database on Australian record sized fish; and (4) data on fish landed as part of game fishing tournaments monitoring by Pepperell Research & Consulting. A description of each of these different data sources is provided below.

This study focussed on marlin caught in the east coast recreational fishery, from southern Queensland to southern New South Wales (Fig. 1). The fishery was split into four different regions/zones: (1) Southern QLD, from Fraser Island (24.65°S) to the QLD NSW Border (28.2°S); (2) Northern NSW, from the QLD NSW Border to Terrigal Head (33.505°S); (3) Central NSW, from Terrigal Head to the Shoalhaven River (34.846°S); (4) Southern NSW, from Shoalhaven River to the NSW VIC border (37.705°S). These regions were chosen to group game fishing clubs which fish in similar latitudes and similar distances from the coast. Any fish caught outside the latitudinal bounds of the east coast fishery (North of 24.65°S and South of 37.705°S) were removed.

Data sources and cleaning

As the east coast marlin season typically occurs from October to May, data were analysed by Australian fiscal year (1st July to 30th June) rather than the Gregorian year to avoid splitting natural fishing seasons. To eliminate duplicate entries from the different data sets, any records of two marlin with identical capture weight, date, species, and location were deemed duplicates and one entry was removed (this typically occurred if anglers were simultaneously members of multiple clubs, or when record captures were also present in club data). Fish in all four datasets were used for analyses of species composition of the fishery, however for any analysis of weight, the Game Fishing Association of Australia—Australian Record Fish dataset was not used since, due to the nature of the dataset, weights will only increase over time potentially biasing results.

Game fishing club data

Game fishing clubs affiliated with the NSWGFA have usually recorded data on individual fish captured and weighed at their club, both during and outside of tournaments. Typically, the records published in the club annual reports provide the species and weight of each marlin, date, location (either location of capture or location weighed), along with the angler's name, boat name, and breaking strain of the line used. The earliest of these records is from 1933, with the number of submitted records increasing in the 1960s as more clubs were formed. These physical reports were produced annually by many clubs until the early 2010s when hard copy reports were progressively replaced by digital point score information for clubs on closed social media platforms. Consequently, data from game fishing clubs after 2011 were obtained by contacting individual clubs, identifying those that still maintained records of weighed fish for particular years, and requesting copies of the data. Scans of the reports were obtained and all records were digitally entered. The number of reports obtained from 23 clubs for each year varied (Appendix 1).

Once digitised, several steps were taken to clean the data. All records of captured marlin were binned into one of the four zones based on the capture location. If capture location was blank, the fish was assumed to have been caught at the latitude of the clubs' home port. To identify potential errors in species identification or weights, any marlin outside expected size ranges for the species in the region (taken as 5kg to 300kg for black marlin, 60kg to 300kg for blue marlin, 40kg to 140kg for striped marlin) were cross-checked against the original scan for any potential transcription errors.

Many 5kg to 60kg marlin caught in the early years of the fishery, particularly those caught by Sydney Game Fishing Club in the 1950s, were recorded by clubs as blue marlin. Blue marlin within this size range rarely occur in the study area (Pepperell 2023) and, according to photographs and club data on marlin caught in the same areas on the same days but from neighbouring clubs, these smaller 'blue marlin' were deemed far more likely to be black or striped marlin. For fish under the 50kg threshold, the records were corrected to black marlin as they are the only marlin to commonly occur at this size on the East Coast, whilst a range of records of earlier fish listed as blue marlin above the 50kg but below 70kg threshold, particularly those from Sydney Game Fishing Club, were discounted from the study due to too much uncertainty and lack of any evidence of blue marlin caught at the time. This was supported by assessment of the photographic records together with the fact that identification of blue marlin at the time by some club weighmasters was simply based on colour (Pepperell, pers. comm.), which can vary and overlap between species and is not a diagnostic characteristic. Further, we interviewed several anglers who fished in the earlier years about specific fish and they confirmed that with current knowledge those fish were certainly not blue marlin.

NSW DPI recreational tagging program data

Founded in 1973, the New South Wales game fish tagging program has become one of the largest and longest running citizen science recreational tagging programs in the world (Brodie et al. 2018; Pepperell 2023). Shortly after its introduction, successful promotion of the program saw tag and release became widely adopted by fishing clubs and for competitions as an alternative to capturing and weighing marlin. Through this program, over 126,600 marlin (three species combined) have been tagged with conventional plastic 'spaghetti' tags as of the end of the 2021/2022 season (June 30th) (Pepperell 2023). For each marlin tagged, anglers are required to submit a tag card to the NSW DPI gamefish tagging program with the following data: species of marlin, date, estimated weight/length of the marlin, location (typically GPS however some anglers provide general locations—i.e., "Offshore of Tomaree Head"), angler and boat names and gear used (line breaking strain, circle or 'J' hook).

Records of tagged marlin were binned into one of the four zones based on the submitted GPS coordinates. Where GPS coordinates were not given, the fish were binned based on the provided general location. For well-documented specific fishing grounds e.g. "12 Mile reef" or "the carpark" off Port Stephens, multiple anglers were consulted and provided coordinates for these locations.

Expected weights for each species could not be used as an identifier of questionable records because weights and lengths are estimated rather than measured in the tag and release program, therefore, no such data-cleaning based on size of fish was performed.

Game Fishing Association of Australia—Australian record fish

The Game Fishing Association of Australia (GFAA) keeps a progressive database of all the Australian record (whole weights) marlin for each line class (the

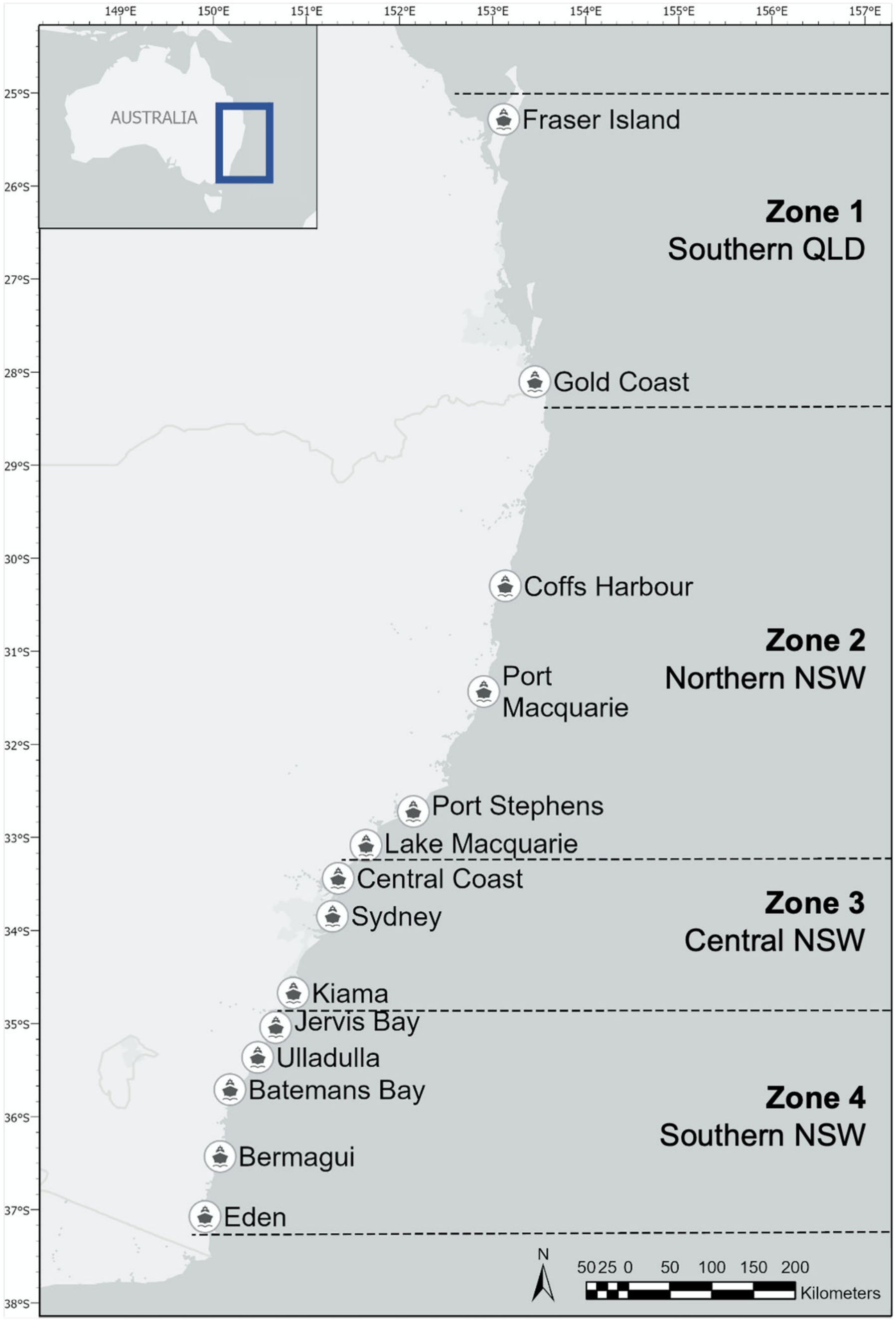


Fig. 1 Map of the four different marlin fishing zones in Eastern Australia. Regions split to group game fishing clubs which fish in similar latitudes and similar distances from the coast

breaking strain of the fishing line used to catch the fish), and for different angler age categories and genders. Each time a record is beaten, the previous record remains in the database. For each record, the species, weight, length, and capture location of the marlin plus angler and boat name and line class used are also recorded. All fish were binned into one of the four zones based on the capture location.

Pepperell research tournament monitoring

While the majority of marlin caught as part of tournaments in New South Wales are released, a large proportion of those brought to the weigh stations and weighed for competition points are sampled by Pepperell Research (Pepperell 2024). For each record, the species, whole weight, sex (usually) and capture location of the marlin are recorded. Data cleaning was not required for this dataset as the data were recorded by experts trained in identification of the three marlin species. As for the other data sets, fish were binned into one of the four zones based on the capture location.

Analysis

All analyses for this study were conducted in R (R Core Team 2023) version 4.3.1. Figures were produced using the package ggplot2 (Wickham et al. 2016) with some figure layouts done in Microsoft PowerPoint. Generalized additive models (GAMs) (mean weight ~ s(year), where s() represents a non-linear thin-plate spline) were used to analyse changes in marlin mean weight across different years. GAMs were fit using the 'mgvc' R package (Wood and Wood 2015). Six individual models were run for each of the three species for both tag and release and capture datasets.

To test whether differences in catch composition changed significantly over time, multivariate Bayesian generalized additive mixed models (GAMMs) using Stan were run with the brms package (Bürkner 2017). To test for overall changes in composition in the marlin fishery over time we modelled the proportion of catch comprised by each of the three species using a multinomial error distribution. These proportions were modelled against a nonlinear effect of year with the different zones and data sources included as correlated random intercept effects. Models were run with default weakly informative priors with 4 chains each with 6000 iterations (half as a warm-up). Model convergence was assessed using Rhat values (rhat $\leq$ 1.01) and visual inspection of the chains. Significant effects from factors in the model were identified as effect sizes for which the 95% credible intervals did not overlap zero. The model structure can be visualised as:

$$Prop\left(BLUE_{i,k,x}, BLACK_{i,k,x}, STRIPED_{i,k,x}\right) \sim s(Year_i) + (1|a|Zone_k) + (1|b|Dataset_x)$$

where $Prop\left(BLUE_{i,k,x}, BLACK_{i,k,x}, STRIPED_{i,k,x}\right)$ represents the proportional catch of blue marlin, black marlin, and striped marlin in Year i, Zone k and dataset x. $s(Year_i)$ represents a thin-plate regression spline over Year. $(1|a|Zone_k)$ and $(1|b|Dataset_x)$ represent random intercept effects of Zone and Dataset where the effect sizes are correlated between the three species. The included random effects account for dependency structure within the overall dataset including potential spatial biases and the nesting of data within different original datasets. This model structure also represents the coding used within R. To test whether there were region-specific changes in composition over time we ran the same model (but with 12,000 iterations to assist convergence) on subsets of the data for each of the 4 different zones without the Zone random effect.

To visualise the results of both GAMM analyses, we generated prediction plots over time for each species (and zone for the zonal analysis). Prediction plots were made using the tidybayes package in R and excluding the random effects to give estimates of the 'true' values excluding differences from the random effects.

Results

In total, records of 7803 captured marlin and 79,808 tagged and released marlin (87,611 total) were analysed. Specifically, after errors and fish outside of the range were removed, the game fishing club data contributed 7051 captured marlin, the Game Fishing Association of Australia—Australian Record Fish contributed 232 captured marlin, the Pepperell Research Tournament Monitoring contributed 678 captured marlin (158 duplicates between datasets removed) and the NSW DPI GFTP contributed all 79,808 of the tagged and released marlin. Capture records comprised 10% of the total data and ranged from 1933 until 2022. Tagging records made up 90% of the total data and ranged from 1973 until 2022 (Fig. 2). From 1973 until 1990, the proportion of fish tagged and released to captured rapidly increased and by 2000 the records were dominated by tag and released fish (Fig. 2).

Overall the species composition of the catch clearly changed through the history of the fishery to date with this result evident in both the raw data and the GAMM analysis (Figs. 3, 4). Clear non-linear effects were observed, suggesting change in species proportion through the history of the fishery was significant (Fig. 4). The proportion of black marlin increased in the 1930s and remained high until the 1980s but has since proportionally declined (Fig. 4). The proportion of striped marlin decreased at the end of the 1930s and remained relatively low until the 1980s, after which it increased, peaking during the 2000s and have since decreased again slightly (Fig. 4). Blue marlin were almost non-existent in the catch until the 1980s, after which they steadily increased proportionally in the catch.

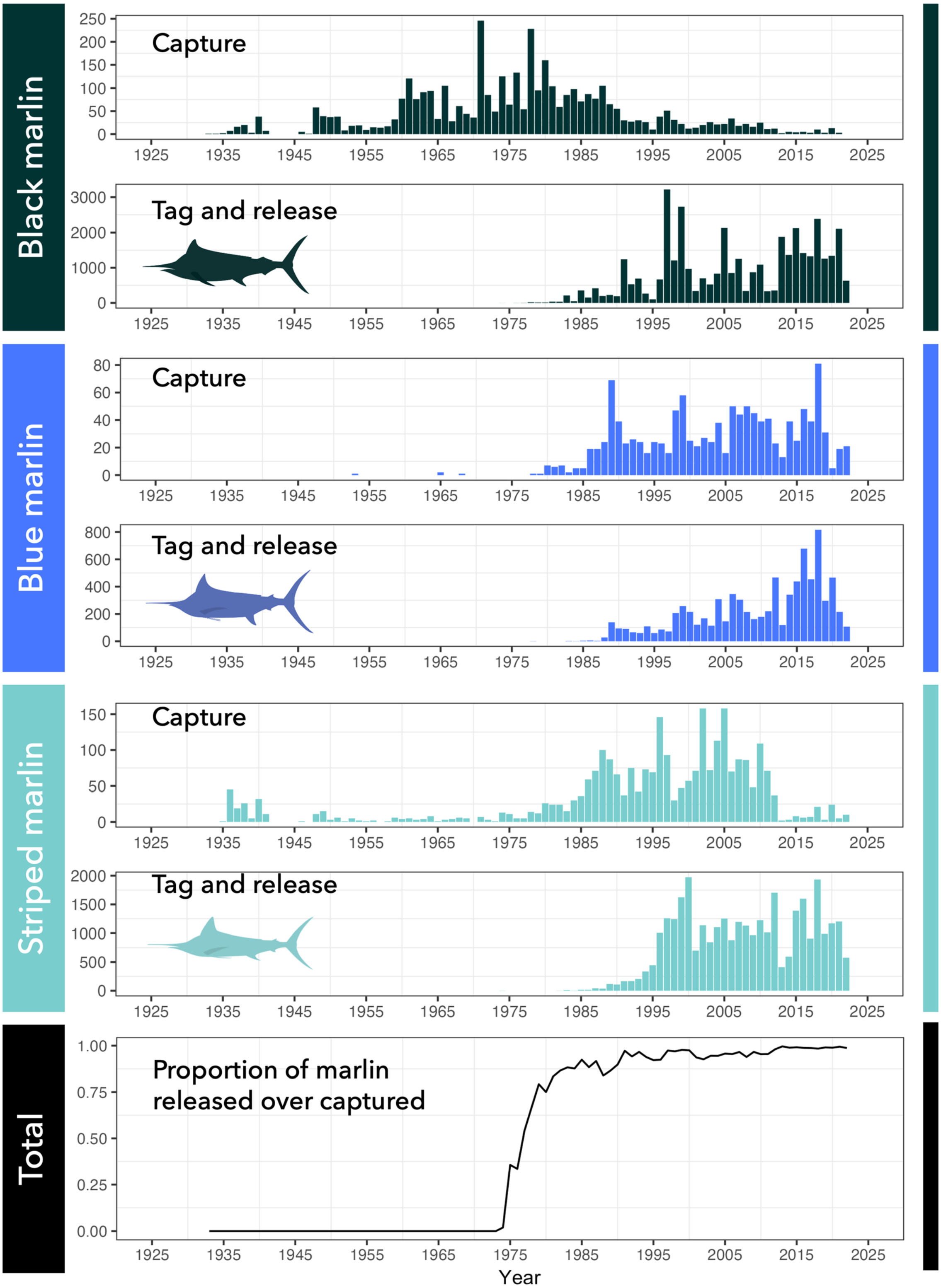
The secondary analysis by zone identified differences in how the catch composition changed over time. Overall, some spatial variability in catch composition was observed among the three species, with striped marlin increasing in proportion towards the southern range of the datasets, with a corresponding decrease in proportion with black and blue marlin (Fig. 3, Appendix 2).

In the analysis of mean weight, the non-linear smooth term for year was significant for black and striped marlin suggesting their average weight changed non-linearly over time, but insignificant for blue marlin (GAMs: black marlin $F = 238.3$, estimated degrees of freedom 8.83, $p < 0.001$, blue marlin $F = 1.59$, estimated degrees of freedom 3.46, $p = 0.19$, striped marlin $F = 34.54$, estimated degrees of freedom 8.83, $p < 0.001$). Mean weights of captured black marlin decreased from the 1930s until the 1970s but increased after the implementation of minimum weight limits for point-score by NSWGFA (Fig. 5). Mean weights of captured striped marlin were significantly higher in the 1930s than in subsequent years, but the average weight decreased in the 1940s and has been relatively stable up to 2022 with some insignificant year-to-year fluctuations (with the exception 2016 and 2017 which reached the significant highs of the 1930s; Fig. 5). Mean weights of blue remained relatively stable with some year-to-year fluctuations (Fig. 5). The non-linear smooth term for year was significant for all three marlin species tagged and released, suggesting their average weight changed non-linearly over time (GAMs: black marlin $F = 102.5$, estimated degrees of freedom 8.99, $p < 0.001$, blue marlin $F = 8.54$, estimated degrees of freedom 18.61, $p < 0.001$, striped marlin $F = 45.29$, estimated degrees of freedom 8.11, $p < 0.001$). Mean weights of black marlin tagged varied greatly between years, those of blue and striped marlin tagged have been relatively stable since the number of each tagged stabilised in the mid 1980s (Fig. 5).

Discussion

Through successful novel integration of the four disparate datasets, changes in both the species and size (weight) composition of the Australian east coast recreational marlin fishery were identified over the 90 year history of the fishery. These results provide evidence of changing composition in a recreational fishery possibly driven by the increasing accessibility to fishing grounds due to vessel, equipment, technique and technological advances. These results also demonstrate the importance of non-traditional data sources in understanding historical changes in recreational fisheries with the methods applied here likely applicable to other similar fisheries around the world.

The change in catch composition, particularly away from a black marlin dominated fishery in the 1980s supports trends previously identified in the Australian east coast marlin fishery. Kalish et al. (2002) and Campbell et al. (2021) analysed recreational data from the Australian east coast marlin fishery through time, although the latter focussed only on striped marlin. Kalish et al. (2002) identified shifts from a striped and black marlin fishery to a black marlin dominated fishery in the 1940s and a shift away from black marlin dominance and increases in blue and striped marlin catches in the 1980s. Campbell et al. (2021) similarly noted a decrease in the proportional and actual catch of striped marlin from the 1940s through to 1970s followed by a subsequent, steady increase in the 1980s. In the 20 years since the work of Khalish et al. (2002), blue marlin proportion has continued to increase despite a slight decrease in the last five years. Black marlin have continued to proportionally decline until 2005 though slightly increased since. While striped marlin proportions have decreased.


Black marlin
Capture
Tag and release
Blue marlin
Capture
Tag and release
Striped marlin
Capture
Tag and release
Total
Proportion of marlin
released over captured
Year

◀**Fig. 2** Total records of three marlin species, black, blue and striped either captured or tagged and released off Eastern Australia, 1933 to 2022. Bottom panel: Proportion of fish tagged of all captured and tagged fish. Note the difference in scales of y axis between each plot. Black marlin n = 42,812, blue marlin n = 9,409, striped marlin n = 35,390

Changing species composition can be caused by a range of different environmental, technological, or societal changes. The preferred distributions of the three marlin species assessed in this study are known to occur at different distances from the coast, with black marlin, especially juveniles, preferring more coastal habitat, striped marlin occurring further from shore, but still predominantly over the shallow continental shelf and blue marlin the furthest offshore, primarily occurring at or beyond the edge of the continental shelf (Guillemin et al. 2022; Murphy et al. 2002). Increasing boat and engine size enabling an increasingly offshore shift in the fishery since the mid 1980s has thus been suggested as a cause for the sudden proportional increase in blue and striped marlin in recreational catch (Kalish et al. 2002; Ward and Bromhead 2004). Improvements in boat size, power/speed and technology have opened access to new fishing grounds in other recreational fisheries such as the Puget Sound salmon fishery in the USA (Beaudreau and Whitney 2016) and the Queensland snapper fishery in Northern Australia (Thurstan et al. 2018). Advancements in sounders have improved the ability of anglers to detect bait balls, which is a key component to finding striped marlin (Guillemin et al. 2022) and may have attributed to their increase in catch proportion. Other technological advances, including newer electronics, fishing gear and social media have improved navigation, safety, fish finding and knowledge sharing in fisheries and have also been attributed to offshore shifts in fishing grounds (Cooke et al. 2021). However, the absolute effects of these on the Australian east coast marlin fishery are unknown. It is highly likely that increases in fishing power through technological advances have contributed to the changing composition of the fishery, however, more research is needed to understand the relative impact of this and other potential drivers.

Varying environmental factors drive the seasonal abundance and catch of each marlin species differently. In particular, inter-annual variability in the strength and spatial range of the EAC, which drives warm waters and productive waters poleward down the coast, impacts the distribution of productivity and prey species for a range of pelagic fish (Champion et al. 2018; Suthers et al. 2011). This variability may favour certain marlin species over others due to each marlin species having unique responses to: temperature (Carlisle et al. 2017; Domeier 2006; Hill et al. 2016), bathymetry (Domeier 2006; Guillemin et al. 2022; Murphy et al. 2002), El Nino Southern Oscillation index (Hill et al. 2016), and prey availability (Guillemin et al. 2022). It is therefore likely that annual variations in species composition may reflect availability based on environmental conditions. Additionally, favourable recruitment years for black marlin drive large pulses of juveniles to move down the east coast over the following season. Years when these pulses of juveniles are particularly strong drive spikes in the proportion of black marlin captured as well as decreases in the mean weight of black marlin for that year (i.e. 2013, 2015 or 2018—Fig. 2 & 5). These juvenile pulses are the primary driver behind the year to year fluctuations in black marlin catch and mean weight (Pepperell 1990). The higher year-to-year variability in species composition following the expansion of the fishery to include all three species in the 1980s may reflect fishers now having a choice in which species to fish for and targeting the species found to be most abundant during a given season. Again, more research is required to understand these drivers. Such research could utilise many of the same data sources used in this paper to generate species distribution models that would quantify favourable habitat conditions, potentially even opening up the possibility of dynamic ocean management in the future (Hobday et al. 2013).

Differences in club or tournament rules and incentives between capture and tagging of marlin apply unique biases onto each data source. Since marlin of any size can be and are tagged (both in and out of tournaments), mean tag and release weights best represent the actual size classes of fish available in the fishery out of the datasets assessed. The size classes of blue and striped marlin available were relatively consistent across years in our results likely due to the lack of juveniles in the fishery. This was not the case for black marlin, however, with the observed pulses of juvenile black marlin clearly driving the high year to year variability in mean weight. As most tournaments

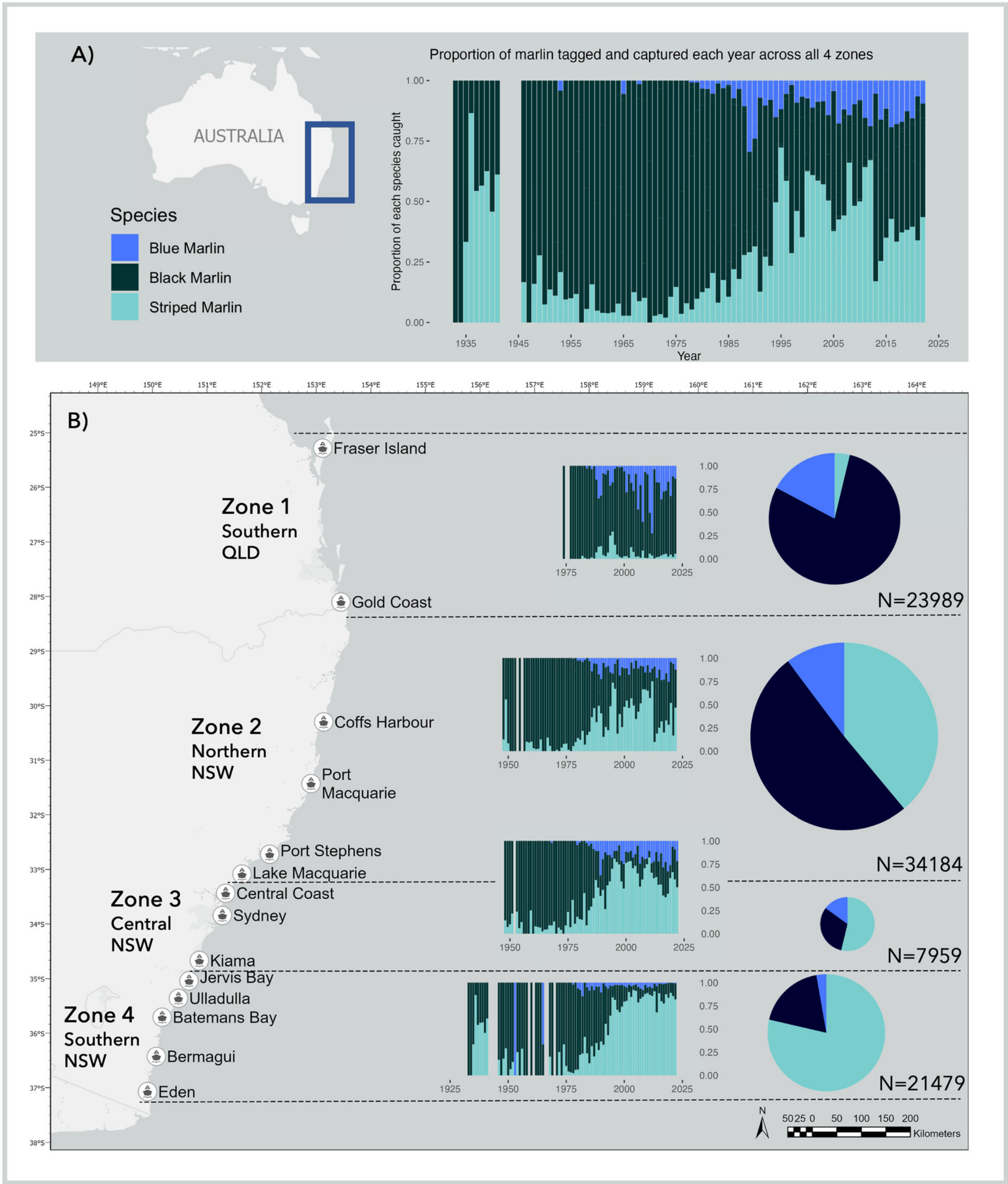


Fig. 3 Proportions of three marlin species, black, blue and striped, caught (both captured or tagged and released) through time in Eastern Australia. **A** Annual proportion of each species caught through time for the entire east coast Fishery. **B** Proportion of each species caught and pie charts showing the total proportions of each species for each of the 4 zones

are centred around "biggest fish", capture data are less representative of the entire size range and more representative of the larger fish available. The sharp increase in proportion of tag and release shortly after

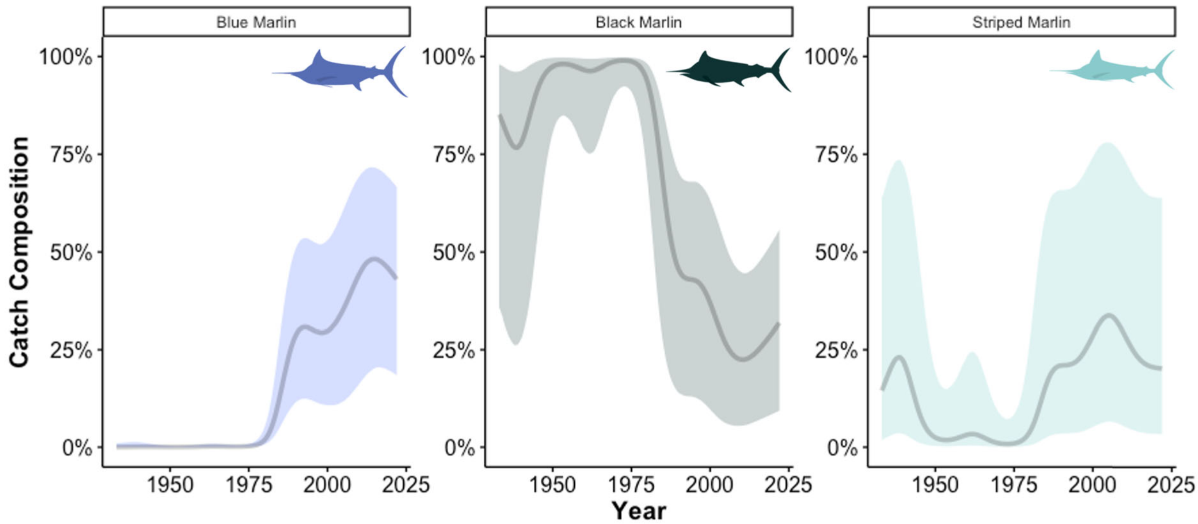


Fig. 4 Fitted trends in species proportions through Bayesian modelling framework of the three marlin species over 90 years (1933–2022) in the Australian east coast marlin fishery. The solid line in each panel represents the predicted proportion of the total catch based upon the GAMM analysis. The shading represents the 95% credible interval around these predictions

the inception of the program may reflect successful promotion of the program as an alternative to killing fish, more research is required to understand the drivers behind this widespread adoption.

Periodic implementation of minimum weight limits by the NSW Game Fishing Association most likely drove the increase in mean size of black and striped marlin captured and weighed since no such change was seen in the mean weights of fish tagged and released during the same period. It is unclear what drove mean sizes of black and striped marlin to decrease in early years, although these differences may be more reflective of spatial differences in size classes of the fish. Specifically, the early records are predominantly from Bermagui, smaller juvenile black marlin are rarely caught further south than Sydney (Pepperell 1990) and striped marlin average size is consistently larger through time in Southern NSW (Ghosn et al. 2012). The trend of latitudinal decline in striped marlin mean weight potentially being due to spatial distribution of size classes is discussed by Ghosn et al. (2012). These declines may also be due to changes in available size classes of fish, or that only records for larger more impressive fish persisted this long.

In the 1930s, striped marlin made up a greater proportion of the marlin catch than in any of the following years. This trend in catch proportion was also noted by Kalish et al. (2002), Bromhead et al. (2003) and Campbell et al. (2021). The reasons for this sudden and persistent decrease in striped marlin catch, reflected both in the total catch and the proportion of the catch, is unknown. Unfortunately, a lack of effort data limits our ability to understand whether this decline reflects an actual decline in availability, but similar declines over the same period in the geographically close New Zealand striped marlin fishery (Bromhead et al. 2003), along with continued reporting of marlin catches in the same area over this period with so few striped marlin caught, suggests that a decline in availability was possible. It is unclear whether the seeming disappearance of striped marlin from the catch composition was due to a change in availability or abundance or changes in effort or fishing, but similar evidence in New Zealand suggest it was more likely a change in availability.

Lack of effort metrics limited our ability to determine whether changes in catch composition were influenced by changes in marlin availability or populations. The international pelagic longline fleet in western and central Pacific ocean catches and retains orders of magnitude more marlin than the east Australian recreational fishery and likely has a far greater impact on marlin stocks (Vidal 2023). In particular, commercial catch may influence observed changes in striped marlin with the latest stock assessment classing striped marlin as depleted (Butler et al. 2023). No stock assessments have been conducted for black or blue marlin in the region so it is unclear how

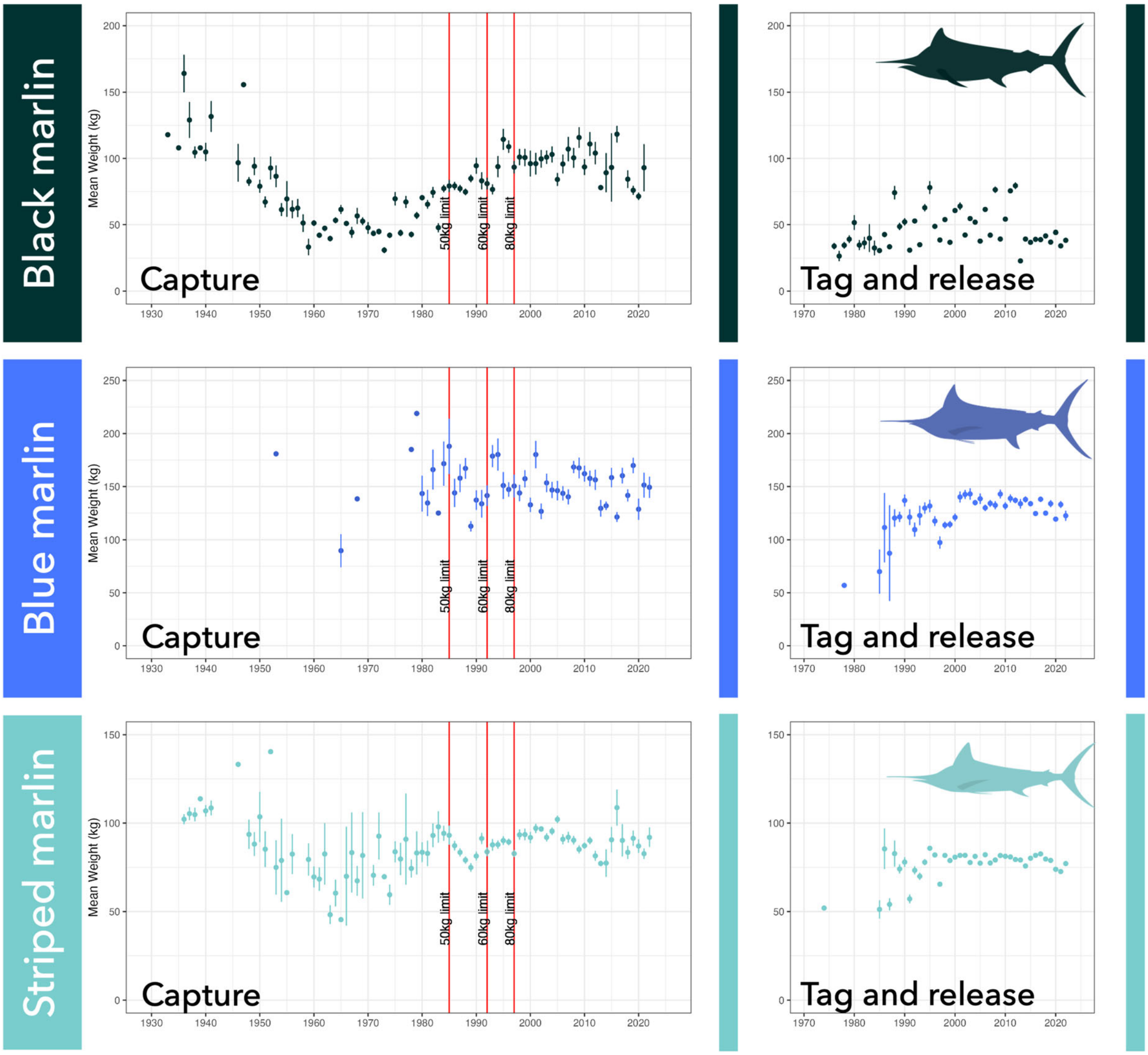


Fig. 5 Mean weights (± 1 SE) for the three marlin species either captured (NSW club data) or tagged and released (NSW DPI Tag program data) off Eastern Australia per year from 1933 to 2022. Red lines represent minimum weights for marlin implemented by the NSWGFA at that year

longline catches may be influencing their availability. While the present study focussed on expansion of the recreational fishery rather than absolute numbers of fish caught, future studies which standardise recreational fishing effort and incorporate longline data could assess changes in CPUE and marlin abundance. This would allow for consideration of spatial and temporal distribution, environmental predictors and method and gear designs that may drive marlin catch in the region.

As with many historic datasets, this study faced limitations associated with the availability and accuracy of data, particularly in the earlier years (such as the complete lack of club data in the WWII years 1939–1945). As data were largely recorded by untrained recreational fishers, there are likely errors across the datasets, particularly in estimated weights of tagged fish and identification of species captured and weighed, especially in earlier years. For example, we removed a number of marlin labelled as blue marlin from the early period of the club captures dataset due to uncertainties around species identification by club officials at the time. Despite these limitations, key changes in relative composition within and between species were identified and we are confident of their accuracy. Our research highlights the value of underutilised datasets such as those used in this study. Similar datasets have been used in other regions to better understand long-term fishery trends such as in the Florida Keys bonefish fishery (Boucek et al. 2023) or the Central European lake fishery (Lyach and Čech 2018). These long-term recreational datasets can be key to managing future changes. It is likely that similar datasets exist in other recreational fisheries, particularly in areas where game fishing is equally popular and the current study can possibly serve as a template for similar work in other fisheries.

These findings have key implications for the management of the Australian east coast marlin fishery and for recreational fisheries worldwide. Historic shifts in species composition of the east coast marlin fishery highlight the potential for future changes with further technological, societal, and environmental changes that need to be considered in future management of the marlin fishery. This study adds to the growing body of literature that supports the value of non-traditional historic datasets for understanding changes within fisheries (Boucek et al. 2023; Gledhill et al. 2015; Pecl et al. 2014; Pepperell 1992; Pita and Freire 2014; Thurstan et al. 2018). Further research is needed into the drivers of change, particularly those observed in the 1980s. If these changes were indeed driven by increased access to offshore waters, for example, our study may provide an example of improved technology and gear reshaping a fishery. Our findings have implications for fisheries worldwide as gradual adoption of new technologies may cause shifts in species targeting, and therefore catch composition of other recreational fisheries altering their environmental and economic impacts.

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Author contribution Tristan Guillemin, Julian Pepperell and Jane Williamson contributed to the study conception and design. Material preparation and data collection and cleaning were done by Tristan Guillemin, Julian Pepperell and Jane Williamson. Analyses were performed by Tristan Guillemin and Hayden Schilling, code for modelling was provided by Hayden Schilling. The first draft of the manuscript was written by Tristan Guillemin and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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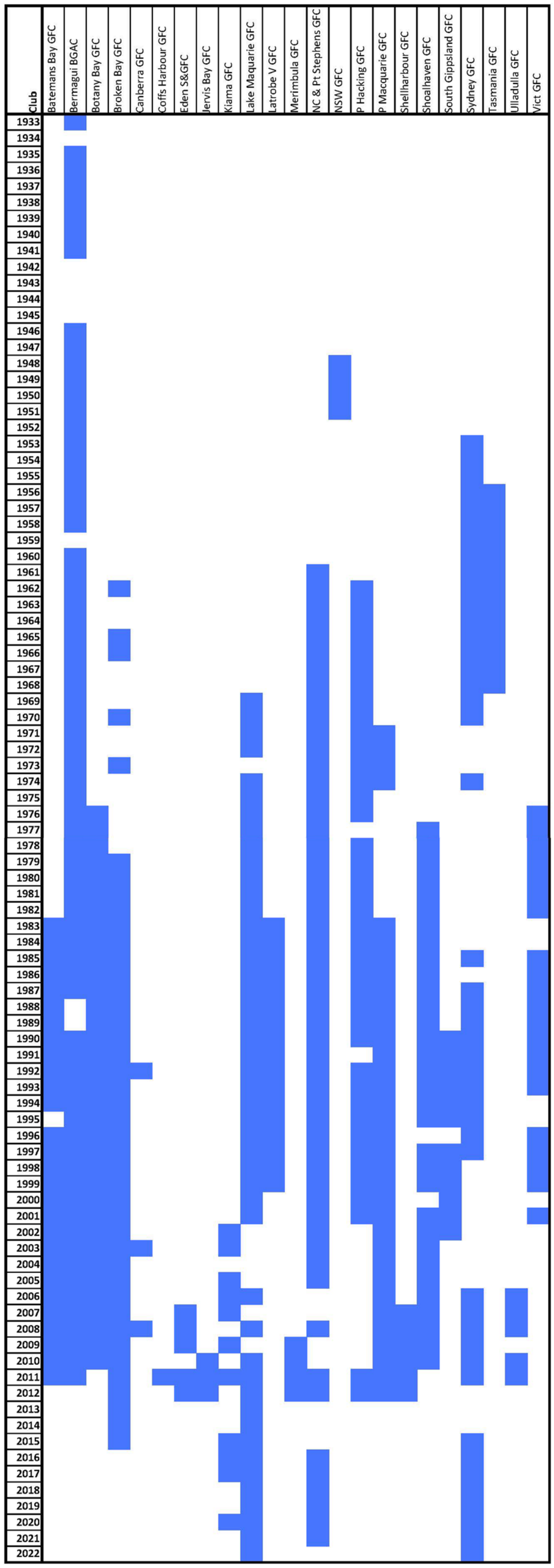
Data availability The current study, *90 years of recreational catch data reveal changes in catch composition in the Australian east coast* marlin *fishery*, used 4 different datasets: 1. Game fishing club data. 2. NSW DPI Recreational Tagging program data. 3. Game Fishing Association of Australia—Australian record fish. 4. Pepperell Research Tournament Monitoring. Datasets 1, 3 and 4 are available from the corresponding author on reasonable request. The NSW DPI Recreational Tagging Program Data are available from NSW DPI but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. For access to the NSW DPI gamefish tagging program data, all data can be found through: https://www.dpi.nsw.gov.au/fishing/recreational/resources/fish-tagging/game-fish-tagging.

Declarations

Conflict of interest The authors have no potential conflict of interest to disclose.

Human and animal rights This study only used pre-existing data sources and as such, no human or animal ethics were required. Authors had consent to access and use all data sources used in this study.


Club
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Bermagui BGAC
Botany Bay GFC
Broken Bay GFC
Canberra GFC
Coffs Harbour GFC
Eden S&GFC
Jervis Bay GFC
Kiama GFC
Lake Maquarie GFC
Latrobe V GFC
Merimbula GFC
NC & Pt Stephens GFC
NSW GFC
P Hacking GFC
P Macquarie GFC
Shellharbour GFC
Shoalhaven GFC
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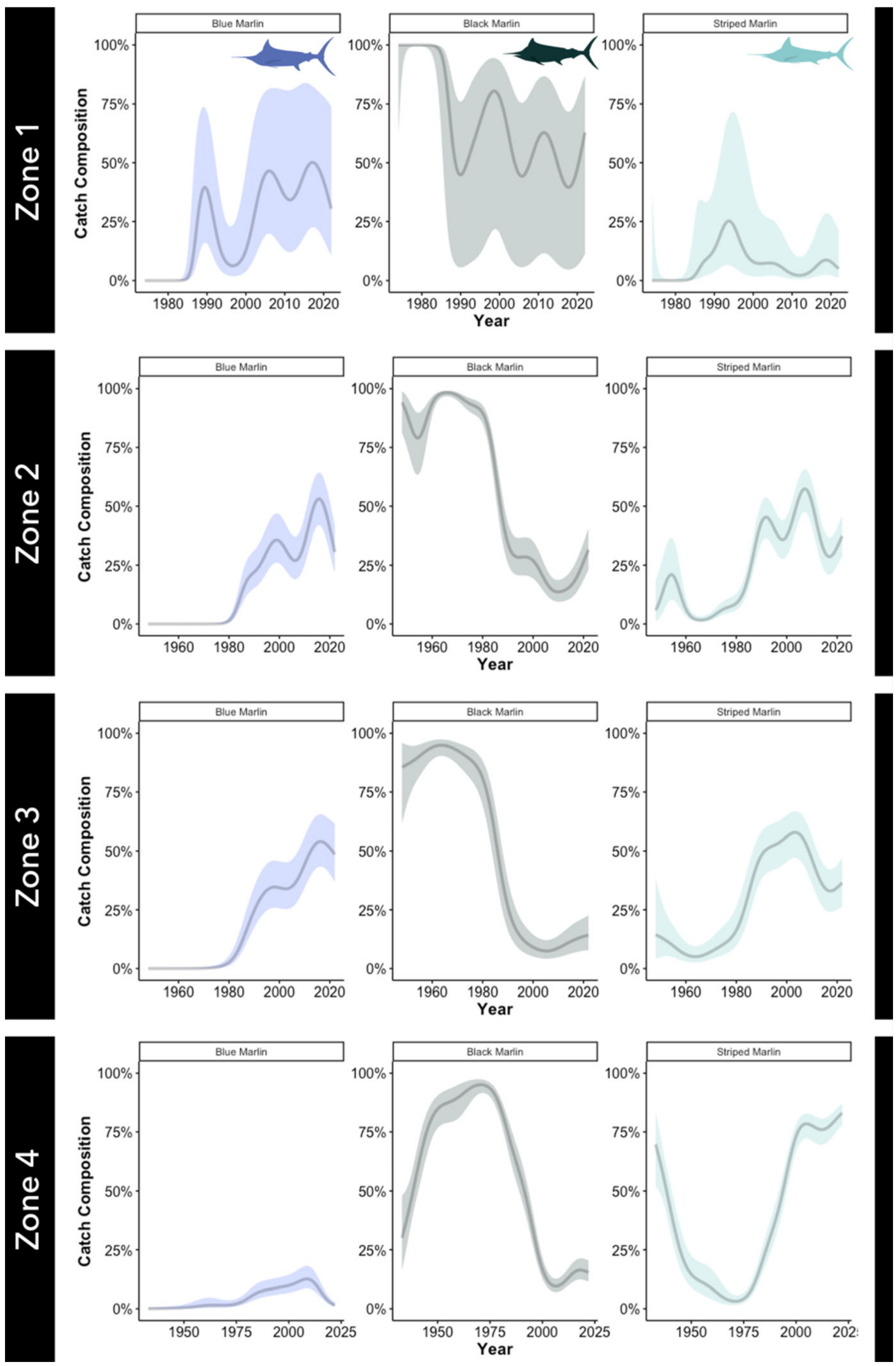
Appendix 1

Yearly availability of data from game fishing clubs in eastern Australia. Columns represent different clubs as indicated by titles, rows represent different years. Cells filled with blue represent years for which data is



available, blank cells indicate no data was available for that club for that year.

Appendix 2

Fitted trends in species proportions through Bayesian modelling framework of the three marlin species for each different zone in the Australian east coast marlin fishery. Note different scales on the x axis due to data not going back as far for some zones. The solid line in each panel represents the predicted proportion of the total catch based upon the GAMM analysis. The shading represents the 95% credible interval around these predictions.

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