**Title:** Quantifying the historical development of recreational fisheries in Southeast Queensland, Australia

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**ABSTRACT:**

Recreational fisheries are of global socio-ecological importance and contribute significantly to local economies and fisheries harvests. In some regions of Australia, organized recreational fishing activities have existed for over 150 years. However, historical understanding of the spatio-temporal development and resource usage of recreational fisheries has been hampered by the lack of continuous time-series catch and effort data. This study used historical newspaper articles of reported landings by fishing clubs to reconstruct catch rate trends and evaluate changes in catch composition of marine recreational fishing activities in Moreton Bay, Queensland, Australia, from 1920 to 1984. Using generalized additive mixed models (GAMMs), two catch rate metrics (number fish fisher$^{-1}$ trip$^{-1}$; kg fish fisher$^{-1}$ trip$^{-1}$) were constructed as functions of time and distance travelled. Significant nonlinear relationships were found for n fish fisher$^{-1}$ trip$^{-1}$. Fluctuations in n fish fisher$^{-1}$ trip$^{-1}$ were strongly influenced by time, while increases in distance travelled predicted larger n fish fisher$^{-1}$ trip$^{-1}$. Kg fish fisher$^{-1}$ trip$^{-1}$ was tightly linked to increases in distance travelled but did not vary with time. Spatial analysis revealed shifts in areas fished, from inshore reefs during the 1920s and 1930s (pre-WWII), towards isolated offshore island systems in later decades (>1950s; post-WWII). Reported catches pre-WWII were strongly associated with reef species, while reported catches post-WWII were predominantly characterized by demersal coastal fish. Spatially resolved time-series fisheries data can be reconstructed from archival sources, providing valuable information about the development of recreational fishing activities and explaining the historical social-ecological dynamics that led to current ecosystem states.

**Keywords**: Time series, historical fisheries, Australia, angling, recreational fishing

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## 1. INTRODUCTION

Recreational fishing is a popular leisure activity which contributes significantly to local economies and fisher's welfare (Arlinghaus et al. 2015, Griffiths et al. 2017). It is estimated that approximately 120 million people engage in marine recreational fishing activities globally, generating economic revenue of USD$39.7 billion annually (Cisneros-Montemayor & Sumaila 2010, Roberts et al. 2017, Hyder et al. 2018, Arlinghaus et al. 2021). Participation rates vary regionally, with general trends showing signs of declines over time (Brownscombe et al. 2014, Hyder et al. 2018, van der Hammen & Chen 2020). Nonetheless, landings by recreational fishers can match or exceed commercial harvests, particularly in nearshore areas (West & Gordon 1994, Coleman et al. 2004), contributing substantially to total fishing mortality (Radford et al. 2018).

To evaluate the effects of fishing on marine populations, catch and effort data are commonly used in stock assessments to estimate population trends and provide sustainable fisheries strategies (Punt 2019, Maunder et al. 2020). Historically, commercial fisheries have been subject to mandatory documentation of fishing activities (i.e. total catches, vessel and gear types, locations and hours fished). Fisheries data have been used to improve our understanding of ecosystem-level responses to fishing by evaluating the ecological impact of commercial fishing and inform about fishing spatial expansion due to local depletion of marine resources (e.g. Thurstan et al. 2010, Cardinale et al. 2011, Buckley et al. 2017, Watson & Tidd 2018). Fisheries-dependent research has highlighted how severe depletion of high trophic level species can disrupt complex ecosystems leading to declines in overall species diversity, and reduction in species' geographical ranges (Jackson et al. 2001, Estes et al. 2011, Maxwell et al. 2013). Conversely, recreational fisheries are rarely subjected to mandatory documentation of their fishing activities, and often have fewer spatial and temporal effort limits than commercial fisheries (Camp et al. 2018). Despite recent efforts by governmental agencies to collect recreational fishing data (Griffith & Fay 2015), lack of long-term fisheries data can make assessments of the cumulative impacts of recreational fishing extremely challenging (Pitcher 2001, Post et al. 2002).

Compared to their commercial counterparts, recreational fisheries are characterized by their greater temporal and spatial heterogeneity, with effort distributed across large geographical areas (Haab et al. 2012, Hunt et al. 2019). Therefore, systematic compilations of recreational fisheries statistics are often logistically demanding and expensive due to the temporally and spatially diffuse nature of these fisheries (Griffiths & Fay 2015). While fishing effort is commonly concentrated in coastal areas that offer easy access points (Cooke & Cowx 2004), fishers' spatial distribution can vary significantly depending on the species targeted, fishers' motivation, and personal definition of what constitutes a positive fishing experience (Johnston et al. 2010, Beardmore et al. 2015, Pokki et al. 2020). For example, some fishers might value landing greater numbers of fish over larger-sized fish, while others might seek relaxation or an outdoors experience (Johnston et al. 2010, Griffiths et al. 2017). Spatial heterogeneity of fishing effort can also be influenced by non-fishing motives, such as accessibility, travel costs, uncrowded surroundings, nature, and regulations (Hunt 2005, Johnston et al. 2010, Arlinghaus et al. 2014, Koemle et al. 2021). When the spatial and temporal complexity of fishing activities can be accounted for, impacts from recreational fisheries can be useful for assessing the effectiveness of management strategies (e.g. catch or size limits regulations), delineating boundaries of marine protected areas, avoiding conflicts among stakeholders, and informing strategies for conservation and restoration of essential fish habitats (Lorenzen et al. 2010).

Whilst some data exists for recreational fisheries, they are frequently characterized as data-limited (Griffiths & Fay 2015). Commonly, management agencies collect fishing effort data over relatively short time periods (e.g. one survey every two or four years), through telephone surveys or boat ramp interviews (QDAF 2017, Ryan et al. 2019, Teixeira et al. 2021). These 'snapshots' are valid representations of the fishery at a particular time and place but might not capture the overall variability of the fishery, such as participation rate fluctuations, landing trends, or environmental changes (Gartside et al. 1999). As such, short-term fisheries perspectives can provide inaccurate representations of the state of the fishery, and potentially underestimate the cumulative impact of recreational fisheries on marine resources (Post et al. 2002, Thurstan et al. 2015).

In the absence of long-term historical fisheries data, unconventional data sources can provide useful information for reconstructing fishery trends and help to fill gaps in historical knowledge (Lotze & Mcclenachan 2013). Fishing club records, newspapers, magazines, and logbooks have been used to reconstruct catch rate trends, catch compositions, and spatial usage of marine resources through time (e.g. McClenachan 2009a, Young et al. 2015, Buckley et al. 2017, Thurstan et al. 2017). Moreover, qualitative data derived from open-access news media (e.g. newspapers, magazines) can inform about societal and cultural drivers that have led to current fisheries states (Thurstan et al. 2017, Chong-Montenegro et al. 2021). Historical reconstructions of recreational fisheries have described catch rate declines of popular recreational fish species, including bonefish (*Albula vulpes:* Santos et al. (2017)) and, Atlantic goliath grouper (*Epinephelus itajara*: McClenachan (2009b)), as well as changes in overall ecosystem productivity (Altieri et al. 2012, Lawson et al. 2021). Documenting past ecosystem states provides valuable information about the ecological footprint of fisheries and can provide context for choosing appropriate recovery targets for species and ecosystems at risk (Goodall 2008, Thurstan et al. 2015, Beller et al. 2020).

Recreational fishing in Australia ranks among the most popular leisure activities in the country, with approximately four million Australians participating in fishing activities, generating economic revenue of AUD$2.56 billion annually (Colquhoun 2015). In Queensland, written documentation of organized fishing activities (e.g. social fishing, fishing club competitions) can be traced back as early as the 1870s via recreational fishing excursions, charter businesses (Thurstan et al. 2016), and the establishment of local and regional fishing clubs (i.e. The Amateur Fishermen's Association of Queensland, founded in 1904). Despite the existence of recreational fishing activities for at least 150 years in Queensland, government-based recreational catch and effort data are limited to four statewide annual surveys and one boat-based survey, the earliest of which commenced in 2000-01 (Webley et al. 2009, Teixeira et al. 2021). Additional literature exists on catch and effort in individual species including summer whiting (Thwaites & Williams 1994) and a few species of mackerel (Cameron & Begg 2002, Zischke et al. 2012) but studies into long-term trends in multi-species recreational catch rates remain rare. Using records of fishing excursions submitted by clubs to newspapers, this study aimed to quantify and reconstruct the development of marine recreational fishing activities in Moreton Bay, Queensland, since its earliest inception. More specifically, we aimed to i) reconstruct and evaluate trends of two catch rate metrics (i.e. number of fish per fisher per trip and the amount of kilograms of fish per fisher per trip) of recreational fisheries in Moreton Bay, ii) evaluate temporal changes in distance travelled to fishing grounds, iii) identify historical fishing hotspots, and iv) identify shifts in catch composition over time. Finally, we acknowledge the Traditional Owners of the land on which carried out our study, the Turrbal/Jagera and Quandamooka people and the long history of Aboriginal fishing practices in Quandamooka Sea Country (Moreton Bay). We note that no written records specific to Indigenous recreational fishing were found, and therefore Aboriginal fisheries were not included in this study.

## 2. METHODS

### 2.1. Study area

The Moreton Bay catchment region is located adjacent to the city of Brisbane in Southeast Queensland, the third most populous city (*c.* 2.5 million people) in Australia (ABS 2021). Covering an area of *c.* 1,500 km$^2$ Moreton Bay is a relatively shallow body of water (max. depth ~30 m) bordered by four large sand islands (i.e. North and South Stradbroke Island, Bribie Island, and Moreton Island) (Lanyon 2019). A range of marine ecosystems exist in the region, including inshore reefs, seagrass meadows, mangroves, and sand flats, which provide suitable habitats for a large diversity of fish species (Olds et al. 2019) (Fig. 1). Moreton Bay has experienced a long history of fisheries exploitation by Indigenous, commercial, and recreational groups (Thurstan et al. 2019). Currently, the Moreton Bay catchment region is the most heavily fished area across the state of Queensland, supporting *c.* 12% (combined commercial and recreational) of the total fish catches of the state (Thurstan et al. 2019).

In Queensland, fisheries regulations commenced during the 1870s for the commercial and recreational fishing sectors, with the establishment of catch size limits for eight fish species [The Queensland Fisheries Act 1877] and mandatory licensing for commercial fishers (Thurstan et al. 2019). Since that time, size limits have been adopted for several fish species in line with the following legislations: *The Fish and Oyster Act of 1914*, *Fisheries Act of 1957* and the *Fisheries Act of 1994* (supplementary material). The latter piece of legislation introduced regulations on bag limits (i.e. in-possession limits), a first for recreational fisheries in Queensland (Thurstan et al. 2019). Subsequently, in 2009, a zoning plan was introduced in Moreton Bay with no-take zones (i.e. green zones) (QDAF 2020). Although not fisheries legislation, it does restrict fishing activities and access to specific grounds.

At present, there are no restrictions on the number of participants that enter the recreational sector (i.e. marine recreational fishing is open access). Between 2019 and 2020, it was estimated that approximately 943,000 Queenslanders participated in recreational fishing activities, with 43% of the fishing effort (1.2 million fishing days) occurring in the Moreton Bay catchment fishing region (Teixeira et al. 2021). The primary fishing gear used by recreational fishers is lines (i.e. rod and line), commonly used to target finfish, such as whiting (*Sillago maculata*) and yellowfin bream (*Acanthopagrus australis*) (Teixeira et al. 2021).

### 2.2. Data collection

Historical fishing records were systematically sourced from local and state libraries, including digitized collections from the National Library of Australia TROVE repository

(NLA 2019). A combination of keywords was used to maximize the number of relevant recreational fishing articles resulting from online and library catalogue searches. These keywords included: "fishing" AND "club". Results were filtered to popular newspapers from the Brisbane metropolitan area between the 1900s and the 1980s, including all subsequent name variations. The newspapers were: i) *The Courier* (1861-1864) (later titles: *The Brisbane Courier* (1864-1933); *The Courier-Mail* (1933-1954)), ii) *The Telegraph* (1872-1947) (later title: *Brisbane Telegraph* (1948-1984)), iii) *The Daily Mail* (1903-1926), and iv) *Daily Standard* (1912-1936). The temporal extent of the digitized material was limited to pre-1954, hence, more recent newspapers were manually searched from microfilm archives from the Queensland State Library. All articles were reviewed in a chronological matter to avoid potential double counts.

Due to the large quantities of newspaper issues per year, a stratified random sampling approach was implemented to maximize temporal coverage. This approach consisted of sampling newspaper articles covering four months within every other year (even years) between 1900 and 1984 inclusive. To account for any potential catch variability related to weather, we chose the months of January, April, August, and December to be representative of the two predominant seasons in southeast Queensland: the wet season (November-March), and the dry season (April-October). Newspapers after 1984 were excluded due to a lack of publicly available archives (e.g. paywall restrictions to newspaper articles, and overcoming hesitancy in information/data sharing among recreational fishing clubs), and to avoid potentially catch biases from fishing legislation such as the *Queensland Fisheries Act 1994* that introduced bag limits for several fish species in the state of Queensland.

2.3. Catch rate standardization

From each recreational fishing article, quantitative and qualitative fisheries data was extracted, including information on: *location fished; total number of fish caught; total weight of the catch; number of fishers per fishing trip; hours fished; fishing club name;* and *list of species caught* (Fig. 2). While Moreton Bay is a popular fishing location for international and interstate travelers, here we focused on fishing clubs located in and around the Brisbane metropolitan area and assumed that most fishers were local members of these clubs and were commonly residents of the area.

Locations fished were geo-referenced based on historical fishing and boating guides (supplementary material). Catch rate metrics were defined as number of fish fisher$^{-1}$ trip$^{-1}$ and kg of fish fisher$^{-1}$ trip$^{-1}$ based on data availability. Effort was estimated as the number of hours fished per fishing trip. This value was taken from articles that explicitly mentioned the starting and end time of the fishing trip. For records in which fishing effort was not explicitly stated, a conservative value of 5 hours was estimated based on *a priori* data estimation of the mean hours calculated from completed articles.

For fishing records in which *number of fishers* was not explicitly stated, a multivariate imputation by chained equations (MICE) approach was implemented to complete this missing data (Rubin 1987). This approach assumes that the data are missing at random and uses multiple imputations (*m* times) to generate missing values based on observed data (i.e. when *number of fishers* was provided), and relationships between that observed data and a set of variables included in the imputation model (i.e. *year* and *club name* variables) (Schafer & Graham 2002, Azur et al. 2011).

Catch rates were analyzed using generalized additive mixed models (GAMMs) to evaluate trends in the number fish fisher$^{-1}$ trip$^{-1}$ and kg fish fisher$^{-1}$ trip$^{-1}$ over time (Maunder & Punt 2004). Using smoothing functions (e.g. splines), this modelling approach evaluates nonlinear relationships between a given response variable and various covariates (i.e. explanatory variables), and quantifies the variance found in the model. Two catch rate models (*n* and *kg*) were performed using the *gam* function from the *mgcv* R package (Wood 2017). The response variable for each catch rate model was number fish fisher$^{-1}$ trip$^{-1}$ and kg fish fisher$^{-1}$ trip$^{-1}$. Each model was constructed with two covariates, 'year' and 'distance' (i.e. distance between fishing location and closest access point, such as boat ramps or jetties), with 'fishing club' as a random factor. Both models were fitted using a gamma distribution with a log link function. Model assumptions were validated by inspecting the distribution of the residuals against the fitted values (homoscedasticity) using the *DHARMa* R package (Hartig 2020).

Given that fishing origin (i.e. point of departure) was missing from fishing articles, distance to fishing grounds was assumed to begin from the closest access point to the fishing location. Distance travelled was calculated as geodesic distance from fishing locations to the coordinates of the nearest access point. Estimates of distance were calculated using the *st_distance* function from the *sf* R package (Pebesma 2018). Geo-referenced access points were obtained from the Queensland Spatial Catalogue (QDTMR 2019). A non-parametric Kruskal-Wallis (KW) test followed by a Dunn's post hoc test was applied to test for significant differences distance travelled by recreational fisheries in Moreton Bay at a decadal scale. All statistical analyses were run in R (version 4.0.3).

## 2.4. Geographical distribution of fishing hotspots

Historical fishing hotspots were identified by overlaying a 0.05 degree (5 km) grid over the area of Moreton Bay (152.9°S, 28°E to 153.7°S, 25°E). This resolution was chosen to account for spatial distribution of effort surrounding fishing grounds. Hotspots were identified as areas experiencing more than 5% of the total reported trips that occurred per decade, that fell within each fishing location. For visualization purposes, raster files were created for each decade and stacked for standardization. All spatial analyses were performed using the *raster* and *stack* functions from the *raster* R package (Hijmans 2020).

## 2.5. Species catch composition

Changes in catch composition were analyzed using a presence-absence (Jaccard) dissimilarity matrix for species mentioned in each sampled year. The dissimilarity matrix was used to create a non-metric multidimensional scaling ordination plot (nMDS) to identify and visualize shared and unique species among groups (i.e. decades, years). Given the information derived from most fishing articles, fish were identified to the lowest possible taxonomic level. In most instances, identification to genus was possible (i.e. flathead = *Platycephalus* spp.; whiting = *Silago* spp.). Species were assigned to a habitat type according to information published in the *Fishes of Australia* atlas (i.e. coastal, reef, and pelagic) (Bray 2018). For species that could be assigned to more than one habitat, the preferred habitat was chosen based on the location described in the fishing article.

To test for significant differences ($p < 0.05$) in catch composition among decades, a permutational multivariate analysis of variance (PERMANOVA) was used with 999 permutations. Multivariate analysis was performed using the *adonis* function from the vegan R package (Oksanen et al. 2020).

## 3. RESULTS

We searched approximately 41,000 articles from digitized newspaper articles and microfilms for recreational fishing in Moreton Bay, of which 8,800 articles were subsampled for review. Of these, 913 articles contained quantitative and qualitative information on recreational fishing in Moreton Bay, spanning from the 1920s to the 1980s.

### 3.1. Catch rate reconstruction

Quantitative and qualitative data derived from 913 articles allowed us to reconstruct catch rates over six decades. Six hundred and thirty-three articles mentioned the number of fish caught, and 339 articles mentioned total catch in weight (kg). Two hundred and ninety-eight articles explicitly reported the number of hours fished (effort), and 496 articles mentioned the number of fishers participating in the fishing activity. Using imputation, the *number of fishers* increased from 496 observations to 592. Five hundred and eighty-eight articles subsequently provided completed information on *number of fish caught*, *number of fishers*, and *hours fished*, the three variables used to reconstruct number fish $fisher^{-1}$ $trip^{-1}$, while 331 articles provided completed variables for kg fish $fisher^{-1}$ $trip^{-1}$.

The number fish $fisher^{-1}$ $trip^{-1}$ catch rate GAMM explained 23.1% of the deviance in the data. The model showed a significant nonlinear trend in n fish $fisher^{-1}$ $trip^{-1}$ through time ($F = 4.8$, $p < 0.05$, Table S1) (Fig. 3A). In 1920 (at the beginning of the time series), the mean n fish $fisher^{-1}$ $trip^{-1}$ was estimated as 3.61 (95% confidence intervals

= 3.02 - 4.31). The n fish $fisher^{-1}$ $trip^{-1}$ peaked in 1930 (4.01 n fish $fisher^{-1}$ $trip^{-1}$, 95% CI = 3.53 - 4.55) pre-WWII, then sharply declined to 2.63 (95% CI = 2.29 - 3.02) in 1950. From approximately 1960, the mean n fish $fisher^{-1}$ $trip^{-1}$ increased again, with average catch rates of 3.10 n fish $fisher^{-1}$ $trip^{-1}$ (95% CI = 2.61 - 3.67) in 1980. In addition, the model predicted a slight but significant increase in n fish $fisher^{-1}$ $trip^{-1}$ for trips as distance away from the closest access points increased ($F = 3.07$, $p = 0.04$) (Fig. 3B). For example, for a fishing trip that took place one km away from the closest access point, an average of 2.15 n fish $fisher^{-1}$ $trip^{-1}$ (95% CI = 1.87 -2.48) was expected, while for a trip of 35 km away, 2.84 n fish $fisher^{-1}$ $trip^{-1}$ (95% CI = 2.01 - 4.02) was expected.

The kg fish $fisher^{-1}$ $trip^{-1}$ catch rate GAMM explained 35.5% of the deviance in the data. The model found no significant trends in the kg fish $fisher^{-1}$ $trip^{-1}$ through time (year covariate, $F = 2.61$, $p = 0.06$, Table S2), but values clearly declined between 1920 and 1960 (Fig. 3C). However, the model showed a significant nonlinear, but overall increasing, trend in kg fish $fisher^{-1}$ $trip^{-1}$ with distance from the closest access points ($F = 5.02$, $p < 0.05$) (Fig. 3D). For example, for a fishing trip that took place five km away from the closest access point an average of 0.71 kg fish $fisher^{-1}$ $trip^{-1}$ (95% CI = 0.55 - 0.91) was expected, while for a trip 30 km away 1.43 kg fish $fisher^{-1}$ $trip^{-1}$ (95% CI = 0.92 – 2.22) was expected.

Distances travelled by recreational fishers significantly differed among decades (KW, $chi^2 = 74.41$, $p < 0.05$). The mean distance travelled in the 1920s was 5.41 km (± 4.93 sd), while in the 1950s, the mean distance travelled was 10.9 km (± 8.63 sd), a two-fold increase. The post hoc test revealed significant differences in distance travelled between the 1920s and 1950s (z = -5.59, $p < 0.05$), and between the 1920s and 1960s (z = -7.56, $p < 0.05$) (Fig. 4). The 1930s significantly differed from the 1950s (z = -3.15, $p = 0.02$) and 1960s (z = -4.52, $p < 0.05$). The 1940s were excluded from this analysis due to the low number of observations (n = 7). This might be due to a shift in publication focus, from local news to more global news events such as World War II (1939 - 1945).

### 3.2. Historical fishing hotspots

Spatial analysis revealed a shift in the reported areas fished, from inshore reefs during the 1920s and 1930s to island areas with sandy and seagrass habitats (i.e. Moreton and Stradbroke Islands [North and South]) in the 1950s through the 1980s (Fig. 5). In the 1920s and 1930s (pre-WWII), most of the reported fishing trips (24% and 18%, respectively) took place around the inshore reefs of Moreton Bay, such as Peel Island. Additional fishing locations included the southeast of Bribie Island (15%) in the 1920s and Jumpinpin (16%) in the 1930s. In the 1950s, Jumpinpin (37%) was the most heavily fished location, followed by Tangalooma (16%) and Comboyuro (7%) on Moreton Island, areas whose habitats are primarily sandy flats. In the 1960s, most of the trips were to Jumpinpin (36%), Tangalooma (13%), Donnybrook (9%) and Comboyuro (7%). In the 1970s, most of the fishing trips were to Jumpinpin (23%), Comboyuro (9%), Reeders Point (5%) and Caloundra heads (5%). In the 1980s, most fishing trips took place at Jumpinpin (19%), Caloundra heads (15%) and Hayes Inlet (7%). Overall, Jumpinpin was consistently the most heavily fished location during the 1950-1980s.

3.3. Species composition of catch

Reported catch composition significantly differed among decades (PERMANOVA, F = 4.6, $p < 0.05$, Table S3). To maximize information on catch composition and due to the low number of fishing articles in the 1940s (n = 7) and 1980s (n = 27), articles in these decades were pooled with the 1950s, and 1970s, respectively. Overall, the non-metric multidimensional scaling (nMDS) ordination plot showed two clusters associated with the catch composition: the 1920s and 1930s (pre-WWII) grouped distinctly from the 1950s, 1960s, and 1970s (post-WWII) (Fig. 6A). The pre-WWII period was strongly characterized by the reported capture of reef species such as *Chrysophrys auratus* (snapper), *Argyrosomus japonicus* (mulloway), *Choerodon* spp. (parrotfish), and *Epinephelus* spp. (cod) (Fig. 6B). The post-WWII period was primarily characterized by the demersal species *Platycephalus* spp. (flathead), *Sillago* spp. (whiting), and *Acanthopagrus* spp. (bream).

## 4. DISCUSSION

Recreational fisheries are often characterized as data-limited due to a general lack of continuous catch and effort fisheries data. In this study, we highlight the use of newspaper articles as valuable data sources to fill gaps in historical knowledge about the spatial and temporal development of recreational fishing activities over the span of six decades in Moreton Bay, Australia. We demonstrate that detailed spatially resolved fisheries data derived from open-access sources (e.g. historical newspapers) can be used to reconstruct historical catch rate trends and evaluate social-ecological changes in recreational fishing activities. Catch rate models (n fish $fisher^{-1}$ $trip^{-1}$, kg fish $fisher^{-1}$ $trip^{-1}$) showed highly dynamic nonlinear trends strongly associated with time and distance travelled by recreational fishers. In addition, quantitative and qualitative data obtained from fishing articles allowed for spatial reconstructions of fishing hotspots, demonstrating the historical heterogeneity of fishing activities in Moreton Bay, as well as detecting shifts in the targeted fish reported species through time.

## 4.1. From quantity to quality, changes in fishing club targets

Catch rate reconstructions showed a significant increase in n fish fisher$^{-1}$ trip$^{-1}$ in pre-WWII decades, followed by a sharp decline post-war, while kg fish fisher$^{-1}$ trip$^{-1}$ displayed a steady decrease throughout the study period. Fluctuations in catch rates models might be attributed to a combination of factors such as changes in fishing club's rules/aims, increases in fishers' participation, fishers' behavior and attitudes towards fishing.

In the early 20$^{th}$ century (i.e. pre-WWII), recreational fishing clubs incentivized the landing of the greatest numbers of fish and the heaviest cumulative weight (e.g. Daily Standard, 17 December 1920). Fishing reports commonly included a list of the total number of fish caught and total weight of the catch for each participant. For example, on 21 October 1921, The Telegraph published a list of all fishers and their respective catch and weight, such as the landing of “93 fish weighing a total of 15 kg by Mr H. Shaw”. The goal of landing as many fish as possible was prevalent into the 1930s, and is reflected in catch rates trends during this period. A similar temporal pattern in catch rates, where n fish fisher$^{-1}$ trip$^{-1}$ was higher pre-WWII and was followed by a significant decline in later decades, was found for recreational fishers in the Noosa Estuary (approximately 140 km north of Brisbane) (Thurstan et al. 2017). This incentivization by fishing clubs statewide likely explained the increase in catch rates (n and kg) in pre-WWII decades.

The subsequent decline in catch rate trends (n and kg) which began in the late 1930s and early 1940s might be attributed to changes in fishing clubs aims driven by the public's perceptions on the effects of fishing on fish populations. For example, toward the latter half of the 1930s, fishing columnists began to report concerns about the landing of undersized fish (e.g. "Throw back undersized fish", The Telegraph, 24 April 1936). Articles about the ecological consequences of landing undersized fish were concurrently being reported statewide (e.g. Noosa, Thurstan et al. (2017); Rockhampton, Chong-Montenegro et al. (2021)), and in other regions of Australia (e.g. Western Australia, Christensen and Jackson (2014)) and around the world (e.g. North America and England, Policansky (2002)). Following public concerns, fishing articles transitioned to highlighting the largest fish in a given catch, rather than the greatest number of fish (e.g. "Light gear experts land big fish", The Telegraph, 5 August 1938; "Big game fishing association had notable first year" The Telegraph, 26 August 1938). The observed decline in catch rate trends from the late 1930s and early 1940s onwards might be attributed to shifts in fishing clubs aims and incentives which influenced fishers' decisions to catch fewer but larger fish during this period.

In addition, catch rates are also influenced by the number of actively participating fishers. After World War II ended in 1945, Australia saw a period of economic and infrastructure growth, with high levels of employment in addition to receiving a large number of European immigrants (Clark 2017). Increases in disposable incomes combined with cheap, accessible, and effective fishing gear allowed more people to engage in fishing activities more readily (Clark 2017, Thurstan et al. 2018). Fishing reports showed an increase in the number of fishers per club from the 1950s onwards (Fig. S1), likely influencing fluctuations in catch rate trends, as total catches in terms of number of fish caught and total weight was shared among more individuals.

By the end of the time series, an era of growing environmental consciousness became apparent in the 1980s and 1990s, as fishers' attitudes shifted towards the conservation of nature (Young et al. 2014, Young et al. 2015, Thurstan et al. 2018). This attitude might have been influenced by global and local public awareness on issues related to a changing climate, such as the Kyoto Protocol, an international treaty committed to the reduction of greenhouse gas emissions, signed by 192 countries (including Australia) in 1997 and the later introduction of the *Environment Protection and Biodiversity Conservation Act 1999 that* focuses on the protection of species and ecological communities in Australia. During this period, catch-and-release fishing became increasingly popular (Thurstan et al. 2018). Awareness of the ecological impacts of fishing was common among other branches of recreational fishing, such as spearfishing. For example, Young et al. (2014) found that spearfishing-themed magazines would report concerns of declining fish populations and encouraged self-regulation, even prior to the establishment of governmental regulations. Changes in overall fishers' attitudes towards nature in combination with catch-and-release practices might have influenced the relatively low catch rates from the later years of the time-series, despite the fact that some fishers were still driven to catch large numbers of fish if they could (Claydon 1996, Thurstan et al. 2018).

### 4.2. Spatial and temporal expansion of fishing effort

Fishers' site choice is associated with travel costs, accessibility to fishing grounds, environmental conditions, encounters with other fishers, and fishing regulations (Hunt 2005). Given the limitations in the qualitative information derived from the fishing articles, determining the specific reasons and motives of Moreton Bay fishers falls outside the scope of this research. However, our spatial analysis combined with the catch rate models suggests overcrowding and technological advancements as possible factors influencing the expansion of fishing effort through time.

In the 1920s and 1930s, the inshore reefs experienced the highest levels of fishing effort in Moreton Bay, becoming hotspots for many fishing clubs. These reefs are located in proximity to populated urban areas and have easy access points to the Bay via public boat ramps and jetties. The popularity of these reefs might have led to overcrowding, boosting the need for fishers to travel farther distances to enhance or maintain their fishing experiences. In addition, engine power and car ownership increased rapidly after WWII, allowing fishers to reach more distant access points and fishing grounds (Clark 2017, Thurstan et al. 2018). Detailed evaluations of the effects of fishing gear by recreational fishers could not be achieved due to minimal data on vessels and gear used. However, Thurstan et al. (2018) investigated the transition and adoptions of technological innovations of recreational and commercial fishers over the span of 140 years (1870-2010) in Moreton Bay. During the post-WWII era vessel engine power and the adoption of eco-sounders and GPS increased significantly, allowing fishers to discover new productive fishing grounds (Thurstan et al. 2018). In addition, changes in fishing gear from natural fiber lines and cane rods to monofilament line and cheap but durable fiberglass rods made fishing gear more efficient and accessible (Clark 2017, Thurstan et al. 2018, Chong-Montenegro et al. 2021). Ultimately, improvements in refrigeration and cold storage systems allowed fishers to keep fish fresh for extended periods (Clark 2017), enabling extended trips and greater spatial coverage.

4.3. Shifts in catch composition and broader ecological changes in Moreton Bay

Fishing reports demonstrated a shift in catch composition over time, from reef fish to demersal fish. Deriving species-specific information from newspaper articles was challenging due to the common use of generic fish names to report catches and the early confusion associated with names of fish. For example, the Brisbane Courier, 28 June 1886, published this confusion: “It is greatly to be regretted that so much confusion exists with regard to the names of fish - that is the common or popular names… It is when the common name is used that uncertainty and vagueness prevails”. However, identification of the catch was possible during the 20$^{th}$ century, when columnists would clarify the fish species. The Sunday Mail, 26 November 1933, published an article referring to the Queensland groper (*Epinephelus lanceolatus*) using various common names: “The groper, or giant perch is the largest fish we possess, and is sometimes taken of an enormous size, as much as 6 ft long and 450 lb in weight”. These general descriptions allowed for identification of fish, generally to the family level, providing an opportunity to understand ecological changes from a broad functional perspective.

Catches in the 1920s and 1930s (pre-WWI) consisted mostly of groupers (Epinephelidae) and parrotfish (Labridae). Groupers are often the first group of reef species to succumb to fishing pressure due to their particular life history characteristics: they are relatively long-lived (>30 yr) top-predators, with late maturity, high site fidelity, and complex reproductive strategies (e.g. protogynous hermaphrodites) (Sadovy de Mitcheson et al. 2020). High fishing selectivity of groupers, such as the targeting of the largest fish (e.g. trophy size fish) can lead to reproductive failure, jeopardizing the sustainability of the population (Alonzo & Mangel

2005). The historical targeting of the largest Atlantic goliath grouper (*Epinephelus itajara*) by recreational fishers in Florida led to severe local depletions and changes in the age and sex structure of the population (Bullock et al. 1992, McClenachan 2009b).

Large marine predators (e.g., groupers) are important in marine ecosystem, often playing significant roles in the structure of fish communities (Stallings 2008, Sadovy de Mitcheson et al. 2013), and can have positive physical effects on habitat structure (Coleman et al. 2010). The mass removal of large predatory marine species can significantly impact complex ecosystems, causing declines in overall species diversity, reduction in geographical ranges, and alteration of trophic structures (Estes et al. 2011, Maxwell et al. 2013). Subsequently, severe overfishing can lead to local and functional extinctions, jeopardizing the long-term sustainability of fisheries (Jackson et al., 2001).

While temporal shifts in the catch composition from reef species to demersal species might have been a result of exploitation, it is also possible that the observed trends are responses to wider ecological changes in Moreton Bay (Lybolt & Pandolfi 2019, Richards 2019). Since the settlement of non-Indigenous people in the 1820s, the entire Moreton Bay catchment has undergone major ecosystem changes (Richards 2019). Over the past 200 years, the inshore coral reefs assemblages shifted from fast-growing branching (i.e. *Acropora*) to slow-growing massive corals (i.e. *Favia*) as a response to long-term anthropological impacts, including increases in sedimentation and nutrient runoff associated with European colonization (Lybolt & Pandolfi 2019). Loss of structural complexity of reef systems can significantly reduce fish density and biomass (Graham & Nash 2013). Thus, overall declines in reef structure and habitat quality caused by declines in water quality probably acted in combination with fishing mortality of reef species to drive fishers' decisions to target more readily available demersal species such as whiting, bream, and flathead.

## 5. CONCLUSION

This work demonstrated that long-term spatially resolved catch and effort data can be derived from unconventional data sources, thus filling significant knowledge gaps on social-ecological drivers and trends in recreational fishing activities over decadal time scales. Despite the challenges associated with interpreting historical data, we presented evidence of ecological and societal changes in recreational fishing activities in Moreton Bay since the 1920s. Readily available archival sources provide opportunities to uncover broad social-ecological processes that have led to the current fisheries state and have the potential to inform fisheries management about the cumulative impact of fishing on marine resources and ecosystems. Ultimately, this study highlights the importance of archival data for fisheries science and management and its potential to contribute to knowledge gaps about the historical development of recreational fisheries.


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"SEACHANGE: Quantifying the impact of major cultural transitions on marine ecosystem functioning and biodiversity").

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## Figures

**Figure 1.** Map showing Moreton Bay region and major benthic habitat types. Black dots are access points to the water. Inset map showing the study area location in Australia (black square). Moreton Bay habitat shapefiles were obtained from the Department of Environment and Science (DES) (2008).

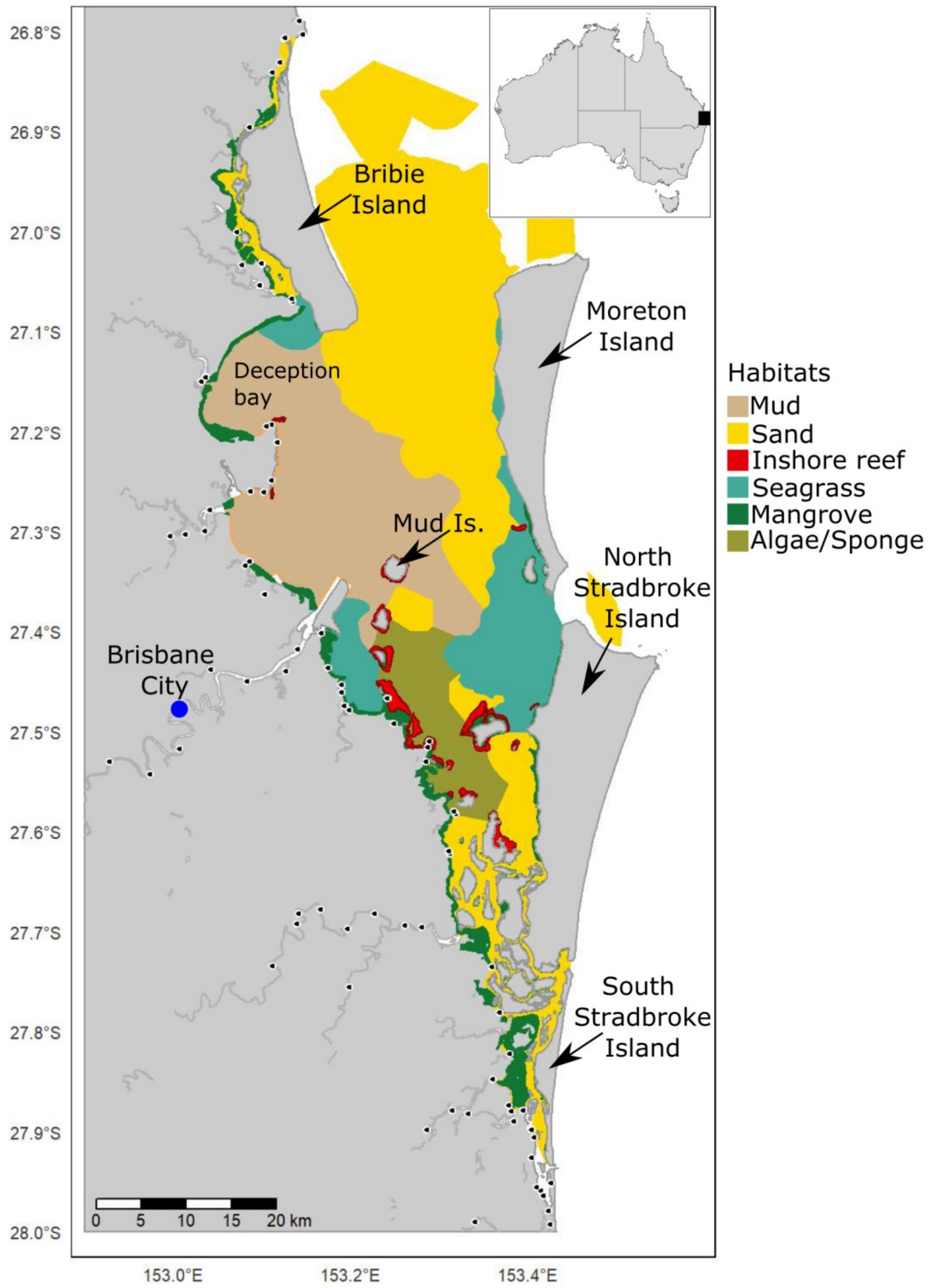
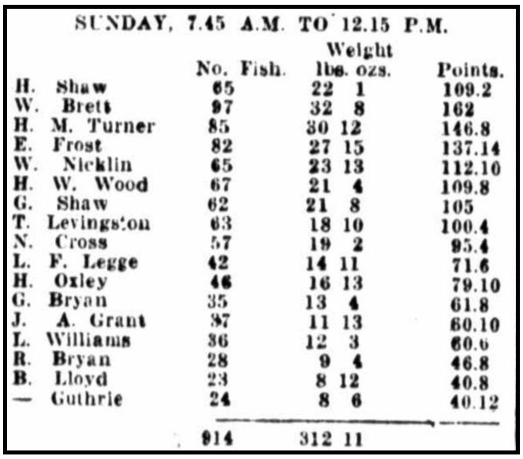


**Figure 2**. Example of newspaper articles reporting recreational fishing information in Moreton Bay through time.

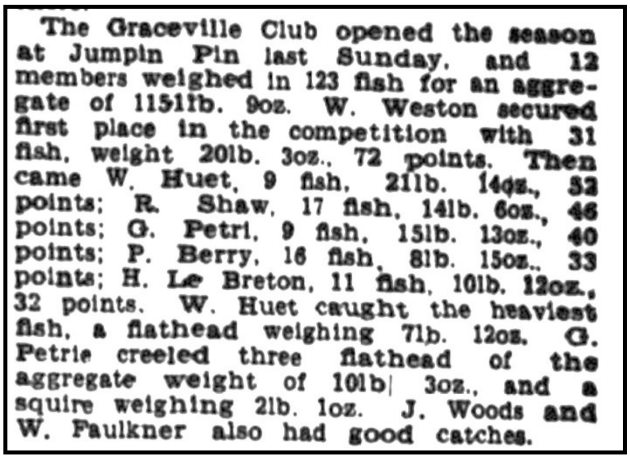
A) The Telegraph 1921



SUNDAY, 7.45 A.M. TO 12.15 P.M.

| | No. Fish. | Weight lbs. | ozs. | Points. |
|---|---|---|---|---|
| H. Shaw | 65 | 22 | 1 | 109.2 |
| W. Brett | 97 | 32 | 8 | 162 |
| H. M. Turner | 85 | 30 | 12 | 146.8 |
| E. Frost | 82 | 27 | 15 | 137.14 |
| W. Nicklin | 65 | 23 | 13 | 112.10 |
| H. W. Wood | 67 | 21 | 4 | 109.8 |
| G. Shaw | 62 | 21 | 8 | 105 |
| T. Levingston | 63 | 18 | 10 | 100.4 |
| N. Cross | 57 | 19 | 2 | 95.4 |
| L. F. Legge | 42 | 14 | 11 | 71.6 |
| H. Oxley | 46 | 16 | 13 | 79.10 |
| G. Bryan | 35 | 13 | 4 | 61.8 |
| J. A. Grant | 37 | 11 | 13 | 60.10 |
| L. Williams | 36 | 12 | 3 | 60.6 |
| R. Bryan | 28 | 9 | 4 | 46.8 |
| B. Lloyd | 23 | 8 | 12 | 40.8 |
| — Guthrie | 24 | 8 | 6 | 40.12 |
| | 914 | 312 | 11 | |

B) The Courier-Mail April 1934



The Graceville Club opened the season at Jumpin Pin last Sunday, and 12 members weighed in 123 fish for an aggregate of 115lb. 9oz. W. Weston secured first place in the competition with 31 fish, weight 20lb. 3oz., 72 points. Then came W. Huet, 9 fish, 21lb. 14oz., 32 points; R. Shaw, 17 fish, 14lb. 6oz., 46 points; G. Petri, 9 fish, 15lb. 13oz., 40 points; P. Berry, 16 fish, 8lb. 15oz., 33 points; H. Le Breton, 11 fish, 10lb. 12oz., 32 points. W. Huet caught the heaviest fish, a flathead weighing 7lb. 12oz. G. Petrie creeled three flathead of the aggregate weight of 10lb. 3oz., and a squire weighing 2lb. 1oz. J. Woods and W. Faulkner also had good catches.

C) The Telegraph April 1960

GRACEVILLE landed 161 at the Pin. M. Shaw won from H. Blummell. J. Evans caught a 3lb. 11oz. Flathead, next trip is to the Pin on May 7. leaving Graceville at 2 a.m.

**Figure 3.** Fitted generalized additive mixed models (GAMMs) of two catch rates metrics (number of fish fisher$^{-1}$ trip$^{-1}$ [A,B], and kg of fish fisher$^{-1}$ trip$^{-1}$ [C,D]) and the additive effects of year and distance (km) for recreational fishing in Moreton Bay. Mean catch rate (n and kg) estimates are shown in the black solid line. Blue and green shading represents the 95% confidence intervals of the mean for each catch rate model. The grey bar represents War World II period (1939-1945). Within each plot, the short vertical tick marks (known as "rug") along the x-axis represent the relative density of data points.

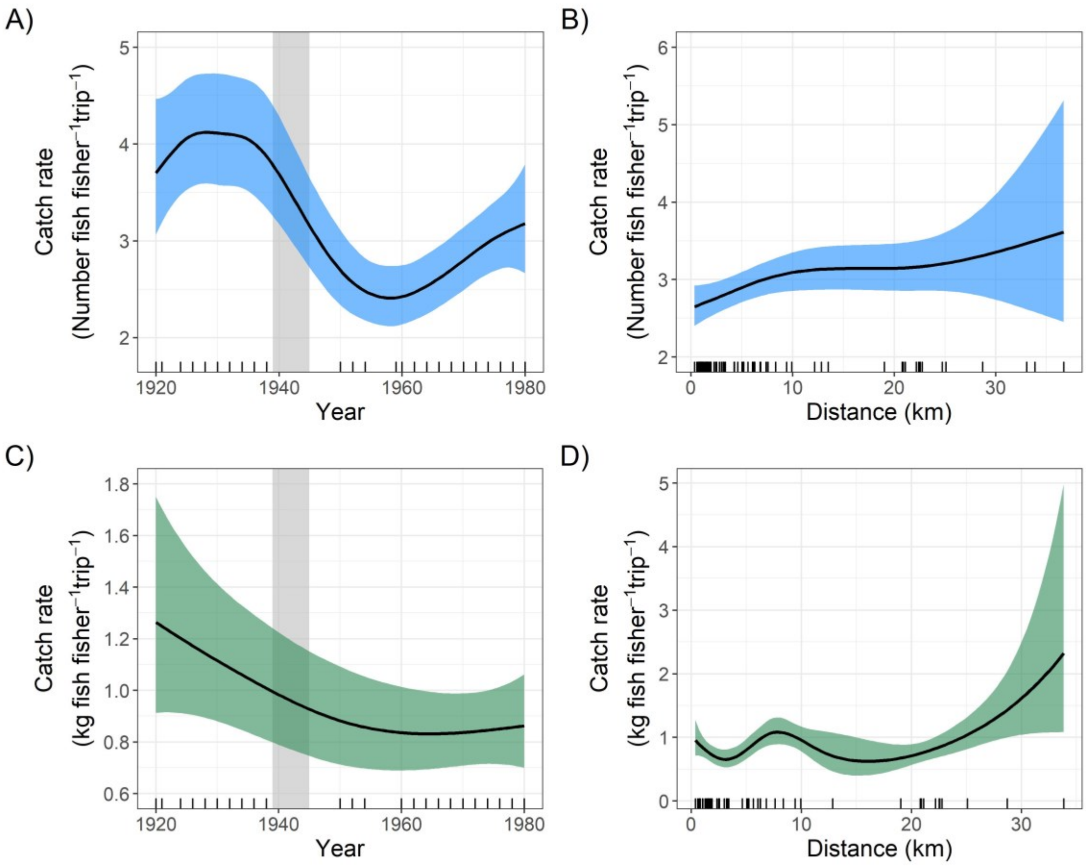


**Figure 4**. Boxplots showing the distance travelled between the closest coastal access point and fishing location (kilometers) by recreational fishers per decade in Moreton Bay. Asterisk above the boxplots indicates that distance travelled significantly differed among decades according to the Kruskal-Wallis test, followed by a Dunn's post hoc test. NS = not significant.

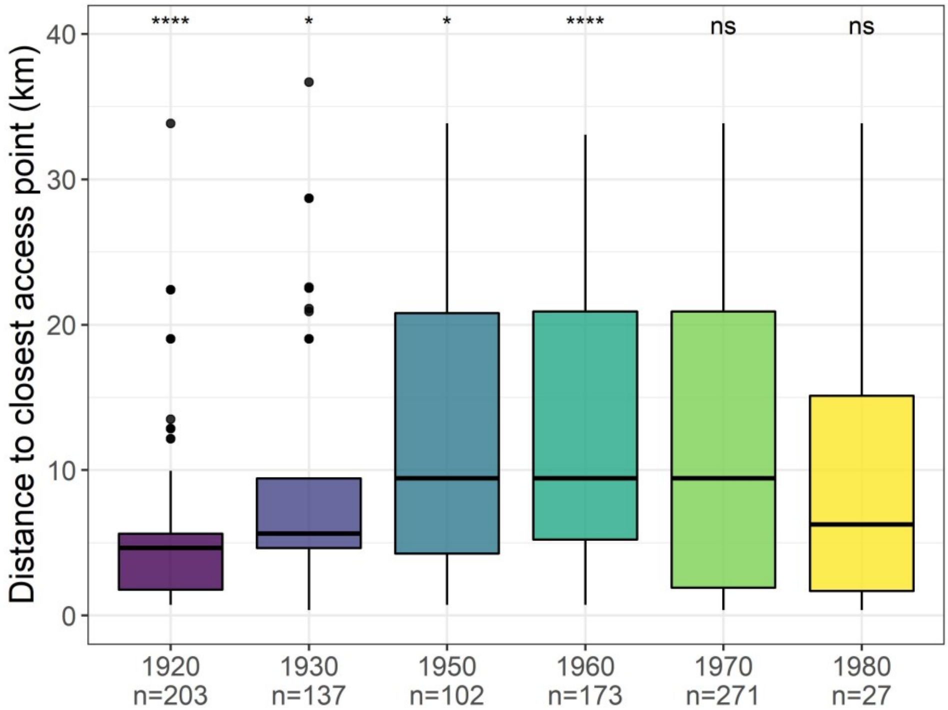


**Figure 5.** Recreational fishing hotspots represented by the fishing intensity (percentages) per decade in Moreton Bay. Fishing locations inside white rectangles are mentioned in the text. P = Peel Island, BI = Bribie Island; J = Jumpinpin; T = Tangalooma; C = Comboyuro; D = Donnybrook; CH = Caloundra Heads; RP = Reeders Points; HI = Hayes Inlet.

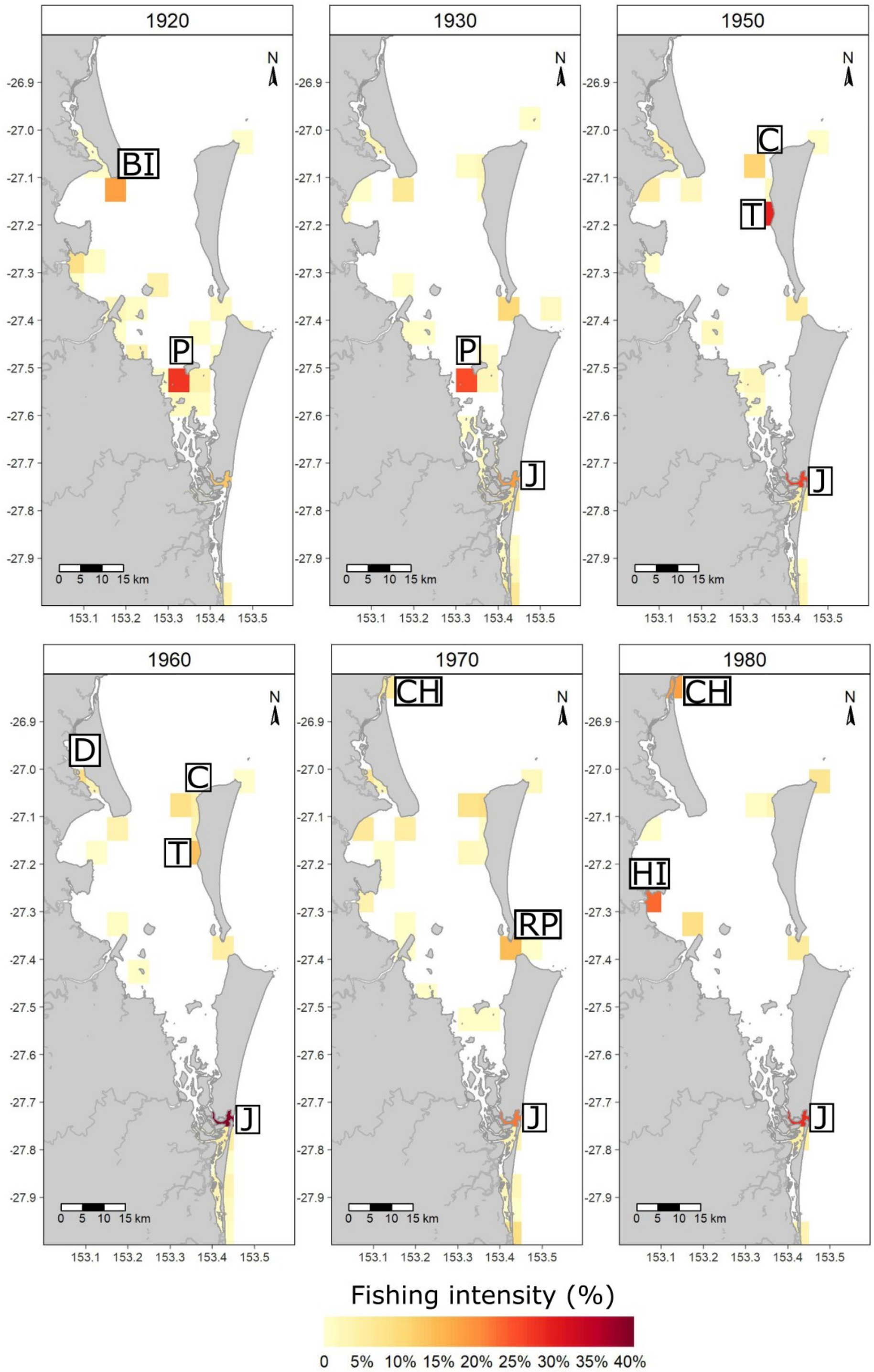


**Figure 6.** Non-metric multidimensional scaling (nMDS) ordination plot for historical catch composition of recreational fisheries in Moreton Bay. A) Recreational catch composition by decade (convex hulls), and B) vectors and magnitudes of significant fish species ($p$ > 0.05) in the nMDS.