Marine fisheries catches to 2018 for Australia and associated islands and territories*

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Abstract
Australia's marine fisheries catches were originally reconstructed from 1950 to 2010 by mainland state/territory (including Tasmania), Torres Strait, Christmas Island, Cocos (Keeling) Islands, Heard & McDonald Islands, Macquarie Island, Lord Howe Island and Norfolk Island. These original reconstructions have been updated to 2018. National (Commonwealth) and state-level data were utilized as the reported catch data baseline for Australia, and this baseline was complemented with estimates for unreported catches for subsistence (traditional) and recreational fisheries, industrial sector discards, and small-scale catches on Lord Howe and Norfolk Islands. From the 1960s to 1990s, industrial discards were the main contributor to unreported catches, whilst in recent years the main discrepancy between reported catches and total catches was due to internationally unreported recreational catches.

Introduction
Australia has a high affinity to marine resources, both traditionally and economically. In 2014 and 2015, Australia's commercial marine fisheries generated a catch worth $1.57 billion and comprised 15,000 license holders (Anon. 2016; Mazur and Curtis 2019). The present study reconstructed Australia's domestic catches by collating the reported data from the eight jurisdictions (the Commonwealth, states, and territories), identifying the unreported components and deriving catch estimates for these unreported components.

Australia has six coastal states (Queensland, New South Wales, Tasmania, Victoria, South Australia and Western Australia) and one coastal territory (Northern Territory) that are considered the 'mainland' in the present study. Several islands fall under state jurisdiction: Lord Howe Island – New South Wales; Macquarie Island - Tasmania; Torres Strait Islands – Queensland. There are also four external territories of the Commonwealth of Australia: Norfolk Island – self-governed from 1979 to 2015; the Heard and Macdonald Islands – Commonwealth managed; and Christmas Island and Cocos (Keeling) Islands – both of which have management delegated to Western Australia. States/territories manage most of their fisheries independently; however, there are several federally managed fisheries, called 'Commonwealth fisheries,' which operate in the EEZ waters associated with one or multiple states/territories.

An initial reconstruction of Australia's maritime capture fisheries was first undertaken for the 1950 to 2010 period by Kleisner *et al.* (2015) with several Australian co-authors; see also Kleisner *et al.* (2016). Kleisner *et al.* (2015) did not include the Christmas Island and Cocos (Keeling) Islands which were examined separately (Greer *et al.* 2012; Greer *et al.* 2014).

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The data as made available by individual state/territory or Commonwealth sources were used as the reported data baseline for local catches in EEZ waters. Where possible, we tried to minimize or avoid the non-sharing of catch data due to confidentiality rules, by requesting taxonomically or spatially pooled data sets. Emphasis was thus on optimizing total reported catch amounts rather than optimal taxonomic or spatial details in the data provided by the various sources. Catches of freshwater taxa, marine mammals, marine reptiles, aquatic plants and polychaete worms were removed, as these taxa are not considered by the *Sea Around Us* marine reconstructions. Commercial (industrial and artisanal) and some recreational fisheries catches were reported, whilst discards and subsistence (indigenous) fisheries were entirely unreported. We recognize that state/territory/Commonwealth authorities have access to better and more detailed data; however, as such data are not publicly available, they cannot be used for the present purposes. We call on all Australian jurisdictions to continue improving public transparency and open-access of all fisheries data.

Methods

Mainland (including Tasmania)

Subsistence fisheries

Indigenous fishing is here considered as Australia's "subsistence" catches in global *Sea Around Us* data terminology (Zeller *et al.* 2016). Kleisner *et al.* (2015) estimated these catches by utilizing a survey on indigenous fishing in northern Australia that encompassed the states of Queensland, Western Australia, and the Northern Territory (Coleman *et al.* 2003). Using the estimated weights of commonly caught taxa, Kleisner *et al.* (2015) derived a northern region per capita consumption rate (40 kg·person^{-1}·year^{-1}) and multiplied this by the northern coastal indigenous population. The coastal indigenous population in the southern regions (Tasmania, New South Wales, Victoria, and South Australia) was multiplied by a more conservative 20 kg·person^{-1}·year^{-1}.

New state-specific indigenous population data (Anon. 2017) were available to update these catches, but were not separated by location, i.e., coastal versus inland, and were thus compared to the existing state-specific subsistence catch as derived by Kleisner *et al.* (2015) from 2000 to 2010. New state-specific subsistence to total indigenous population catch rates were derived for each state, and these rates were carried forward with the existing trends to 2018. The state-specific catch rates were then applied to the total indigenous population in that state (Anon. 2017) to estimate subsistence catch from 2011 to 2018. Catches for the northern regions covered by the survey of Coleman *et al.* (2003), were taxonomically accounted for using the 2010 taxonomic ratios as per Kleisner *et al.* (2015), while the subsistence catches for the southern states were assigned entirely to "marine fishes nei" (marine fishes not elsewhere included) due to an absence of taxonomic data on indigenous catches in southern states.

Queensland

Reported catch data for Queensland were available by gear type and taxon. Catch amounts listed as "N/A" were assumed to represent zero catch if the total catch for that year, taxon, and gear type matched the sum of known catch (Table 1, row 1). However, if the total catch was greater than the sum of the listed catch per taxon, then any value of "N/A" was assumed to represent "confidential data" and thus the difference between total catch and sum of catch by taxon and gear (Table 1, row 2). If there were multiple taxa with "N/A" catch, the catch differential was split equally between them (Table 1, row 3). Both marine and freshwater catches were reported together, and thus the total reported catch reflected both taxonomic groups. Thus, freshwater catches were retained in the calculation of "N/A" before being excluded from the final data.

Table 1. Reported trap landings in Queensland as an example of how "N/A" data entries were treated in different scenarios. As both marine and freshwater catches were reported together, freshwater catches were retained in the calculation of "N/A" before being excluded in the final data.

Calendar year	Mud – crab	Eels (freshwater)	Glass eel	Unknown	Total	N/A =
1996	--	53.97	N/A	--	53.97	0
1997	N/A	34.64	0.13	--	35.27	0.5
2005	--	31.14	N/A	N/A	31.28	0.07

Because catches by trawling were frequently not reported at a taxonomic level, i.e., commonly listed as "N/A", these catches were reconstructed by subtracting the available taxonomically detailed catch data from the total catch before the remaining non-taxonomically reported ("N/A") trawl catch was disaggregated by taxon. All taxa and catches reported under gear type "collection" were excluded from the reconstruction because these were deemed to represent the aquarium collection trade, and such catches are not included in catch reconstruction records at present, since they are not for direct or indirect human consumption (Zeller and Pauly 2016). Gear disaggregation by taxon was interpolated between 1989 and 2010 and held constant to 2018 using the 2010 split from Kleisner *et al.* (2015). Future research should improve or revise this assumption.

Recreational fishing surveys were available for Queensland (Taylor *et al.* 2012; Webley *et al.* 2015) and described the number of fish retained by year and taxon. The number of landed fish were converted to weight using the taxon-specific average weight (available from FishBase; www.fishbase.org) for the "common length". If species-level data were not available, the information at genus or family level was used instead but limited to genera and family members with known biological occurrence in Australian waters. When the "common length" was not available, it was assumed to equal 0.5 the maximum length as reported in FishBase. The 2010 recreational survey for Queensland (Taylor *et al.* 2012) listed the taxonomic composition of fishes as "miscellaneous marine fishes", and thus the retained number of fish were converted to catch weight by using the common length and weight information for the taxon with the highest catch amount during the survey, i.e., barramundi (*Lates calcarifer*).

Participation rates were determined for Queensland by taking the total number of recreational fishers recorded for surveys years (Taylor *et al.* 2012; Webley *et al.* 2015) divided by the state-level total population in those years to derive recreational participation rates. The participation rate was then applied to state-level total population data from 1950 to 2018 and interpolated between the anchor point years (2010 and 2013) to derive estimates of the annual number of recreational fishers.

Recreational catch rates were determined for Queensland by dividing the total catch in survey years by the number of recreational fishers recorded for surveyed years (Taylor *et al.* 2012; Webley *et al.* 2015). The recreational catch rates were interpolated between the anchor point years, and the catch rate trend was maintained for the years after the last survey. The annual number of recreational fishers from 1950 to 2018 were then multiplied by the derived recreational catch rates to estimate catch for years without surveys. The taxonomic breakdown from the most recent survey (Webley *et al.* 2015) was adjusted to include 2% "miscellaneous marine fishes", with the remaining 98% of each year's catch assigned to the taxonomic composition throughout the time series. These data were all considered unreported.

Western Australia

Western Australia reported data were available by year and to some taxonomic resolution, but were not disaggregated by commercial sector or gear types. In order to assign catch to sectors, the original ratio from Kleisner *et al.* (2015) were applied across the total commercial catch (36% artisanal and 64% industrial). Future research should improve or revise this assumption. The taxonomic composition of the state data was maintained when state data were available and applied to the catch tonnages from 1950 to 1999. There were 65 taxa reported with catch of "N/A". As in the Queensland reported data, these "N/A" catches do not always represent zero catch due to confidentiality rules. To estimate these catches, we re-proportioned the total catch to account for these 65 taxa to a combined total of 2% of total catches. This was assumed to be very conservative, because it includes some significant taxa such as shark and billfish. Future research should improve or revise this assumption.

Tour (charter) operated recreational fishing trip catches were reported and reconstructed independently from locally-based recreational catches. Of the catches by tour operators, 290 out of 592 taxa were reported as catches being "N/A". To estimate the "N/A" catches, we assumed these 290 taxa accounted for 10% of all fish landed. Percentages were then re-ratioed to include the 10% of "N/A" taxa and applied to the total fish counts for the year. Future research should improve or revise this assumption. Average weights for taxa were taken directly from Smallwood *et al.* (2018) when possible and otherwise were derived via FishBase, as described above for Queensland, to convert fish counts to weight. We conservatively assumed tour operations did not start until 1998.

Locally-based recreational catches were calculated using the same methods as described above for Queensland, and were retroactively updated back to 1950. Recreational fishing participation rates were applied to updated population data to estimate the number of annual recreational fishers. The recreational participation rates were interpolated between the anchor points of 19.5% in 1950-1970, to 34% in 1980, to 26.6% in 1989, to 28.5% in 2000 (Henry and Lyle 2003; Kleisner *et al.* 2015), to 32% from 2008 to 2012 (Ryan *et al.* 2013), to 29.6% in 2013 (Ryan *et al.* 2015), to 31.1% in 2015 (Ryan *et al.* 2017), and to 25.4% in 2018 (Ryan *et al.* 2019). Catch rates were applied to the number of recreational fishers to estimate recreational catch. Catch rates from Kleisner *et al.* (2015) were used to reconstruct recreational catch for 1950-1989 due to the later years of available surveys. The reported recreational catches available in surveys (Ryan *et al.* 2013; Ryan *et al.* 2015, 2017; Ryan *et al.* 2019) were divided by the number of recreational fishers in those years to calculate anchor point catch rates, which were then interpolated between known years. The first available recreational survey was in 2011, and it represented lower catches than reconstructed for previous years (Ryan *et al.* 2013). However, the Western Australia fisheries survey reports (Ryan *et al.* 2015, 2017) estimated that the surveys covered 46% and 54% of all recreational catch. Thus, annual boat-based catches were doubled to include shore-based fishing.

The taxonomic composition from the 2011/2012 recreational survey was carried back to 1950 (Ryan *et al.* 2017), and the taxonomic compositions from the 2013/2014 (Ryan *et al.* 2015), 2015/2016 (Ryan *et al.* 2017) and 2017/2018 surveys (Ryan *et al.* 2019) were used for the corresponding years. Average taxon weights were taken directly from Smallwood *et al.* (2018) when possible and otherwise were derived via FishBase, as described above for Queensland, to convert fish counts to weight. All recreational catches were considered unreported.

Northern Territories

Northern Territories commercial data were reported to 2018. The catch was disaggregated into sector and gear type using the ratios from the original reconstruction (Kleisner *et al.* 2015). For catches of taxa not

represented in Kleisner *et al.* (2015), we utilized the breakdown of taxa within the same taxonomic family. If a given family was not represented at all in the data for the Northern Territories, then the family composition from a neighboring state (Western Australia or Queensland) was utilized.

The Northern Territories also reported recreational data as number of fish caught in recreational charter fisheries since 1994. These data were converted to catch weight following the methods described for Queensland and Western Australia above. The average weight (available from FishBase) was converted to common length, and weight was therefore estimated using the length-weight relationship. If species-level data were not available, the information for genus or family level data were used instead. When a common length was not available, the common length was assumed to equal half the maximum length reported in FishBase. As barramundi (*Lates calcarifer*) is caught in both marine and freshwater environments, 25% of recreational barramundi catches were assumed to have been caught in freshwater (Matthews *et al.* 2019) and were excluded from current consideration. These reported recreational charter catches were considered as additions to local non-charter recreational catches, which were estimated using the same recreational participation methods as described above for Queensland using state-specific participation rates from West *et al.* (2012) and Henry and Lyle (2003).

New South Wales

Catches for New South Wales were provided for commercial fisheries in fiscal years up to 2017/18. Thus, no full calendar year 2018 data sets were available. Following the original reconstruction by Kleisner *et al.* (2015), fiscal year reported data for New South Wales for the 2010-2017 period was divided equally between calendar years. As reported data were available only to fiscal year 2017/18, the 2018 calendar year catches were assumed to be the same as for the derived 2017 calendar year. Gear information was not available within the New South Wales reported data. Thus, the gear breakdown from the original reconstruction (Kleisner *et al.* 2015) was used. Future research should improve or revise this assumption. Taxa that were not previously accounted for in Kleisner *et al.* (2015) were assigned to gear type "unknown". The sector disaggregation per taxon was amended to account for more industrial catch because the original breakdown caused a sudden and unrealistic drop in industrial reported landings with a shift in reported taxa.

Recreational fisheries catches for New South Wales were updated using the recreational participation method as described above for Queensland, with state-specific participation rates (Henry and Lyle 2003; West *et al.* 2015). These data were considered unreported.

Tasmania

Tasmanian reported data were available for commercial fisheries from fiscal years 1987/88 to 2018/19. Following the original reconstruction by Kleisner *et al.* (2015), the fiscal year data were divided equally into calendar years for 1988-2018. Broad taxonomic groupings rather than species, genus or family level data were reported, as such the groupings were disaggregated using the corresponding species, genus and families in Kleisner *et al.* (2015) and associated sector and gear breakdowns. Tasmanian authorities should improve the taxonomic composition of the publicly available data, to increase public transparency and accountability.

Recreational fisheries catches for Tasmania were carried forward using the same methods as described for Queensland above, with state specific participation rates (Henry and Lyle 2003; Lyle *et al.* 2014). Recreational catches for Tasmania were considered unreported data.

Victoria
Reported commercial catch data for Victoria were not provided by gear type or sector. Thus, the 2010-2014 disaggregation between artisanal (19%) and industrial fisheries (81%) was used (Kleisner *et al.* 2015). Interpolation between artisanal and industrial sectoral split was used to disaggregate catch by sector between 1999 and 2010. Existing gear breakdowns were also utilized (Kleisner *et al.* 2015). Future research should improve or revise this assumption.

Recreational fisheries catches for Victoria were updated using the same methods as described for Queensland, with state specific participation rates (Henry and Lyle 2003; Ernest and Young 2009). Recreational catches in this state were considered unreported in the international context.

South Australia
Catches for South Australia were updated using data from the Australian Bureau of Agricultural and Resource Economics and Sciences (Mobsby 2018), since no state-specific data were made available to us. The taxonomic and sectoral disaggregations from the original reconstruction (Kleisner *et al.* 2015) were used to disaggregate catch by sector and taxon. Future research should improve or revise this assumption. Due to the family-level grouping in the reporting of South Australia's sardine fishery, reported catches of South American pilchard (*Sardinops sagax*) were hidden within Clupeidae. Thus, catches of Clupeidae within South Australia was disaggregated into *S. sagax* and Clupeidae from 1992 onward using *S. sagax* catch statistics in Ward *et al.* (2017). For any years where Ward *et al.* (2017) indicated a higher amount of *S. sagax* caught than South Australian Clupeidae in the reconstruction, the excess *S. sagax* catch was considered unreported.

Recreational fisheries catches for South Australia were updated using the methods described above for Queensland, with state specific participation rates (Henry and Lyle 2003; Giri and Hall 2015). Recreational catches for South Australia were considered unreported.

We were given to understand that South Australian scientists are in the process of reconstructing their state's catches. We look forward to being able to use such data in the future for integration into the global Sea Around Us database.

Commonwealth managed fisheries
Logbook data were used to update landings data for fisheries managed by the Commonwealth of Australia, because these data covered a larger number of species and included information on gear type. It should be noted that logbook data may have errors and inconsistencies in species identification, since logbook entries are raw and unverified data, and are completed by fishers at sea.

Northern Prawn Fishery (NPF) catch data were available from Laird (2018) and Laird (2019). Data by state were available for banana (*Fenneropenaeus merguiensis*), tiger (*Penaeus* spp.), endeavor (*Metapenaeus* spp.) and king prawns (*Melicertus* spp.) from fiscal years 1994/1995 to 2016/2017 as presented by Laird (2018). In the subsequent year, Laird (2019) presents total catches by family but not by state for 1970-2018. Following the original methods in Kleisner *et al.* (2015), the state-specific fiscal year data by Laird (2018) was divided equally between calendar years up to 2016. The Laird (2018) state breakdown per prawn family from 1995 onward was used to estimate the ratio of prawns caught in each state from 1970 to 1994, and the 2016 state breakdown was applied unchanged to 2017-2018. The Laird (2018) state breakdown per prawn family were applied to the totals presented in Laird (2019) from 1970 to 1994 and 2017 to 2018. The ratio and taxonomic disaggregation of the NPF bycatch was maintained from Kleisner *et al.* (2015). This fishery was considered to

be exclusively bottom trawlers and thus, in line with *Sea Around Us* gear/sector definitions (Zeller *et al.* 2016, Martín 2012), was treated as industrial in nature.

The Coral Sea Fishery (CSF) based in Queensland has artisanal (set gillnets, pots and traps) and industrial catches. New capture data with some taxonomic resolution were available to fiscal year 2017/18 (AFMA 2019). Following the original methods in Kleisner *et al.* (2015), the fiscal year data were divided equally between calendar years up to 2017. The reported taxonomic groups were disaggregated using the existing taxonomic, gear and sectoral breakdown in Kleisner *et al.* (2015). Due to the absence of data for fiscal year 2018/19, the 2018 calendar year catches were assumed to be identical to the 2017 calendar year data. Future research should improve or revise these assumptions.

The Bass Strait Central Zone Scallop Fishery (BSCZSF) was disaggregated as 70% by Victoria and 30% by Tasmania and was considered to have minimal bycatch and negligible discards. New capture totals were available to 2018 (Knuckey *et al.* 2018). These were incorporated, along with the existing catch breakdown from Kleisner *et al.* (2015).

Catches by the North West Slope Trawl Fishery (NWSTF) primarily targeting deepwater prawns and scampi were assigned to industrial bottom trawl and Western Australia. The Kleisner *et al.* (2015) discard rates and taxonomic disaggregation of discarded catches from 2010 were maintained. Future research should improve or revise this assumption.

The Small Pelagic Fishery (SPF) continues to target Jack mackerel (*Trachurus* spp.) and other small pelagic fishes off southern and eastern Australia. The fishery extends south from the border area between Queensland and New South Wales, along Victoria, Tasmania, South Australia and Western Australia, to just above Perth on the west coast. Midwater trawl and purse seine were considered to be the primary gears. Catch was ratioed by state, with 30% in Western Australia, 15% each in New South Wales, Victoria, Tasmania and South Australia and 10% in Queensland.

The Southern Squid Jig Fishery (SSJF) targets Gould's flying squid (*Notodarus gouldi*) with squid jig gear. Catches were assigned to state, with 10.5% in New South Wales, 68.5% in Victoria, 7.5% in Tasmania, 9% in South Australia, 4.45% in Western Australia and 0.05% in Queensland.

Western Deepwater Trawl Fishery (WDTF) continues to utilize mainly bottom trawl gears and was assigned entirely to Western Australia. The Kleisner *et al.* (2015) discard rates and taxonomic disaggregation of discarded catches from 2010 were maintained.

The Southern and Eastern Scalefish and Shark fishery (SESSF) has multiple sub-fisheries. The Commonwealth Trawl Fishery (CTS), operates in the south-east and was split between South Australia (12%), Victoria (35%), Tasmania (35%) and New South Wales (18%). This undocumented split was based on abbreviated coastal length ratio available from the Australian Government Geoscience Australia website[50]. Future research should determine a more realistic split between states for this fishery.

Another component of the SESSF is the East Coast Deepwater Trawl Fishery (ECDW) which is active near Lord Howe Island, and was split 70% to New South Wales and 30% to Queensland. The Gillnet, Hook and Trap fishery (GHAT) is also part of the SESSF. Catch by gillnet was disaggregated between South Australia,

[50] https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/border-lengths

Tasmania, and Victoria, and catch by hook or pots and traps were split between South Australia, Victoria, Tasmania, New South Wales, and Queensland. Scalefish and sharks were caught by hook, and only sharks were caught by gillnet for this fishery. The Great Australian Bight Trawl Sector (GAB) comprises part of the SESSF, and uses Danish seines, a form of bottom trawling. Catch was assigned 60% to Western Australia and 40% to South Australia.

Trawling on the South Tasman Rise (STR) within the Australian Fishing Zone (EEZ) uses mainly bottom trawl gear. These catches were assigned 100% to Tasmania. All fishing ceased in this area after 2007 based on an agreement between Australia and New Zealand.

Eastern Skipjack Tuna (ESTF), Eastern Tuna and Billfish (ETBF), Southern Tuna and Billfish (STBF), Western Skipjack Tuna (WSTF) and Western Tuna and Billfish (WTBF) Fisheries were all industrial catches of tunas, billfishes and other highly migratory large pelagic species, and were not considered here. Catches for all large pelagic fisheries around the world are addressed separately in Coulter *et al.* (2020).

Offshore island fisheries

The waters around the sub-Antarctic Heard and McDonald Islands host exclusively industrial fisheries which are managed by the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR). National data were used to update the Heard and McDonald Islands reported baseline from 2011 to 2018. The original baseline for Heard and McDonald Islands used FAO data for 1990-1999 and CCAMLR data from 2000 to 2010 (Kleisner *et al.* 2015). New CCAMLR data from the statistical bulletin 2019 for subarea 58.5.2 is now being used as the baseline for the entire time series (CCAMLR 2019).

The main target species in the Heard and McDonald Islands fishery includes Patagonian toothfish (*Dissostichus eleginoides*) and Mackerel icefish (*Chamsocephalus gunnari*) with all other catch considered to be non-target bycatch. All bycatch is required to be retained by fishery according to the AFMA, but there are some exceptions. Skates, sharks, jellyfish, and crabs are generally discarded, because they are thought to have a high chance of survival, do not attract seabirds or marine mammals, or cannot be effectively processed onboard (AFMA 2013).

The sub-Antarctic Macquarie Island hosts exclusively industrial fisheries, which are managed by the Australian Fisheries Management Authority (AFMA). Australian boats have been venturing to Macquarie Island since 1994, and reported data for the Macquarie Island toothfish (*Dissostichus eleginoides*) fishery were available for 2011-2016. The CCAMLR data were utilized for 2017-2018 (CCAMLR 2019).

Lord Howe and Norfolk Islands host small populations and are thus home to small local fisheries that go unreported. Lord Howe Island is home to approximately 400 people who fish for personal consumption (57 $kg \cdot person^{-1} \cdot year^{-1}$) and sale to tourists (0.5 $kg \cdot tourist^{-1} \cdot year^{-1}$), based on Environment Australia data (Anon. 2002). Population and tourist arrival numbers were available up to 2015 for Lord Howe Island. As the numbers were constant from 2013 to 2015, the 2015 catch amounts were then held constant to 2018. Norfolk Island is also home to a small population who fish for recreation, artisanal and subsistence purposes. These sectors were split 50:25:25 (Leatherbarrow *et al.* 2010) and had a combined catch rate of 3 $kg \cdot person^{-1} \cdot year^{-1}$ (Anon. 2010; Kleisner *et al.* 2015). As updated population data were not available for Norfolk Island after 2014, the 2014 catch amounts have been kept constant to 2018.

The Torres Strait Islands host a population of approximately 4500 people, the majority of whom identify as indigenous (ABS 2017). Traditional and commercial fisheries including a large-scale prawn fishery are present

in these waters. Catches in the Torres Strait Islands are considered within the Queensland state; however, the Protected Zone Joint Authority (PZJA) is responsible for the management and reporting of these fisheries. The managed fisheries include the Torres Strait Prawn Fishery (TSPF), Tropical Rock Lobster Fishery (TSTRL), Finfish Fishery (TSFF), Pearl Shell Fishery (TSPS), Crab Fishery (TSCF), Trochus Fishery (TSTF), Sea Cucumber (bêche-de-mer) Fishery (TSSC) and the dugong and turtle fisheries. The traditional dugong and turtle fisheries were not included in this reconstruction because these taxa are among those currently excluded from the *Sea Around Us* marine reconstructions (Zeller *et al.* 2016). The remaining subsistence catches for the Torres Strait Islands were assumed to be encompassed in the national indigenous subsistence calculations as described above.

The commercially managed TSPF began in 1974 (TSRA 2020). However, PJZA annual reports reported only catches by taxon back to 1989 (AFMA 2007). To determine the catches from 1974 to 1988, a time series of the number of annual licences was determined using license numbers from the annual reports (AFMA 2007, 2008, 2009a, 2009b, 2012, 2014, 2015, 2017a, 2017b) and TSRA (2020). Total catch (t) per license in 1989 was determined and held constant back to 1974. The catch per license was multiplied by the number of licenses from 1974 to 1988 to determine annual prawn catches, and the 2005 taxonomic breakdown was held constant from 1974 to 2005. In addition, the TSPF had catch data up to 2018 presented in Turnbull and Cocking (2019) which were also included. All catches were assumed to be industrial. A discard rate of 39.6% (Kleisner *et al.* 2015) was applied to annual catches because no new information on discarding was available. The taxonomic composition from Kleisner *et al.* (2015) was forward-carried to 2018.

Annual catches for the TSTRL fishery were available for 1978 – 2018 from PJZA annual reports (AFMA 2007, 2008, 2009a, 2009b, 2012, 2014, 2015, 2017a, 2017b), Plagányi *et al.* (2010) and Plagányi *et al.* (2019). The TSTRL fishery began in 1967 with 3 licenses (Pitcher *et al.* 1997), increasing to 164 licenses in 1982. Similar to the TSPF, the annual catch per license in 1982 was determined. It was held constant back to 1967 and multiplied by the number of vessels each year to estimate the TSTRL fishery catch from 1967 to 1982. During 1980-1986 TSTRL was caught from trawls as well as hand collection or diving. Catches from the trawls were considered reported industrial and all catches from hand collection or diving were considered reported artisanal.

The TSFF is comprised of two components: the reef line fishery and the Spanish mackerel (*Scomberomorus commerson*) fishery. The reef line fishery mainly targets coral trout (*Plectropomus* spp.) due to their high value, although they catch small numbers of other species (AFMA 2017a, 2017b). Due to limited catch information of these other species, only catches of coral trout were considered in this reconstruction. The reef line fishery began in 1966, and the coral trout species targeted included *P. leopardus*, *P. maculatus*, *P. areolatus*, and *P. laevis* (Williams *et al.* 2007). Annual catches from 1966 to 2000 were available from Williams *et al.* (2007), 2001-2014 from PJZA annual reports (AFMA 2007, 2017a, 2017b) and 2015-2018 from Patterson *et al.* (2016; 2018; 2019). Industrial Spanish mackerel catches from 1989 to 2017 were available from the Queensland Government's 2017-2018 stock assessment (Anon. 2018) and 2017 catches were held constant to 2018.

According to TSRA (2020), fishing for bêche-de-mer, sea cucumber, has occurred since 1860. However, there was limited information on commercial sea cucumber fisheries until 1996. Sea cucumber fisheries often occur in boom-and-bust cycles (AFMA 2017b). Therefore, to remain conservative, sea cucumber catches in this reconstruction were assumed to begin in 1996, when commercial fishing data are available. Catches from 1996 to 2001 were provided by Skewes *et al.* (2004), 2002 to 2011 by PJZA annual reports (AFMA 2007, 2008,

2009a, 2009b, 2012) and 2012 to 2018 by Patterson *et al.* (2016; 2018; 2019). All catches were considered artisanal and reported.

The Pearl Shell Fishery has been operating in the Torres Strait since the 1900s, primarily targeting pearly oyster, *Pinctada maxima* (O'Brien and Colgan 1995). Although there was limited information on the fishery, numbers of shells caught were reported for 1950-1967, 1969, 1971, 1972-1985, 1990 and 1992 from O'Brien and Colgan (1995) and from the PJZA annual reports from 2005 to 2018 (AFMA 2007, 2008, 2009a, 2009b, 2012, 2014, 2015, 2017a, 2017b). Catches between known years were interpolated. However, this can be considered a rough estimate, because the pearl fishery has often followed a boom-and-bust cycle and thus should be investigated further. To convert the number of shells to whole weight in tonnes, the common length of *P. maxima* from SeaLifeBase (www.sealifebase.org) was determined. Information on the length-weight relationship for *P. maxima* was unavailable, so the length-weight relationship for *P. margaritifera*, a species with similar distribution, was used from Galtsoff (1931). All catches were considered artisanal and reported.

The Crab Fishery (TSCF) and Trochus Fishery (TSTF) catches were available from PZJA annual reports (AFMA 2007, 2008, 2009a, 2009b, 2012, 2014, 2015, 2017a, 2017b).

Discards

Discards were updated for the industrial sector only for all states and fisheries from 2010 to 2018. The Kleisner *et al.* (2015) discard rates and taxonomic disaggregation of discarded catches for 2010 for each industrial state and industrial commonwealth fisheries were maintained. Since completing the update, new data sources for state-specific discards, e.g., Western Australia's Kimberley Prawn Managed Fishery, were shared with us from collaborators. This new discard information will be incorporated into the next catch reconstruction update. Heard and Macdonald, Lord Howe, and Macquarie Islands did not have any associated mortality-causing discards throughout the entire time period.

Marine biodiversity protection

Australia (including Tasmania) has agreed to protect its biodiversity through the international agreements of the Convention on Biological Diversity (Aichi), the United Nations Convention on the Law of the Sea, the Ramsar Convention on Wetlands of International Importance, the International Coral Reef Initiative and the World Heritage Convention. Australia is a signatory to regional treaties and agreements such as the Regional Seas Convention. It is also part of the international network of UNESCO Man and the Biosphere (Marine Conservation Institute 2020).

"The Australian Government has power to pass legislation to implement those treaties and has done so through the Environment Protection and Biodiversity Conservation Act 1999 (EPBCA). [...] Multiple provisions protect the Great Barrier Reef and link the EPBCA to the Great Barrier Reef Marine Park Act 1975. The object of the Great Barrier Reef Marine Park Act 1975 is to provide for the conservation and protection of the Great Barrier Reef Region. The Act establishes the Great Barrier Reef Marine Park and the Great Barrier Reef Marine Park Authority whose functions include making recommendations and providing advice to the relevant Minister, undertaking investigations and making zoning and management plans. [...] In Tasmania, the National Parks and Reserves Management Act 2002 (NPRMA) provides for the declaration of protected areas on land, defined as including land under the sea" (Wescott and Fitzsimons 2016).

Australia has 1,357 MPAs and 51 marine managed areas, which jointly cover 3,248,400 km^2 (Marine Conservation Institute 2020), corresponding to 51% of the EEZ of 6,369,270 km^2 (Kleisner *et al.* 2016). "Although Indigenous people have applied traditional marine management and customary laws since ancient

times [...], contemporary marine protected area (MPA) legislation first emerged in Australia just over 50 years ago" (Wescott and Fitzsimons 2016).

"Australia has an advanced marine protected area legislative framework, however, with the evolving threats to the ocean environment, effectiveness of current laws must continually be examined. One of the regulatory challenges, in a federation such as Australia, is the fragmentation of the legal landscape across the eight states and territories. This is in part an historical legacy and can allow different jurisdictions to address localized issues. However, given the interconnectedness of the marine environment and many activities within it, it is important that legal protections and management approaches do not differ unnecessarily across anthropocentric politico-legal boundaries. [...] Promoting the harmonization of statutes, where appropriate, is one way to enhance the quality of conservation and management of Australia's overall marine environment" (Yin and Techera 2020). "[...] marine protection may be achieved through a combination of tools in different pieces of legislation. Given the existing web of laws and policies, the way forward perhaps lies in better integration: ensuring there is a more comprehensive and coordinated approach. What is needed is a coherent framework if both fisheries resources and biodiversity outcomes are to be achieved for the benefit of overall marine health" (Wescott and Fitzsimons 2016).

Catches outside the Australian EEZ

The total reported catches for Australia's EEZ as assembled here were compared to the total catches as reported by the FAO on behalf of Australia for FAO areas 81(Southwest Pacific), 71 (Western Central Pacific) and 57 (Eastern Indian Ocean). Any excess FAO reported catch, i.e., reported catch not included in state or Commonwealth reporting statistics as outlined and summarized in this report, was assumed to occur outside of Australia's EEZ (Zeller *et al.* 2016), and was assigned to "marine fishes not elsewhere included" (Figure 1).

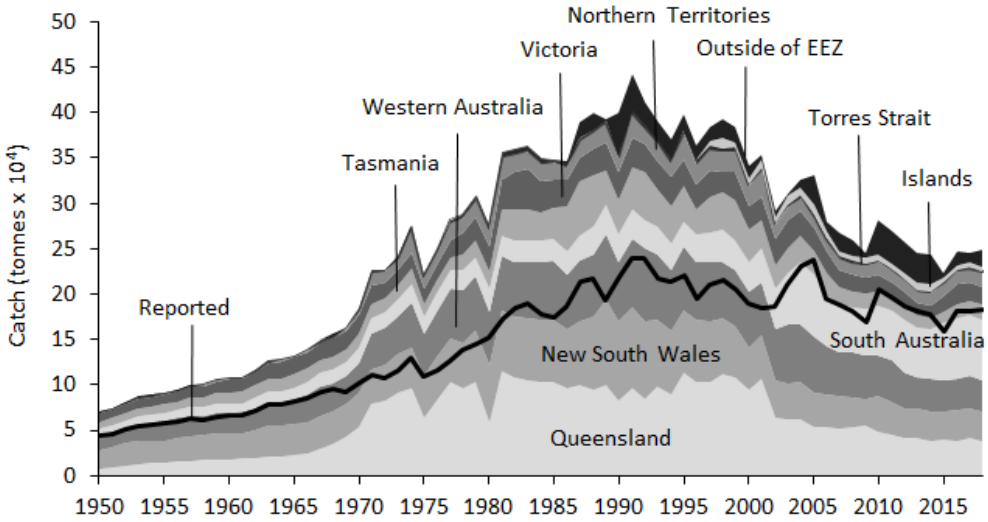

Figure 1. Australia's marine fisheries 1950-2018, by fishing area. "Islands" consists of two islands under state jurisdiction; Lord Howe Island – New South Wales and Macquarie Island – Tasmania, and two external territories of the Commonwealth of Australia, Norfolk Island and the Heard and Macdonald Islands.

Christmas Island

Since completing the original reconstruction to 2010 (Greer *et al.* 2012; Greer *et al.* 2014), see also Greer *et al.* (2016a), new census data were released by the Australian Bureau for Statistics (ABS) and were utilized to update the catches presented here. To update catches in the Christmas Island EEZ, new information on the number of boats operating in the Christmas Island Line Fishery (CILF) was used to re-estimate industrial

catch in the late 2000s. We maintained the assumption that individual boats were active for 100 days per year with a catch rate of 30 kg·day^{-1} (Greer *et al.* 2012). Christmas Island population data from the 2011 Australian Census (ABS 2011) were used to carry forward small-scale catch. We maintained the conservative assumption that 60% of the population were engaged in small-scale fishing and interpolated the 2000 consumption rate of 25 kg·person^{-1}·year^{-1} forward to 21 kg·person^{-1}·year^{-1} in 2017, assuming the decline in fresh fish in mainland Australia was representative of a decline in Christmas Island.

The small-scale sector breakdown of artisanal (25%) was maintained, whilst recreational catches continued to increase from 20% in 2010 to 22% in 2018, and subsistence sector catches declined the reciprocal amount. The small-scale taxonomic breakdowns were conserved from Greer *et al.* (2012) (Figure 2). The large-scale taxonomic breakdown was changed to 94% pelagic species, with 80% of that being wahoo (*Acanthocybium solandri*), 10% Yellowfin tuna (*Thunnus albacares*), 5% Scombridae and 5% Common dolphinfish (*Coryphaena hippurus*). The remaining 6% of the total industrial catch was assigned to Deepwater longtail red snapper (*Etelis coruscans*) (Newman *et al.* 2015). However, large-scale pelagic catches are now covered in Coulter *et al.* (2020).

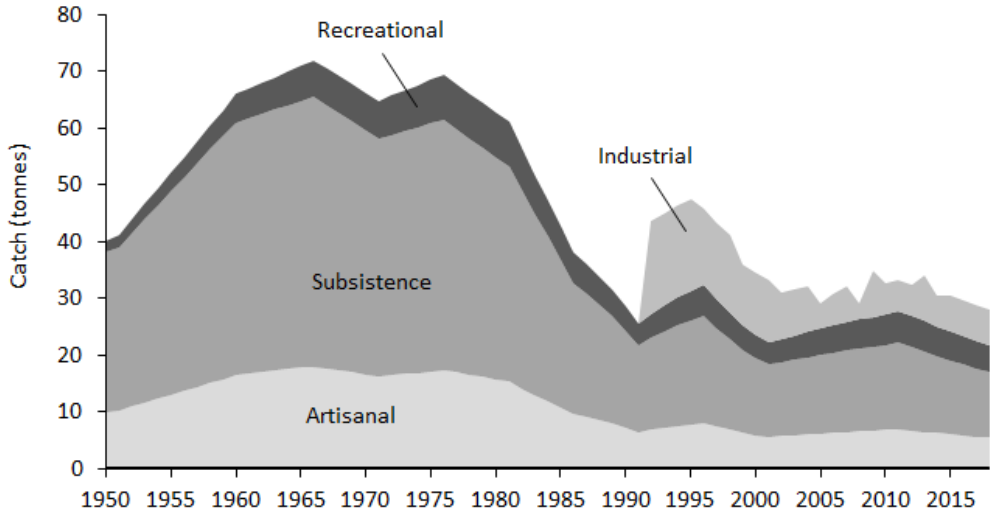

Figure 2. Domestic marine fisheries catches in the Christmas Island EEZ waters from 1950-2018 by fishing sector.

Marine biodiversity protection

Australia has agreed to protect the biodiversity of the Christmas Islands through the international agreements of the Convention on Biological Diversity (Aichi) (Marine Conservation Institute 2020).

Most of the land in Christmas Island is dedicated to the National Park (63%) and the mine lease (14%) (Director of National Parks 2014). The Christmas Island National Park is a commonwealth reserve managed by the Director of National Parks under the *Environment Protection and Biodiversity Conservation act 1999* (Director of National Parks 2014). The marine part of this reserve (from coast to 3 nm) covers 2.1 km^2 (Director of National Parks, 2014), corresponding to 0.0007% of the EEZ of 327,992 km^2 (Greer *et al.* 2016).

"The Territory's waters (to 12 nautical miles) are managed in accordance with any applied Western Australian Fisheries laws, which may be applied in the marine part of the park by the Director to the extent they can operate concurrently with the EPBC Act, Regulations and this plan. The Department of Fisheries undertook extensive community consultation from 2006 to 2011 and (at the time this plan was prepared) Christmas Island specific recreational fishing rules were being progressed to legislation. The fishing rules aim to

recognize the island's unique nature and the strong cultural links and subsistence reliance of the community on the marine resources, whilst raising awareness of the need for sustainable fishing. As part of the Department of Fisheries management arrangements, two commercial fishing operators are permitted to fish in Christmas Island's Territorial waters (excluding the park's waters as commercial fishing is not permitted [...]). These operators primarily target a range of pelagic finfish species including tuna (*Thunnus* spp.) and wahoo (*Acanthocybium solandri*), and some demersal species such as ruby snapper (*Etelis carbunculus*)" (Director of National Parks 2014).

"The multitude of governance arrangements in the Christmas and Cocos provinces may make it difficult to plan and implement marine reserve protection, however it increases the risk of biodiversity loss. Following an investigation into the extinction crisis occurring in the terrestrial environment at Christmas Island, a government-assigned expert working group identified that both the level and complexity of governance arrangements was a major hindrance to management actions aimed at conserving biodiversity (Beeton *et al.* 2010). The expert group made a high priority recommendation that environmental governance be changed to a single authority. The Australian Government rejected this recommendation" (Hobbs 2014).

"The shallow marine environment surrounding Christmas Island is extremely limited due to the steep submarine topography and, this combined with its geographic isolation and small size, limits the diversity of the shallow marine species present. [...] Further development on Christmas Island is likely to increase fishing pressure on pelagic species, increase the risk of eutrophication, and may lead to physical alteration of the coastal environment to accommodate increased vessel activity. In addition, increased vessel traffic increases the risk of marine pollution including the introduction of exotic marine species from release of ballast water, which again highlights the need for enhanced quarantine protection for both marine and terrestrial environments" (Beeton *et al.* 2010).

Cocos (Keeling) Islands

Since completing the original reconstruction to 2010 (Greer *et al.* 2012; Greer *et al.* 2014), see also Greer *et al.* (2016b), new census data were released by the Australian Bureau for Statistics (ABS) and were utilized to update the catches presented here. For small-scale fisheries, the population size of Cocos (Keeling) Island was obtained from the 2011 Census (ABS 2011). The original population trend was replaced for 2007-2011 by a new linear interpolation between the 2006 and 2011 census anchor points. The population size was extrapolated forward to 2018 using the same rate as for 2011-2016. The small-scale catch was estimated using the same assumption of 115 kg·person^{-1}·year^{-1} as in the original reconstruction, and the sector breakdown was maintained at 90% subsistence and 10% artisanal (Greer *et al.* 2012) (Figure 3). Future research should improve or revise these assumptions.

Recreational catches were estimated using the same methods as in Greer *et al.* (2012). The annual average hotel occupancy rates were obtained from ABS to determine the weekly number of tourists, and each tourist was associated with 25 kg of recreationally caught fish during his/her stay. Since annual average hotel occupancy rates were unable to be obtained from 2015 forward, the number of weekly tourists were interpolated from 5130 in 2014 to 7502 in 2018, based on the 40% increase indicated in Anon (2019). Future research should improve or revise this assumption.

Industrial catch was assumed to equal 20 tonnes per fishing license issued, and the number of fishing licenses were retroactively changed to 1 for 2008-2010 due to new information from the State of the Fisheries reports by Newman *et al.* (2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015). Following *Sea Around Us* conventions regarding aquarium fisheries, we continued to exclude catches of fish taken for the aquarium trade.

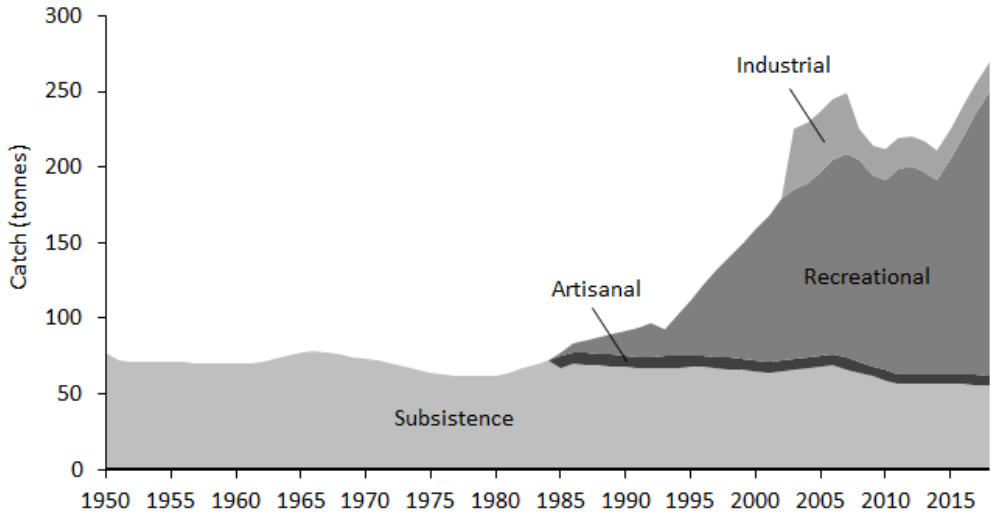

Figure 3. Domestic fisheries catches in Cocos (Keeling) Island EEZ waters from 1950-2018 by fishing sector.

Marine biodiversity protection

Australia has agreed to protect the biodiversity of the Cocos (Keeling) Islands through the international agreements of the Convention on Biological Diversity (Aichi) (Marine Conservation Institute 2020).

The Cocos (Keeling) Islands' MPAs cover 26 km² (UNEP-WCMC and IUCN 2020), contributing to 0.0056% of the EEZ of 467,229 km² (Greer *et al.* 2016). The main MPA present in these waters is the Pulu Keeling National Park (North Keeling Island which is remote from the main atoll), designated in 1995 and the Commonwealth's smallest National Park; (Department of Agriculture, Water and the Environment 2014). "[It] has a number of unique features, including an internationally significant seabird rookery and an historic ship wreck. North Keeling Island is significant to studies of island biogeography because of its evolution in isolation and it continues to be a site of scientific research" (Marine Conservation Institute 2020). The 2004 Management Plan states that "for the next seven years, Pulu Keeling National Park will be managed to preserve its flora, fauna and marine environment, whilst providing controlled visitor access. Although tourism infrastructure may develop on the southern atoll outside the National Park, this Management Plan will ensure that the park's pristine condition is maintained" (Department of Agriculture, Water and the Environment 2014).

"The reason why the Christmas and Cocos provinces have the least protection is because they have been omitted from the NRSMPA [(Australia's National Representative System of Marine Protected Areas)] planning process. This begs the question as to why these two provinces are not part of the Australian Government's management plans for conserving marine biodiversity" (Hobbs 2014).

The little protection found in these Australian Islands stems from different ecological and conservation issues in the islands, such as the accumulation and lack of management of the large quantities of plastic found along their coastlines. From a survey in the islands, "debris on the beach surface, buried, and beach-back vegetation, [was estimated] 414 million anthropogenic debris items, weighing 238 tonnes, currently deposited on the Cocos (Keeling) Island group. Of the identifiable items, ~25% were classified as disposable plastics, including straws, bags, and toothbrushes. Debris buried up to 10 cm below the surface is estimated to account for 93% (~383 million items) of all debris present on Cocos, the majority of which (~60%) is comprised of micro-debris (2–5 mm)" (Lavers *et al.* 2019).

Results and Discussion

The update of Australia's marine fisheries catch reconstructions encompassed data from 1950 to 2018 for the mainland states/territory (Queensland, Northern Territory, Western Australia, New South Wales, Tasmania, Victoria and South Australia), islands under state jurisdiction (Lord Howe Island, Macquarie Island and the Torres Strait Islands, Christmas Island and Cocos (Keeling) Islands), and island territories (Norfolk Island and the Heard and Macdonald Islands). With the availability of new reported and secondary sources of data, the original reconstructions for Australia, Christmas Island and Cocos (Keeling) Islands were updated to 2018, and partially replaced back to 1950 where possible.

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