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Species identification of Australia's most significant octopus fishery – the Western Rock Octopus

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Executive Summary

What the report is about

This Fisheries Research Report (FRR) / FRDC report summarises the scientific and consultation work undertaken to identify a new species name (*Octopus djinda*) and new common name (Western Rock Octopus) for the species that supports Australia's largest octopus fishery, with 734 tonnes harvested in 2022. The species had been previously referred to as *Octopus* cf. *tetricus*, or *Octopus* aff. *tetricus*, otherwise known as the Gloomy Octopus. The species is endemic to Western Australia, and the work was a collaboration between the Western Australian Fisheries and Marine Research Laboratories (Dr Anthony Hart) and Dr Michael Amor of the Royal Botanic Gardens Victoria and the Western Australian Museum. Type specimens including males and females were sampled from across the species distribution in Western Australia, including from Geraldton, Mandurah, and Esperance. Using the latest technology in evolutionary genetics and multivariate morphology, the specimens were analysed, and a scientific manuscript proving they were a unique species was submitted to the journal *Zootaxa*. The species' Holotype and Paratypes were then deposited in the Western Australian Museum. Parallel to this, a stakeholder consultation process investigated a range of options for species names and common names. The new species is now called *Octopus djinda*, and the new common name is Western Rock Octopus. The name "*djinda*" is a Noongar word for star, and the Noongar are traditional custodians of the land in South-Western Australia. The description provided by this project will enable proper reporting of catch statistics for Australia's largest and fastest growing octopus fishery.

Background and objectives

This project was undertaken to resolve the uncertainty around the individual species which make up the octopus harvest from Australia's octopus fishing industry. The objectives were to identify the species and common name of the Western Australian common octopus, which currently supports Australia's largest octopus fishery.

Methodology

Standardised species identification and stakeholder consultation methods were utilised. Using the latest technology in evolutionary genetics and multivariate morphology, the specimens were analysed, and a scientific manuscript proving they were a unique species was submitted to the journal Zootaxa.

Results

The Western Australian common octopus is a distinct species from its east Australian cousin, the gloomy octopus or *Octopus tetricus*. The Western Australian octopus was re-named as *Octopus djinda*, the Western Rock Octopus.

Implications for relevant stakeholders

This report will enable more accurate records of harvest of octopus in Australia, and allow a proper assessment of the significant contribution of *Octopus djinda* to the Australian cephalopod fisheries harvest. It will also provide certainty to the fishing industry in Western Australia, allowing it to differentiate the product in the marketplace in order to create a distinct branding of the Western Australian octopus fishery.

Recommendations

This project recommends that the proposed species name of *Octopus djinda*, and standard fish name of Western Rock Octopus be adopted by the scientific community, the FRDC fish names committee, and the commercial fishing industry of Australia.

Keywords: *Octopus djinda*, Western Rock Octopus, allopatric speciation

1.0 Introduction

The Western Australian Octopus Interim Managed Fishery is Australia’s largest octopus fishery. It is in a sustained growth phase and has been accredited by the Marine Stewardship Council (MSC) for certification under its international sustainability brand. Estimated GVP increased by 50% from 2017 to 2018, and significant capital investment has been made into the fishery. A new processing and export factory has been opened up in Geraldton, and fishing has expanded into new regional areas of WA, such as Esperance and Lancelin. There are 23 vessels operating on a full time or part-time basis, and all are targeting a single species that is currently unnamed. Meetings with industry members in 2017 and 2018 resulted in a unanimous agreement that a formal species name and new common name was a major research priority due to the benefits that would accrue. This project meets the No. 2 national priority “Improving productivity and profitability of fishing and aquaculture” and key deliverables of “improved market access” and “sustainable and profitable use of underutilized and undervalued species” of the FRDC’s R,D, & E plan (FRDC, 2015). This project follows from 2010/200, "Innovative development of the *Octopus* (cf) *tetricus* fishery in Western Australia." Since the 2010/200 project, effort has more than tripled in the fishery, from 80,000 trap lifts in 2011 to 300,000 trap lifts in 2018 and continues to grow at around 10% per year.

1.1 Project Need

Octopus aff. *tetricus* or the Western Australian common octopus is an endemic species of the temperate waters of Western Australia. It is closely related to the cosmopolitan *O. vulgaris* species complex, and the gloomy octopus “*O. tetricus*” on the east coast of Australia and New Zealand, but has been conclusively identified as a separate species through genetic and morphometric studies (Guzik et al., 2005; Amor et al., 2014). Currently, the common octopus supports the largest single-species octopus fishery in Australia, however the animal caught is an unnamed species, and carries the species affinis “*Octopus* aff. *tetricus*” instead. This is not an ideal situation for two reasons. First, it hinders a proper assessment of its significant contribution to the Australian cephalopod fisheries harvest. For example, until the SAFS 2020 edition, there was no dedicated SAFS report for this species, despite the catch levels harvest being three times greater than the 'Pale Octopus' (*Octopus pallidus*) from Tasmania, which does have its own SAFS assessment report. Secondly, there is an industry impetus to differentiate the product in the marketplace in order to create a distinct branding of the Western Australian octopus fishery into the future. Thus, there is both a scientific/administrative need and a marketing need to formalise the correct species name, and its associated common name.

1.2 Objectives

1. Develop a formal species name for *Octopus* aff. *tetricus*

2. Develop an approved common name for *Octopus* aff. *tetricus*

2.0 Method

2.1 Species identification and description

Octopus were obtained in December 2019 via commercial fishing traps from the waters near Esperance, Geraldton and Mandurah, Western Australia, at depths of 7–30 m. They were anaesthetised, transferred to ice, and tissue samples for DNA extraction collected from the mantle region. After 15 months storage in a frost-free freezer, specimens were thawed in seawater baths, and preserved in a solution of formalin (formaldehyde 37% w/w) to a final concentration of 10% (i.e., 3.7% formaldehyde), ensuring that the solution entered the mantle cavity. To remove residual formalin before final preparation, specimens received three seawater baths before being preserved and stored in 70% ethanol. For more details, see Appendix 1.

Morphological traits measurement and DNA sequencing for cytochrome c oxidase subunit I (COI) followed standard techniques. The COI sequence is the main DNA sequence used to distinguish between species of Octopus. For more details, see Appendix 1.

2.2 Stakeholder consultation

Stakeholder consultation was undertaken under the direction of an Octopus Naming Working Group. An initial stakeholder meeting was held in December 2019 at the WAFIC (Western Australian Fishing Industry Council) boardroom. Discussion ensued on a range of names and included the issues of provenance and Marine Stewardship Council certification. The working group invited various experts on trade and investment in relation to fish names and deliberated on the issue for 18 months. After the names were decided upon, an application to the Australian Fish names standard was submitted. For more details, see Appendix 2.

3.0 Results, Discussion, and Conclusion

Extensive multivariate morphological analyses (Amor and Hart, 2021; Amor et al., 2014, 2017) and genome-wide molecular-based inferences (Amor et al., 2019) among all members of the *O. vulgaris* group, including *O. djinda* (treated as *O. cf. tetricus*), provide clear evidence this taxon is a distinct species. Geographically, the closest relative of *O. djinda* occurs along Australia's east coast (*O. tetricus*). To the west, *Octopus* aff. *vulgaris* (South Africa, Madagascar, Tristan da Cunha) has also been reported from the waters off Amsterdam and St Paul Island (Guerra et al., 2010). No other known representatives of the *O. vulgaris* group occur between these two areas.

Octopus djinda is delimited morphologically from its closest relatives (both geographically and phylogenetically), *O. tetricus* and *O. sinensis* (China, Japan, Taiwan, Kermadec Is.), via greater and non-overlapping sucker numbers on the males hectocotylised arm. Voight (2012) noted variation in sucker number of deep-sea conspecifics that occurred at 8° 38′ N and 12° 48′ N. *Octopus djinda* specimens spanning a comparable latitudinal range show similar hectocotylised arm sucker values (Geraldton 28° S = 169 – 196; Mandurah 32° S = 170 – 190; Esperance 33° S = 174 – 184), suggesting that this trait is relatively fixed in this species. Such examples of clear delimiting traits within the *O. vulgaris* group are rare. Indeed, arm length is the primary source of variation within the *O. vulgaris* group (Amor et al., 2017), although intraspecific arm length ranges often overlap with those recorded among close relatives (see Amor et al., 2017; Avendaño et al., 2020; Leite et al., 2008). Highly conserved morphology within Octopus (Amor et al., 2017) and the correlation between octopod morphology and the environment (Amor et al., 2017; Voight, 1993) suggest that local selective pressures are likely driving the increased sucker numbers observed for *O. djinda*, although specific mechanisms are unknown.

3.1 Implications for conservation and fisheries management

The life-history traits of many octopuses (high fecundity, short generation time, rapid attainment of reproductive maturity) make them ideal candidates to relieve the burden on over-exploited finfish stocks. Cephalopods accounted for 2 – 5 % of the global marine catch from 1960–2014 and fishing effort targeted towards invertebrates has recently increased, relative to finfish (FAO, 2021). Although cephalopod fisheries have the capacity to fill voids left by overfished finfish stocks, most regional octopus fisheries are reported to be in decline (Norman and Finn, 2014). In fact, octopod fisheries are typically mis-managed and catch statistics often lack appropriate taxonomic resolution.

Globally, members of the *O. vulgaris* group are one of the highest value fisheries targets, however, most fisheries report declining catch rates (Norman and Finn, 2014). The *O. djinda* fishery off southwest Australia provides an example of how appropriate fisheries management can lead to a sustainable industry. Detailed stock assessments estimate with 90% certainty, that biomass is greater than 3600 tonnes and the fishery may sustain catches of 1000 t or higher (Hart et al., 2019; 2016). Between 2011–2018 fishing effort increased approximately 4 times, and the value of the industry rose 50% from 2017–2018. In 2019, the fishery was accredited as being sustainable by the Marine Stewardship Council—only the second octopus fishery to achieve this accreditation worldwide. This provides a clear example that high-value octopuses can be sustainably managed to ensure persistence of the species and industry. The species description provided here will enable proper reporting of catch statistics for Australia's largest and fastest growing octopus fishery.

Doubleday et al. (2013) analysed long-term cephalopod fisheries catches (including ten octopuses from 21 locations/stocks) and proposed that ocean warming may have helped drive an increase in cephalopod abundance from 1953–2013. Furthermore, niche modelling suggests that *Octopus insularis* (a major fisheries target) has benefited from increased sea surface temperature since the last glacial maxima and will continue to expand its range under projected global warming (Lima et al., 2020b). Projected climate warming may therefore benefit *O. djinda*, especially considering the expansive continental shelf habitat off Western Australia. How such alterations in the range and abundance of this efficient generalist predator will impact local ecological systems remains unknown but warrants future investigation.

4.0 Implications and Recommendations

This report will enable more accurate records of harvest of octopus in Australia and allow a proper assessment of the significant contribution of *Octopus djinda* to the Australian cephalopod fisheries harvest. It was also provide certainty to the fishing industry in WA, allowing it to differentiate the product in the marketplace in order to create a distinct branding of the Western Australian octopus fishery

This project recommends that the proposed species name of *Octopus djinda*, and standard fish name of Western Rock Octopus be adopted by the scientific community, the FRDC fish names committee, and the commercial fishing industry of Australia.

5.0 Extension and Adoption

End users have been an integral component of this report. As a result of this report, a new SAFS (State of Australian Fish Stocks) report was prepared for *Octopus djinda*, and the commercial industry in Western Australia has been geared up to adopt the new name conventions as part of their marketing and distribution strategies. At the time of submitting the final report (June 2023), both the new species name and the common name had been accepted by the scientific community, commercial fishing industry, and the Australian Fish Names Standards. The senior author (Dr Anthony Hart) regularly receives request from various stakeholders (commercial industry, government export trade departments, libraries, scientific colleagues) who require the project information to ensure the trade and marketing names are aligned, as well as the scientific evidence underling the new species delineation. Also, a Taxonomic Serial Number (TSN) for *Octopus djinda* has been requested from the Smithsonian Institution's Integrated Taxonomic Information system - https://www.itis.gov. Once available, this permanent and unique numeric code will facilitate tracking and reporting of international wildlife trade.

5.1 Project Materials Developed

The following scientific manuscript was published by the journal *Zootaxa*

Amor M. D., Hart, A. M. (2021). *Octopus djinda*: a newly described member of the Octopus vulgaris group from southwest Australia (Octopoda: Octopodidae)

The proposal for a new common name of “Western Australian Rock Octopus” was accepted by the Australian Fish Names Committee.

6.0 Acknowledgments

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The Octopus Naming Working Group, chaired by Guy Leyland of WAFIC (Western Australian Fishing Industry Council), and assisted by Joan Lim (DPIRD), Glenn Wheeler (Fremantle Octopus Group) and Don Nichols (Southern Seafood Producers Association), did an excellent job of consulting with stakeholders about possible common names, and steering the candidates to an appropriate consensus for "Western Rock Octopus".

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8.0 Appendix 1: : <u>Manuscript</u>: *Octopus djinda*: a newly described member of the *Octopus vulgaris* group from southwest Australia (Octopoda: Octopodidae).

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Octopus djinda (Cephalopoda: Octopodidae): a new member of the *Octopus vulgaris* group from southwest Australia

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Abstract

A new *Octopus* Cuvier, 1797 species, *Octopus djinda* Amor, 2021 (previously treated as *O.* cf. *tetricus* and *O.* aff. *tetricus*), is described from the shallow waters off southwest Australia. This species was classified as conspecific with *O. tetricus* Gould, 1852 from Australia's east coast and New Zealand but is shown here to be morphologically and genetically distinct. This description is based on 25 individuals across three localities in southwest Australia, encompassing most of its distribution. Greater and non-overlapping sucker counts on the males hectocotylised arm delimit east and west coast forms. DNA barcoding using cytochrome *c* oxidase subunit I also successfully differentiates between these taxa; 13 polymorphisms along a 349 bp partial fragment (3.7% sequence divergence). A close relative of the *O. vulgaris* Cuvier, 1797 species-group, *O. djinda*, sp. nov. supports a highly productive fishery and is currently one of two octopod fisheries worldwide to have received sustainable certification from the Marine Stewardship Council. The taxonomic description presented here provides formal recognition of the taxonomic status of southwest Australia's common octopus, *O. djinda*, sp. nov. and facilitates appropriate fisheries catch reporting and management.

Key words: Allopatric speciation, Bassian Isthmus, cryptic species, *Octopus tetricus*

Introduction

Benthic shallow-water species are among the most studied and best understood octopods (Rosa *et al.* 2019), and are, therefore, of high interest to researchers and fishers. This attention can lead to an improved understanding of species boundaries and distributions, including the potential identification of cryptic taxa. Cryptic speciation is common among octopods (Norman *et al.* 2014) and examples are prevalent throughout the order Octopoda Leach, 1818 (e.g., *Enteroctopus* Rochebrune & Mabille, 1889: Hollenbeck & Scheel 2017; *Pareledone* Robson, 1932: Allcock 2005; *Octopus* Cuvier, 1797: Amor *et al.* 2017). Octopuses have few hard body parts or diagnostic taxonomic traits (Nesis 1998; Allcock 2005; Amor *et al.* 2017). Further, morphological plasticity (Pickford 1964; Burgess 1966; Voight 2001) that is linked to local environmental conditions (Voight 1993; Amor *et al.* 2017) and the limited utility of traditional molecular markers (Amor *et al.* 2019) have compounded our likely underestimation of species richness among octopods.

Within Octopoda, perhaps the most iconic example of this phenomenon is observed among members of the *Octopus vulgaris* group. This species-group represents one of the greatest octopus fisheries targets (global value and effort; Norman & Finn 2014), and are of broad scientific interest (e.g., cell biology, environmental science, fisheries research, neuroscience, physiology, robotics). Recently, however, this group was recognised as comprising several distinct taxa that diversified within the last 2.5 Ma (Amor *et al.* 2019). In fact, morphology is so conserved within *Octopus* that two species, *O. mimus* Gould, 1852 and *O. insularis* Leite & Haimovici, 2008, have only recently been confirmed as distinct from *O. vulgaris* (see Söller *et al.* 2000 and Leite *et al.* 2008, respectively), despite estimates that they diverged from the *O. vulgaris* group 43–18 Ma (Amor *et al.* 2015; Lima *et al.* 2020). Multivariate analyses of 25 morphological traits revealed significant differences among members of the *O. vulgaris* group and the distant relative, *O. insularis*, although overlap was observed among most taxa (including *O. insularis*; Amor *et al.* 2017). Interestingly, the most distinct species were *O. insularis* and *O. americanus* Monfort, 1802, which share overlapping distributions but have distinct ecological (depth) niches (Lima *et al.* 2017).

The gloomy octopus, *Octopus tetricus* Gould, 1852, provides a key example of cryptic speciation within the *O. vulgaris* group. Supposed *O. tetricus* populations have disjunct distributions along (i) Australia's east coast and New Zealand, and (ii) southwest Australia (Fig. 1). Although these taxa have allopatric distributions, they were previously considered conspecifics due to similarities in morphology and behaviour of adults, and connectivity between these populations was assumed to be maintained via dispersal of planktonic paralarvae. Early genetic work investigating the phylogenetic relationships among benthic shallow-water octopuses (sub-family Octopodinae) included one individual from each of Australia's east and west coasts and placed them as sister taxa (Guzik *et al.* 2005).

This prompted the study of Amor *et al.* (2014), who sampled multiple individuals from across the known distribution, thoroughly representing east and west regions. They analysed five mitochondrial (mt) DNA markers and 17 morphological traits and provided robust evidence that east (including New Zealand) and west forms were distinct. Subsequently, Amor *et al.* (2017) placed this finding in context with the wider *O. vulgaris* group, expanding taxon representation and increasing the number of diagnostic morphological traits. In this case, all sampled members of the *O. vulgaris* group, including both *O. tetricus* taxa, were successfully distinguished via multivariate analyses of morphological traits. The length of the males third right arm and its sucker number (hectocotylised arm sucker count) are the primary source of morphological variation among members of the *O. vulgaris* group (Amor *et al.* 2014, 2017).

Octopus tetricus occurs along the east coast of the Australian mainland, from Coffs Harbour, Queensland to Lakes Entrance (Flagstaff Jetty: C. Silvey, pers. obs.), Victoria, as well as being found in the shallow waters off Flinders Island, north of Tasmania (Amor *et al.* 2014). This species maintains genetic connectivity across the Tasman Sea, also occurring in northern New Zealand where it was previously referred to a *O. gibbsi* O'Shea, 1999—a now-recognised junior synonym of *O. tetricus* (Amor *et al.* 2014). The population that occurs on Australia's southwest coast has been treated as *O.* cf. *tetricus* and *O.* aff. *tetricus* (Norman & Hochberg, 2005) and is distributed from Shark Bay to Cape Le Grand, Western Australia. Importantly, these populations have allopatric distributions and are separated by approximately 2,400 kms along the southern Australian coastline. Comprehensive analyses of morphological, phylogenetic (Amor *et al.* 2014, 2017) and phylogenomic data (Amor *et al.* 2019), provide complete evidence that the west coast taxon represents a distinct species that requires formal taxonomic status. Here presented is the description for the star octopus, *Octopus djinda* Amor, sp. nov.

Materials and Methods

Octopus were collected in December 2019 under a permit provided by the Department of Primary Industries and Regional Development (DPIRD), Western Australia (exemption number 3506; Fish Resources Management Act 1994). Samples were obtained via pots/traps from the waters near Esperance, Geraldton and Mandurah, Western Australia, at depths of 7–30 m (Fig. 1). Animals were anaesthetised in seawater baths with supplemented magnesium chloride (2%). Ice (1:1 seawater and ice) was added when the octopus were non-responsive to touch (30–60 minutes). When individuals stopped breathing, they were transferred to ice. Mantle tissue was sampled for DNA extraction and was preserved in 90% ethanol. Whole specimens and tissue samples were transported on ice, then stored at -20 °C, in a frost-free freezer until March 2021 (15 months).

Specimens were thawed in seawater baths over several hours. Formalin (formaldehyde 37% w/w) was added to seawater baths to a final concentration of 10% (i.e., 3.7% formaldehyde), ensuring that the solution entered the mantle cavity. Whole octopus were firm to touch after 12 hours, although they were treated for seven days to ensure that formalin penetrated the thick muscle tissue. Three, 4 to 12-hour seawater baths followed to remove residual formalin. Whole specimens were then preserved and stored in 70% ethanol.

Morphological traits were measured following Roper & Voss (1983) and Huffard & Hochberg (2005), except suckers were counted along the entire arm. Total preserved weight was recorded via digital scales. Total length, web depth and arm length were recorded using non-stretch cord and all remaining length measures were obtained using digital calipers. The included male specimens were all mature, while females had relatively small ovaries (1–28 g) for the species and were thus considered sub-mature. No major effects of long-term freezer storage were evident, although, smooth dorsal skin was observed (as discussed by Leite *et al.* 2008) and poorly defined funnel organs were noted by M. Amor here, which may be related. Scanning Electron Microscopy was performed at 15kV and 25x magnification using a Hitachi TM4000PLUS tabletop microscope. Specimens were deposited at the Western Australian Museum (WAM), WAM S.89000–S.89024 (Table 1).

TABLE 1. *Octopus djinda* sp. nov. material collected and examined by M. Amor, and deposited at the Western Australian Museum, Welshpool, Western Australia (WA).

User id	Catalog no.	Sex	Type	Latitude	Longitude	Location
GER001	WAM S.89000	M		-28.818991	114.528067	Geraldton, WA
GER002	WAM S.89001	M	Paratype	-28.832068	114.545754	Geraldton, WA
GER003	WAM S.89002	M		-28.854928	114.540271	Geraldton, WA
GER004	WAM S.89003	F		-28.866858	114.555946	Geraldton, WA
GER005	WAM S.89004	M		-28.906393	114.574925	Geraldton, WA
GER006	WAM S.89005	F		-28.913360	114.575633	Geraldton, WA
GER007	WAM S.89006	F	Paratype	-28.922786	114.574235	Geraldton, WA
GER008	WAM S.89007	F		-28.926475	114.570960	Geraldton, WA
ESP001	WAM S.89008	F		-33.841345	121.913242	Esperance Bay, WA
ESP002	WAM S.89009	F	Paratype	-33.841345	121.913242	Esperance Bay, WA
ESP003	WAM S.89010	M	Holotype	-33.841345	121.913242	Esperance Bay, WA
ESP004	WAM S.89011	M		-33.852180	121.918307	Esperance Bay, WA
ESP005	WAM S.89012	F		-33.852180	121.918307	Esperance Bay, WA
ESP006	WAM S.89013	F		-33.854211	121.905217	Esperance Bay, WA
ESP007	WAM S.89014	M		-33.856635	121.904231	Esperance Bay, WA
MAN001	WAM S.89015	F		-32.812701	115.539810	Mandurah, WA
MAN002	WAM S.89016	F		-32.812701	115.539810	Mandurah, WA
MAN003	WAM S.89017	F		-32.812701	115.539810	Mandurah, WA
MAN004	WAM S.89018	F	Paratype	-32.784365	115.519275	Mandurah, WA
MAN005	WAM S.89019	F		-32.784365	115.519275	Mandurah, WA
MAN006	WAM S.89020	M		-32.765590	115.526550	Mandurah, WA
MAN007	WAM S.89021	M	Paratype	-32.765590	115.526550	Mandurah, WA
MAN008	WAM S.89022	M	Paratype	-32.751808	115.510596	Mandurah, WA
MAN009	WAM S.89023	M		-32.751808	115.510596	Mandurah, WA
MAN022	WAM S.89024	F		-32.739162	115.517875	Mandurah, WA

DNA sequence data for cytochrome *c* oxidase subunit I (COI) were obtained using the primers described by Folmer *et al.* (1994; forward LCO1490 5′ GGTCAACAAATCATAAAGATATTGG 3′ and reverse HC02198 5′ TAAACTTCAGGGTGACCAAAAAATCA 3′) and are available online (Genbank accessions: MZ021283-MZ021298). DNA extractions were performed using a 'QIAGEN DNEasy blood and tissue kit' on tissue without skin, as octopus skin inhibits PCR efficiency (Amor *et al.* 2019). DNA purity was quantified with a 'Thermo Scientific Nanodrop 2000 spectrophotometer' (absorbance ratio 260/280 = >2). 25 µL PCR reactions comprised 0.5 µL MyTaq DNA polymerase, 5 µL reaction buffer (5x; Bioline), 0.5 µL forward primer (10 µM), 0.5 µL reverse primer (10 µM), 17.5 µL ddH2O and 1 µL DNA (diluted to between 1–5 ng/µL). PCR conditions were as follows; initial denature: 94 °C for 2 minutes; 35 amplification cycles (denature: 94 °C for 40 seconds; anneal: 50 °C for 40 seconds; extension: 72 °C for 90 seconds) and a final extension step of 72 °C for 10 minutes. PCR products were checked via gel electrophoresis using a HyperLadder 100 bp ladder (Bioline). Unpurified PCR products were sent to the Australian Genome Research Facility (AGRF) in Perth, Western Australia for purification and single direction sequencing. Electropherograms were aligned, visually inspected and where necessary, manually corrected and trimmed using Geneious Prime 2021.1 (https://www.geneious.com). Several poor-quality sequences (<10% high quality bases) could not be corrected and were discarded.

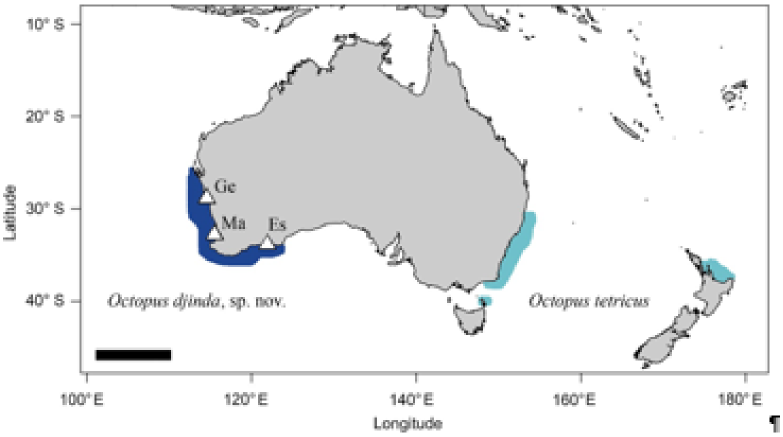

FIGURE 1. Geographic distribution of *Octopus djinda*, sp. nov., along the southwest Australian coast, from Shark Bay (north) to Cape Le Grand (southeast). Sampling localities are shown with white triangles: Ge, Geraldton; Ma, Mandurah; Es, Esperance. The distribution of *O. tetricus* is also shown along the east coast of Australia and northern New Zealand. Scale, 1,000 km.

Systematic description

Family Octopodidae d'Orbigny, 1840

Subfamily Octopodinae d'Orbigny, 1840

Genus *Octopus* Cuvier, 1797

Octopus djinda Amor, sp. nov.

(Figs. 2–3)

Octopus tetricus, Joll *et al.* 1976, 1977, 1978; Roper *et al.* 1984: 209; Kirkman *et al.* 1991: 557; Stranks 1998: 541 (in part); Guerra *et al.* 2010: 1405 (in part); Acosta-Jofre *et al.* 2012 (in part); Reid & Wilson 2015 (in part); Greenwell *et al.* 2019.

Octopus cf. *tetricus*, Roper 1997; Norman & Reid 2000; Finn *et al.* (2005); Guzik *et al.* 2005; Norman & Hochberg 2005: 146; Amor *et al.* 2014; Norman *et al.* 2014: 58; Leporati & Hart 2015; Leporati *et al.* 2015; Hart *et al.* 2016; Reid 2016: 396; Amor *et al.* 2017; Sauer *et al.* 2020; Somaweera & Somaweera 2021.

Octopus aff. *tetricus*, Hart *et al.* 2019.

Type material. Seven type specimens were designated, including at least one male and one female from each sampled locality which encompasses most of the species' distribution. Other material examined (a further 7 males and 11 females) are listed in Table 1 (n = 25). Raw morphological data are available in Tables S1–S4. **Holotype: AUSTRALIA: Western Australia: Esperance:** Male, 138.6 mm ML (Fig. 3). Collected by M. Amor 10-Dec-2019 via non-baited trap, 7–9 m depth. Esperance Bay (-33.84, 121.91) (WAM S.89010). **Paratypes: AUSTRALIA: Esperance:** (i) Female, 163.4 mm ML. Collected by M. Amor 10-Dec-2019 via non-baited trap, 7–9 m depth. Esperance Bay (-33.84, 121.91) (WAM S.89009); **Mandurah:** (ii) Male, 163.4 mm ML. Collected by M. Amor 12-Dec-2019 via baited trap, 22–25 m depth (-32.77, 115.53) (WAM S.89021); (iii) Male, 177.0 ML. Collected by M. Amor 12-Dec-2019 via baited trap, 22–25 m depth (-32.75, 115.51) (WAM S.89022); (iv) Female, 124.3 mm ML. Collected by M. Amor 12-Dec-2019 via baited trap, 22–25 m depth (-32.78, 115.52) (WAM S.89018); **Geraldton:** (v) Male, 176.1 mm ML. Collected by M. Amor 2-Dec-2019 via baited trap, 16–30 m depth (-28.83, 114.55) (WAM S.89001); (vi) Female, 149.7 mm ML. Collected by M. Amor 2-Dec-2019 via baited trap, 16–30 m depth (-28.92, 114.57) (WAM S.89006).

FIGURE 2. Live *Octopus djinda* sp. nov. specimen. Photo, Mark Norman.

Diagnosis. Medium to large (109–177 mm ML), muscular species. Ocelli absent. Long arms taper to narrow tips between 347–745 mm; 3.7–6 times longer than ML. All arms equal width (12.5-32.1 mm). Males right arm III hectocoltylised; shorter than opposite arm (ALR3 84–97% ALL3). Well-defined spermatophore groove ends at base of small calamus. Calamus approximates 31–49% of ligula. Small ligula (LL 1–1.6% ALR3). Biserial sucker arrangement; 182–283 suckers on non-hectocotylised arms, 169–196 hectocotlised arm suckers. Between 1–13 enlarged suckers present in both sexes; between 10th to 23rd proximal suckers on II and III arm pairs.

Description. Based on 11 mature males and 14 sub-mature females. Mantle broad, oval shaped and saccular. Web depth 18–31% of longest arm, formula highly variable. Funnel tube shaped; free length 45–85% of total funnel length (39–66 mm). Funnel organ 'W' shaped. 9–10 lamellae per gill demibranch. Ink sac, anal flaps present. One large papilla above each eye, 2–3 additional smaller papillae adjacent. Typical *Octopus* digestive tract (Fig. 4) comprising a large buccal mass connected to a pair of rounded anterior salivary glands. Posterior salivary glands curved and triangular. Narrow oesophagus leads to crop diverticulum then wide, triangular, stomach. Spiral caecum connected to large digestive glad; ink sac embedded within. Long intestine ending with muscular rectum, pair of anal flaps. Strong beak embedded within buccal mass (Fig. 5A & 5B). Radula comprises rows of seven teeth, two marginal plates. Rhachidian tooth, 2–3 cusps migrating laterally, and asymmetrically over four rows. Pattern offset by two rows (WAM S89017; Fig. 5C).

Spawned eggs 2.5 mm long, 1 mm wide. Larvae planktonic. Mature male testis, large (Fig. 6A), narrow vas deferens opens into a round mucilage gland, then long, curved spermatophore gland (Fig 6B & 6C). Spermatophore sac connected, 32–111 spermatophores within. Spermatophores long (to 50 mm), and narrow (0.6–0.7 mm). Terminal organ 13–24% of ML. Diverticulum elongate, oval-shaped (5–14 mm). Ovaries to 28 g (sub-mature). Short proximal oviducts, lead to spherical oviductal glands and distal oviducts (Fig. 6D).

FIGURE 3. Male *Octopus djinda* sp. nov. holotype specimen (WAM S.89010) from Esperance Bay, Australia. Scale, 30 mm.

Rough skin texture, distinct patches. Live specimens display mottled colour pattern, vary in colour from oceanic (reddish-brown/orange) to estuarine habitats (green/brown tint). Characteristic orange colouration along arm edge; often displayed while denned. Colour muted by preservation.

Distribution. Shark Bay (northernmost distribution; approx. -25.51, 112.87) to Cape Le Grand (southeast; approx. -33.94, 122.55), Western Australia (Fig. 1). Depth to 80 m. Mean sea surface temperatures from ~25–17 (Fig. S1; Huang *et al.* 2017).

Etymology. *Octopus djinda* sp. nov. the star octopus, is distributed along the southwest coast of Australia. This distribution closely reflects the territory of the traditional custodians of this land, the Nyoongar people ('a person of the southwest of Western Australia'). To recognise their connection to this land, a Nyoongar translation of 'star' (djinda), as described by Whitehurst (1997), was selected as a species name. This use of 'star' (luminous) reflects the shared recent ancestry with, and now-understood distinction from, *O. tetricus* (Latin: gloomy octopus). Consultation with the Aboriginal community regarding the use of 'djinda' as a species name was undertaken via the Western Australian Museum's Aboriginal Advisory Committee (WAMAAC). Initial documentation, including the above etymology statement, was presented to the committee on Friday July 2, 2021. Support was provided on July 14, 2021.

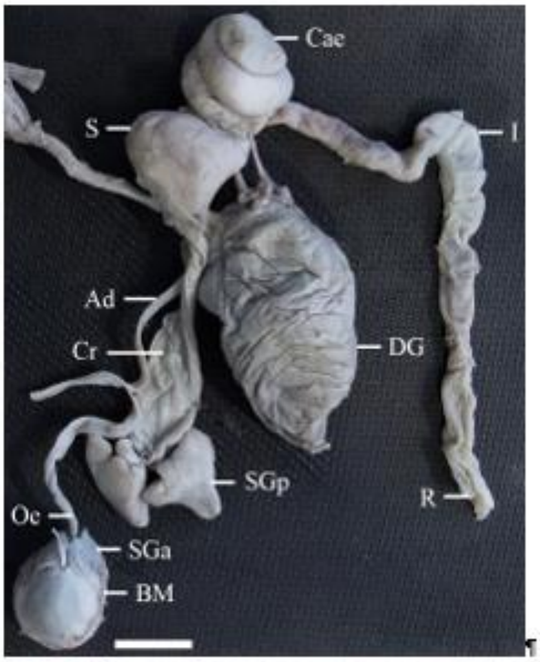

FIGURE 4. Digestive tract of a male *Octopus djinda* sp. nov. specimen: Ad, dorsal aorta; BM, buccal mass; Cae, caecum; Cr, crop; DG, digestive gland; I, intestine; Oe, oesophagus; SGa, anterior salivary gland; SGp, posterior salivary gland; S, stomach; R, rectum. Scale, 20 mm.

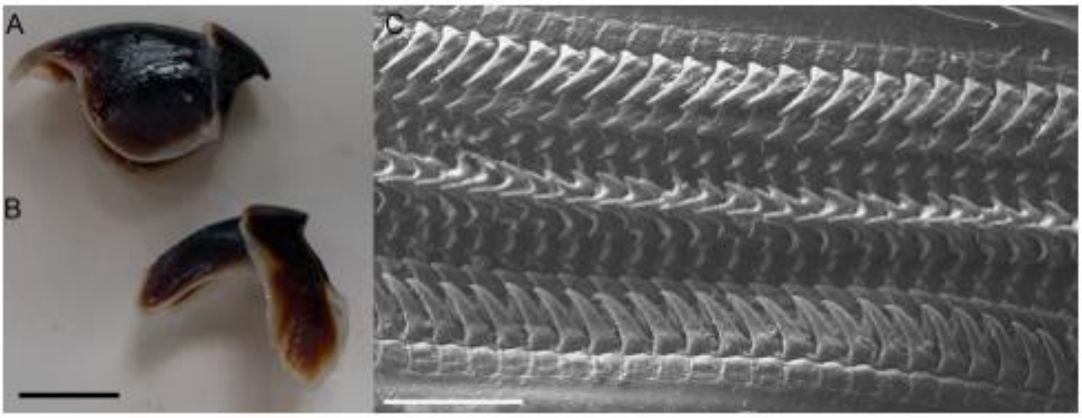

FIGURE 5. *Octopus djinda* sp. nov. upper (A) and lower (B) beak. SEM image of the radula is shown under 25 times magnification (C). Scale, 10 mm (A, B), 1 mm (C).

Remarks. Greater, and non-overlapping, sucker numbers on hectocotylised arm delimit *O. djinda* sp. nov. (169–196) from *O. tetricus* (122–150; Amor *et al.* 2017) and *O. sinensis* d'Orbigny, 1841 from Asia (119–152; Gleadall 2016), but not Kermadec Is. (178–185; Reid & Wilson, 2015). Disjunct distributions reflect species identity among *O. djinda*, *O. tetricus* and *O. sinensis*, which form a monophyletic clade within the *O. vulgaris* group (Amor *et al.* 2019). A 399 bp fragment of the COI gene was sequenced to complement visual identification. Sequence data from 16 individuals, that were of sufficient quality, were retained and represented a single haplotype. 349 bases overlapped with existing accessions for *O. tetricus* and *O.* cf. *tetricus*. 13 polymorphisms along 349 bp partial COI sequence (3.7% divergence) reliably distinguish *O. djinda* sp. nov. from *O. tetricus*; interspecific variation nine times greater than intraspecific differences. Four characteristic large papillae form a diamond pattern on the dorsal mantle, typical for the *O. vulgaris* species-group. Funnel organ was difficult to see in most specimens.

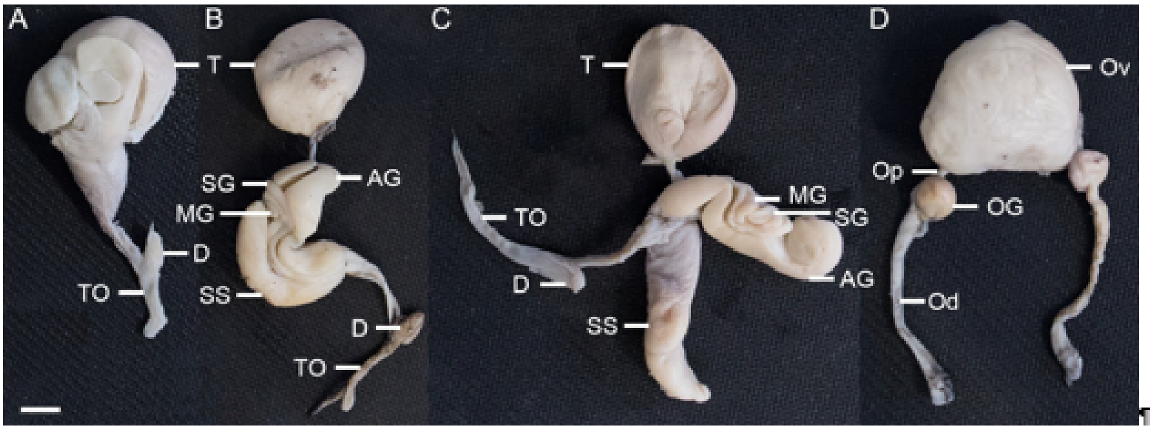

FIGURE 6. *Octopus djinda* sp. nov. male reproductive tract shown in original orientation (A), and after rearrangement (B, C): AG, accessory gland; D, diverticulum; MG, mucilaginous gland; SG, spermatophore gland; SS, spermatophore sac; T, testis; TO, terminal organ. Female reproductive tract is also shown (D): Ov, ovary; Od, distal oviduct; OG, oviductal gland; Op, proximal oviduct. Scale, 10 mm.

Discussion

Comparison with closest relatives. Extensive multivariate morphological analyses (Amor *et al.* 2014, 2017) and genome-wide molecular-based inferences (Amor *et al.* 2019) among all members of the *O. vulgaris* group, including *O. djinda* (treated as *O.* cf. *tetricus*), provide clear evidence this taxon is a distinct species. *Octopus djinda* is delimited morphologically from its closest geographic and phylogenetic relatives, *O. tetricus* and *O. sinensis* (China, Japan, Taiwan), via greater and non-overlapping sucker numbers on the males hectocotylised arm. Such examples of clear delimiting traits within the *O. vulgaris* group are rare. Indeed, arm length is the primary source of variation within the *O. vulgaris* group (Amor *et al.* 2017), although intraspecific arm length ranges often overlap with those recorded among close relatives (see Leite *et al.* 2008; Amor *et al.* 2017; Avendaño *et al.* 2020).

The clade containing individuals from Asia and the Kermadecs was recently renamed to *O. sinensis*, although differences in hectocotylised arm sucker numbers and disjunction were noted (Gleadall 2016). *Octopus sinensis* from the Kermadec Islands was previously described as *O. jollyorum* Reid & Wilson, 2015. Despite synonymy of these taxa, it is recognised that this clade requires further investigation using genome-wide molecular markers (Amor *et al.* 2017), especially considering that inferences based on mtDNA can underestimate diversity within the *O. vulgaris* group (Amor *et al.* 2019).

Allopatric speciation. Disjunct distributions and the resultant lack of gene flow have likely led to speciation between *O. djinda* and *O. tetricus*. Diversification of the *O. vulgaris* species-group, including *O. djinda* and *O. tetricus*, was estimated to have occurred within the last 2.5 Ma (Amor *et al.* 2019) or 3–7 Ma (Amor *et al.* 2014). During this time, cooling waters resulted in lower sea levels and the exposure of the Bassian Isthmus, a landbridge that connected Tasmania to the Australian mainland. This resulted in the northward migration of numerous, now-divided, subtropical populations along Australia's east and west coasts (Wilson & Allen 1987). *Octopus tetricus* maintains gene flow across the Tasman Sea, a 2,000 km open water body. However, the deep and relatively cool waters of the Great Australian Bight appear to be unsuitable for settlement and dispersal of larvae for *O. djinda* and *O. tetricus*, thus allopatry is maintained.

Implications for conservation and fisheries management. The life-history traits of many inshore octopuses (high fecundity and rapid maturation) make them ideal candidates to relieve the burden on over-exploited finfish stocks. Globally, cephalopod fishery catches have declined 27% since 2014 (from a peak of 4.9 million tonnes in 2014 to 3.6 million t in 2017 and 2018; FAO 2020). However, global octopus catches have increased from 1950–2019 (FAO 2021; Fig. S2); European fisheries have steadily declined since peaking in the 1970s, whilst other regions report modest increase (the Americas), potential recovery (Africa: post-crash in the early 2000s) or plateau (Asia: after a sharp increase in the early 2000s). Despite the potential for continued growth of the octopus fishing

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industry, interpretations of catch data are still limited by poor taxonomic resolution and under-reporting of catches (Norman & Finn 2014; Sauer *et al.* 2019).

The southwest Australian *O. djinda* fishery provides an example of how appropriate fisheries management can lead to a sustainable industry. Detailed stock assessments estimate with 90% certainty, that biomass is greater than 3,500 t and the fishery may sustain catches of 1000 t or higher (Hart *et al.* 2016, 2019). Between 2011–2018 fishing effort increased approximately four-fold, and the value of the industry rose 50% from 2017–2018. In 2019, the fishery was accredited as being sustainable by the Marine Stewardship Council—only the second octopus fishery to achieve this accreditation worldwide. The species description presented here provides formal recognition of the taxonomic status of southwest Australia's common octopus, *O. djinda*, and facilitates appropriate fisheries catch reporting and management.

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Author contributions: MDA collected and prepared samples, conducted experiments, interpreted data, wrote the manuscript, and completed revisions. AMH facilitated specimen collection and commented on manuscript drafts.

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9.0 Appendix 2: Application to the Australian Fish Names Standard.

Overview of this proposed fish name (Why the change)

The FRDC funded "*Project No 2018-178 Species identification of Australia's most significant octopus fishery, the Western Australian Common Octopus*" has the objective of giving the Western Australian Common Octopus a formal SNF (Standard Fish Name), and also a species name. This application is in support a SNF of "Western Rock Octopus" being assigned to the species *Octopus djinda*, which is endemic to Western Australia.

Submitting the application

Date submitted:	25/5/21
Signature of applicant (not required if submitted from the applicant's email address):	

Applicant details

Name	Dr Anthony Hart				
Affiliation or company	DPIRD Western Australia				
Address	39 Northside Dr, Hillarys				
City	Perth	**State**	WA	**Postcode**	6025
Phone number	92030111				
Fax number					
Email address	anthony.hart@dpird.wa.gov.au				

Application type

Add a **new** standard fish name	Yes
Amend an **existing** standard fish name	

Proposed standard fish name (SFN)

Current standard fish name:	Gloomy octopus
Proposed SFN	Western Rock Octopus
Additional preferences	

Species details

Scientific name (genus and species):	***Octopus djinda***
Authority	**Zootaxa publication (Amor and Hart, 2021)**
CAAB Code	23659005
Species type (e.g., finfish, crustacean, mollusc, jellyfish, sea cucumber, seaweed, sea urchin, sharks & rays):	**Octopus (Mollusca: Cephalopoda)**
Australian species: specify the States and Territories in which the species is harvested:	**Western Australia**
Imported species: specify the country/s of origin:	

Categories:

Note: If the species falls into multiple categories, mark all relevant categories.

Commercial species:	X	Exported species:	X	Recreational species:	X

Aquaculture species:		Imported species:		Other (specify):	

Additional details (new species only)

If your application is to add a new standard fish name to the Australian Fish Names Standard, you:

- will need to provide colour photographs of the whole animal and product (e.g. fish fillet)
- may need to provide samples for positive identification
- will need to provide samples for taxonomic assessment if samples are not already held by CSIRO or a relevant museum (see Fish Names Procedures)

The following information is required to assist with species identification.

Specify **habitat** type/s for the species	Freshwater		Demersal shelf: under 200 meters	X
	Estuarine	X	Demersal slope: over 200 meters	
	Coastal	X	Oceanic / pelagic	
	Other (Specify): e.g. caught in the Antarctic/sub Antarctic zone			
Specify **harvesting** method/s for the species	Trawl		Pot or trap	X
	Non-trawl net (e.g. seine, gillnet)		Line (e.g. longline, dropline),	
	Aquaculture		Recreational fishing	
	Other (Specify): - e.g. Quota species			

Protocols for selecting standard fish names

The Fish Names Committee will assess whether your proposed standard fish name complies with the protocols for selecting standard fish names.

Comment briefly below on whether you believe your proposed standard name complies with the protocols below.

Protocol	Applicant Comment	FNC Use
6.4.1: Compliance with international obligations requires that a standard fish name • does not create unnecessary obstacles to international trade as per the WTO GATT (General Agreements on Tariffs and Trade) which include the Technical Barriers to Trade (TBT) Agreement.	Yes	
6.4.2: Compliance with Federal and State laws require that a standard fish name: • maintains or enhances the protection of public health and safety • provides adequate information to enable consumers to make informed choices • helps to prevent misleading or deceptive conduct • does not result in anti-competitive practices • does not facilitate unconscionable conduct • is consistent with applicable industry codes of conduct • protects consumers against unfair practices.	Yes Yes Yes Yes Yes Yes Yes	
6.4.3 Preferred names Preference will be given to: • a name that has over-riding historical significance • a name that is internationally accepted • a regional name where the species is most commonly encountered/caught • a name commonly used in Australia	NA-this is a new species and requires a new common name NA NA NA	

Protocol	Applicant Comment	FNC Use
• a name that has strong stakeholder support • a name used in recent mainstream field guides • a name that most effectively distinguishes a species from its closest relatives • a name that generally conforms to other members of the family or generic-level grouping • a name that facilitates market acceptability • a name that is simple, unambiguous, and easily readable.	Yes NA Yes Yes Yes Yes	
6.4.4 One name per species • Requires that each species may be assigned a single, standard fish name, and no two species may have the same approved standard name.	Yes	
6.4.5 Group names: A group standard fish name: • may cover multiple species in a particular scientific family or group of fish, and • may not be the same as a species' standard fish name, and • will follow internationally accepted names unless alternatives are well entrenched in Australian mainstream literature.	NA NA NA	
6.4.6 Subspecies and hybrids • Subspecies and hybrids will not generally be given a standard fish name.	NA	
6.4.7 Structure of names • Requires standard fish names to simplicity in names and structure (see protocols for full details).	NA	
6.4.8 Scientific names • If the scientific name of a species changes, the standard fish name should remain unaffected unless there is a good reason for change.	this is a new species and requires a	

Protocol	Applicant Comment	FNC Use
• Generic or family scientific names may be used as standard fish.	new common name	
6.4.9 Other grammatical rules and exceptions: Standard fish names should adhere to the following: • Use **capital letters** at the start of each word except directly following a hyphen • **Abbreviated forms** of words and combined words are preferred • **Words that end in 'ate':** For adjectives a 'd' is not required at the end of the word. For verbs a 'd' is required at the end of the word. • Combine words that: precede band, banded, bar, barred or blotched; or follow double, false or half; or precede line, lined, speckled, spine, spotted, streak or streaked. • 'Margin' (a noun) is used if the type or colour of the margin is defined (e.g., 'Brownmargin Flathead') • 'Margined' (an adjective) is used if it is stand-alone (e.g., 'Margined Coralfish') • Multi is usually combined (e.g., 'Multispot Lanternfish') • 'Shorthead' is one word (e.g., 'Shorthead Lamprey') • 'Spangled' not 'spangle' (e.g., 'Spangled Emperor')	Candidate name is consistent with these protocols	

Justification and Consultation (Applicant to Complete)

Justification: Summarise why the proposed standard fish names is needed and its benefits. The Western Australian Octopus Interim Managed Fishery is Australia's largest octopus fishery. It is only the 2nd octopus fishery in the world to be certified by the Marine Stewardship Council (MSC). Previously referred to as *Octopus tetricus*, common name Gloomy Octopus, or sometime Common Sydney Octopus, however scientific studies showed it to be a completely separate species. Thus the FRDC

funded "*Project No 2018-178 Species identification of Australia's most significant octopus fishery, the Western Australian Common Octopus*" was approved to give this octopus a species name and a common name. The outcomes of this project were: Species: *Octopus djinda* Standard Fish Name: Western Rock Octopus Please see two attached documents that detail the evidence for this being an endemic octopus species from WA. *Amor and Hart (2021)* *Amor et al (2014)*
Consultation: Summarize the responses of key stakeholders (Attach copies of written responses). Stakeholders in Western Australia were consulted, and an octopus naming working group was formed to deliberate on the appropriate species name and common name. The chosen name was Western Rock Octopus. Evidence of this consultation is given in the attached FRDC Milestone Reports, and a consultation presentation, as follows: *2018-178-Hart-MR3-due-31-Mar-21* *2018-178-Hart-MR2-due-30-Jun-20* *2018-178-Hart-MR1-due-08-Dec-19* *Species name WAFIC Dec 2019*
Impact of Consultation: Summarise any key changes made as a consequence of consultation. The new species name and common name has been adopted by the FRDC as the appropriate names in the most recent SAFS (State of Australian Fish Stocks) Report. Commercial operators have agreed to use the new names in their product placement and delivery, processes.

9.1 Formal notification of successful name

Ms Meaghan Dodd, the Project Manager for the Australian Fish Names standard, gave notice of the successful application to formally change the species and common name was received by DPIRD on 27th June 2022.

[EXT] - CONFIDENTIAL: Fish Names Application 344 Western Rock Octopus...

MD Meaghan Dodd <meaghan@intu

To Anthony Michael Hart

Cc Meaghan Dodd

27/06/2022

You replied to this message on 30/06/2022 1:22 PM.

CAUTION: This email originated from outside of DPIRD. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Dear Anthony,

NOT FOR CIRCULATION

The Fish Names Committee (FNC) met on the 1st of June 2022, where your application (344) for Western Rock Octopus (*Octopus djinda*) was discussed.

The FNC decision:

- Application 344 met the Standard requirement, including policies and procedures.
- Western Rock Octopus (*Octopus djinda*) has been approved by the FNC for the addition into the Australian Standard for Fish Names (AS 5300).

Please wait until this has been formally announced in the FNC e-newsletter before utilising and/or communicating this name. The e-newsletter will be published by COB 30 June 2022 at the latest. The name will be added to the fish names database www.fishnames.com.au after 30 June 2022.

Please get in touch if you have any further questions!

Kind regards,

Meaghan Dodd

Project Manager

Australian Fish Names Standards (AS 5300)

FNC@frdc.com.au

www.fishnames.com.au