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Extended abstract

Monitoring of major by-catch species in the Heard Island and McDonald Islands fisheries

James Dell[1,2✉], Gabrielle Nowara[2], Dale Maschette[1,2], Bryn Farmer[1,2], Emma Woodcock[1,2,3], Philippe Ziegler[2] and Dirk Welsford[2]

[1] Fisheries and Aquaculture Centre, Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Locked Bag 129, Hobart, Tasmania 7001, Australia

[2] Australian Antarctic Division, Department of Environment and Energy, 203 Channel Highway, Kingston, Tasmania 7050, Australia

[3] Current address: Tasmanian Seafood Industry Council, Hobart, Tasmania 7005, Australia

✉Corresponding author: james.dell@aad.gov.au

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Conservation of biodiversity and the sustainable use of living marine resources have been central management goals at Heard Island and McDonald Islands (HIMI) since Australian-managed commercial trawl, and later longline, fisheries for Patagonian toothfish (*Dissostichus eleginoides*) and a commercial trawl fishery for mackerel icefish (*Champsocephalus gunnari*) commenced in 1997. International high-seas fishing occurred in the region prior to the declaration of the Australian Fishing Zone (AFZ) and later exclusion economic zone (EEZ) around HIMI in 1979 (Duhamel and Williams, 2011). However, following these events, the science and management of the living marine resources at HIMI were initiated before the Australian fishery commenced in 1997, a rare occurrence in national and global fisheries. All activities within the Southern Ocean AFZ are governed by the *Australian Fisheries Management Act (1991)*, the *Environment Protection and Biodiversity Conservation Act (1999)* and the *Antarctic Marine Living Resources Conservation Act (1981)*, which establishes the processes for applying conservation measures of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) under Australian law. The key principles and critical developments in precautionary by-catch management at HIMI are summarised in the proceedings of the first Kerguelen Plateau symposium (Duhamel and Welsford, 2011). The Australian by-catch policy is based around the precautionary approach and risk minimisation. CCAMLR has previously identified three main steps to minimise by-catch: (i) avoidance, (ii) mitigation and (iii) the setting of sustainable by-catch limits if mortality is not preventable (SC-CAMLR-XXII, paragraph 5.230). There is a shared acknowledgement that by-catch should not unduly impede fishing operations.

Recently, the monitoring and management of non-target species caught as by-catch in fishing operations has been developed in parallel with environmental risk assessments on the effects of fishing (ERAEF) and is undertaken in all Australian Commonwealth fisheries (Hobday et al., 2011). In summary, the ERAEF process determines which elements of the ecosystem are most at risk using a data-dependent and precautionary three-stage hierarchical process: (i) low data qualitative, (ii) semi-quantitative, and (iii) a data-rich modelling stage. The fishery under review is assessed across five components: (i) target species, (ii) by-product and by-catch species, (iii) threatened and endangered species, (iv) habitats, and (v) ecological communities. The level of risk of each component is assessed and the hierarchical process determines the appropriate assessment required (Figure 1). The longline, midwater trawl and bottom trawl fisheries at HIMI have undergone the ERAEF process in 2007 and 2017 (Bulman et al., 2007a, 2007b; Daley et al., 2007; Bulman et al., 2018; Sporcic et al., 2018a, 2018b). The fishing records, fisheries and ecological research, management decisions and the ERAEF process constitute the structure of the management strategy evaluation cycle that has been developed to ensure management goals are met. Assessments of the target species are well reported in the CCAMLR literature. Here we briefly summarise the recommendations of the ERAEF processes for HIMI and the resultant by-catch research and management in the Australian

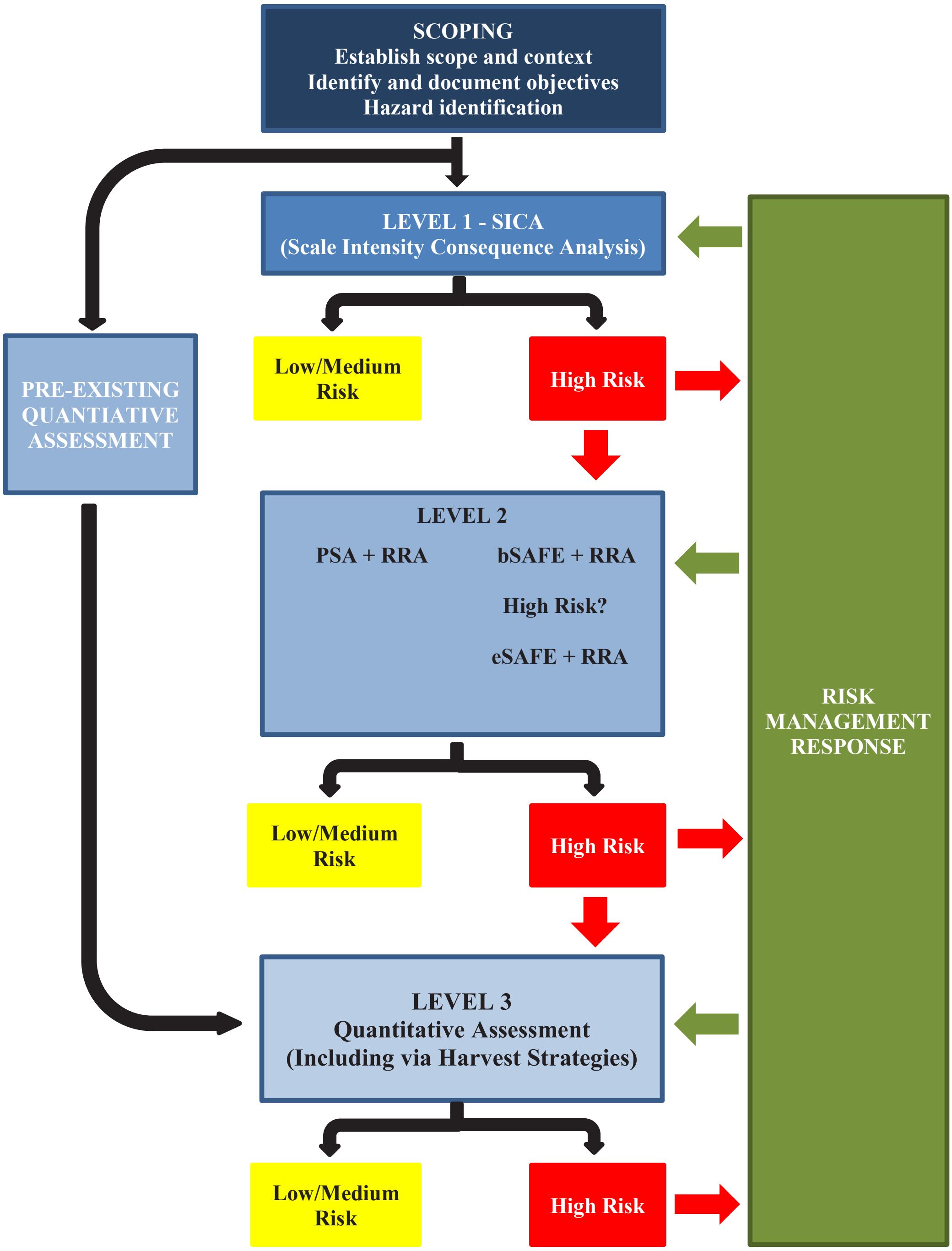

Figure 1: Structure of the three-level hierarchical ERAEF methodology. SICA – scale intensity consequence analysis; PSA – productivity susceptibility analysis; SAFE – sustainability assessment for fishing effects; RRA – residual risk analysis. T1 – Tier 1. eSAFE may be used for species classified as high risk by bSAFE. (Source: Bulman et al., 2018.)

region of the Kerguelen Plateau, the most recent stock assessments and management measures for those species deemed most at risk of unsustainable impacts of fishing. The species groups discussed below are: skates (*Bathyraja* spp.), grenadier (*Macrourus* spp.), unicorn icefish (*Channichthys rhinoceratus*) and grey rockcod (*Lepidonotothen squamifrons*).

In the first assessments in 2007, midwater trawl and longline were assessed as posing a minimal risk (Bulman et al., 2007a, 2007b; Daley et al., 2007). The demersal trawl was considered at a level 2 risk on the two of the three skate species at HIMI, *B. eatonii* and *B. murrayi*, while there was also concern for the impact of the fishery on sleeper sharks (*Somniosus* spp.). The existence of a large MPA, along with sensitive and precautionary fishing practices, were considered to mediate the impacts of fishing on vulnerable marine ecosystems, and high-risk, threatened, endangered and protected (TEP) species.

The precautionary approach to managing fishery impacts on by-catch species included from very early on both the calculation of by-catch limits for the main by-catch species, and move-on rules which prevent the continuation of fishing in an area where by-catch take has been high. More sophisticated assessment and management measures have been introduced as knowledge has increased over time. Here we briefly summarise the research and the development of management measures for by-catch in the trawl and longline fisheries at HIMI.

The first protections for by-catch were implemented by CCAMLR in 1995, in the form of a 'move-on rule' aimed at reducing local depletions. Vessels were required to move 5 n miles for a period of five days if catches of any individual by-catch species exceeded 5% of the weight of any one haul (Conservation Measures (CMs) 78/XIV and 89/XIV, 1995) (Tables 1 and 2). For skates (*Bathyraja* spp.), *C. rhinoceratus* and *L. squamifrons*, initial conservative catch limits allowing for greater than 75% escapement of by-catch, were recommended by CCAMLR, and calculated using a generalised yield model (GYM) (Constable et al., 1998) based on research surveys conducted in the early 1990s at HIMI. These were implemented as a conservation measure in the 1997/98 season (Table 2). This ensured that some species protection was in place even when little was known about the stocks. These measures were revised for *C. rhinoceratus* after an assessment using time-series data gathered from the fishery and annual random stratified trawl surveys (Maschette and Dell, 2015), resulting in a better understanding of the productivity of the stock and an increased catch limit implemented in the conservation measure (CM 33-02, 2015) (Tables 1 and 2).

Similarly, for macrourids, the finfish by-catch group most often caught by the longline fishery, initial conservative limits were introduced based on an analysis by van Wijk et al. (1999) on *Macrourus carinatus* productivity estimates from the near-by BANZARE Bank (Tables 2 and 3). Further work on the cryptic nature of the genus and the description of a new species in the Southern Ocean in 2010 (Smith et al., 2010) and at HIMI in 2015 (Dell et al., 2015) took into account the difficulties in distinguishing *Macrourus* species and suggested the catch be assessed for two morphs based on biological and spatial characteristics. The first morph containing *M. caml* and *M. whitsoni* characterised by smaller body size, higher pyloric caeca counts, and shallower depth distribution, and the second morph with *M. carinatus* and *M. holotrachys* (SC-CAMLR-XXXIV, Annex 7, paragraphs 8.17 to 8.23). These findings built of the previous work and influenced changes to the conservation measures, shifting from a limit applying to four species of the same genus to two limits for species morphs sharing similar biological characteristics (Tables 2 and 3).

After initial catch limits were established for skates, research has continued into the biology and impacts of fishing. A study of the three species of skates taken (*B. eatonii* and *B. murrayi* from trawl fisheries, and *B. irrasa* in the longline fishery) updated the knowledge of the distribution and abundance of skates to the end of 2014 (Nowara et al., 2017). Results showed that overall abundance did not appear to be impacted for the two species taken by trawl, however, the abundance of *B. irrasa* which is taken by the longline fishery has shown a decline and only stabilised in the later years of the study (Tables 2 and 4). Frequency and numbers of sleeper shark by-catch remain too low for a reliable population study, however, the importance of these species to the functioning of a healthy ecosystem is recognised and monitoring continues within the fishery (Stevens et al., 2000; van Wijk et al., 2003).

Australian scientists have been proactive in continuing research into by-catch species beyond that recommended in the first ERAEF (Table 5). A national fishery review in 2013 recognised the low finfish by-catch at HIMI (Tuck et al., 2013) as did the 2016 ERAEF where no management response or level 2 assessment was required for skates, grenadier or rockcod (Bulman et al., 2018; Sporcic et al., 2018a, 2018b). The monitoring of ecologically sensitive habitats, fish populations and TEP species is ongoing at HIMI and the research conducted by the Fisheries and Ecosystem management branch at the AAD continues to support the ecosystem-based fisheries management of the region. These measures, employed by the Australian Fisheries Management Authority (AFMA) within the CCAMLR framework, are considered best-practice resource management of by-catch species in the Southern Ocean (Constable, 2011; Nilsson et al., 2016). A global assessment of the health and services people expect of oceans, quantitatively assessed in an Ocean Health Index (Halpern, 2019),

Table 1: Research on finfish by-catch species taken in the trawl fisheries for Patagonian toothfish and mackerel icefish fisheries at HIMI.

Year	Reference	Species	Research outcome
1995	Williams and de la Mare (1995)	- *Champsocephalus gunnari* - *Channichthys rhinoceratus* - *Dissostichus eleginoides* - *Lepidonotothen squamifrons*	Initial species abundance estimates, length and spatial distribution based on trawl surveys in 1990, 1992 and 1993.
1998	Constable et al. (1998)	- *Channichthys rhinoceratus* - *Lepidonotothen squamifrons* - *Bathyraja* spp.	Initial sustainable yields for by-catch around HIMI using either survey data or proximate estimates for the biological data using the generalised yield model: *Bathyraja* spp. = 50–210 tonnes *Channichthys rhinoceratus* = 62–87 tonnes *Lepidonotothen squamifrons* = 7–991 tonnes.
2012	Nowara et al. (2012)	- *Channichthys rhinoceratus* - *Lepidonotothen squamifrons*	Catch-per-unit-effort (CPUE) trends for the two main by-catch species in the HIMI trawl fisheries
2015	Maschette and Dell (2015)	- *Channichthys rhinoceratus*	Updated assessment based on data from the 2015 random stratified trawl survey, age–length keys and estimated spatially specific biological parameters, and estimation of short and long-term sustainable yield.

Table 2: Conservation measures employed as a result of research into by-catch at HIMI.

Fishing season	Conservation measure	Description
1995/96	CM 78/XIV, CM 89/XIV	If the by-catch in any one haul of *Lepidonotothen squamifrons, Notothenia rossii, Channichthys rhinoceratus* or *Bathyraja* spp. exceeds 5% of total catch by weight, the fishing vessels must move to another fishing location at least 5 n miles distant and not return for five days.
1996/97	CM 109/XV, CM110/XV, CM111/XV	Catches not to exceed 50 tonnes for species not otherwise specified. Otherwise same as previous year.
1997/98	CM 132/XVI	By-catch on *Bathyraja* spp. shall not exceed 120 tonnes. By-catch on *Channichthys rhinoceratus* shall not exceed 80 tonnes. Otherwise same as previous year.
1998/99	CM 157/XVII	By-catch on *Bathyraja* spp. shall not exceed 120 tonnes. By-catch of *Channichthys rhinoceratus* shall not exceed 150 tonnes. By-catch of *Lepidonotothen squamifrons* shall not exceed 80 tonnes. By-catch of fish species not specified shall not exceed 50 tonnes. If the catch of any by-catch species in any one haul exceeds 2 tonnes fishing is excluded within 5 n miles for five days. Otherwise same as previous year.
2000/01	CM 198/XIX	Skates and rays to be considered a single species (50 tonne limit). Otherwise same as previous year.
2001/02	CM 224/XX	*Macrourus* spp. to considered as a single species (50 tonne limit) Non-specified by-catch move-on-rule trigger reduced to 1 tonne. Otherwise same as previous year.
2002/03	CM 33-02 (2002)	By-catch of skates and rays shall not exceed 120 tonnes. By-catch of *Macrourus* spp. shall not exceed 465 tonnes. Catch of other by-catch species not specifically mentioned (e.g. other elasmobranchs) shall not exceed 50 tonnes. If the catch of specified by-catch species in any one haul exceeds 2 tonnes fishing is excluded within 5 n miles for five days. For by-catch species not specifically named, the move-on rule is triggered by 1 tonne. Otherwise same as previous year.
2003/04	CM 33-02 (2003)	*Macrourus* spp. by-catch limit set at 360 tonnes otherwise same as previous year.
2005/06	CM 33-02 (2005)	*Somniosus* spp. now included in the 2 tonne limit move-on rule. Otherwise same as previous year.
2015/16	CM 33-02 (2015)	Catch limit of *Channichthys rhinoceratus* shall not exceed 1 663 tonnes. Catch limit of *Macrourus* spp. recognised as two groups: by-catch of *Macrourus caml* and *Macrourus whitsoni* shall not exceed 409 tonnes; by-catch of *Macrourus holotrachys* and *Macrourus carinatus* shall not exceed 360 tonnes. Trigger weight for move-on-rule has changed to: 5 tonnes for *Channichthys rhinoceratus*; 3 tonnes for all *Macrourus* spp., otherwise by-catch provisions are the same as preceding 10 years.
2017/18	CM 33-02 (2017)	Same as previous year(s).

Table 3: Research on finfish by-catch species taken by the longline fisheries at HIMI.

Year	Reference	Species groups	Research outcome
1999	van Wijk et al. (1999)	*Macrourus carinatus*	First assessment of a *Macrourus* species from samples taken from a trawl survey of BANZARE Bank, within the region of the Kerguelen plateau. The generalised yield model (GYM) was used to determine the long-term precautionary yield of this species. Mean densities of catch rates were calculated. These findings contributed to the CCAMLR Conservation Measure 33-02 adopted in 2003.
2000	Constable et al. (2000)	All by-catch	Paper outlines the appropriate use of the precautionary approach to fisheries management in the context of CCAMLR. The need for a clear and orderly development of a feedback-management framework for any proposed fisheries undertaken by Member and non-Member States within the CCAMLR region.
2002	van Wijk and Williams (2002)	All by-catch	Review of the monitoring of fishing operations with respect to by-catch. The paper presented a calculation of total by-catch removals. This review determined that the risk to by-catch populations from fishing operations at HIMI was low.
2002	van Wijk et al. (2002)	*Macrourus carinatus*	Age range of *M. carinatus* was estimated from 156 otolith samples and was found to be 4–25 years. Sexual maturity estimated from *M. carinatus* caught at HIMI in 2000. Length and weight relationship calculated from HIMI and Macquarie Island samples and no difference was found between the results of each region.
2003	van Wijk et al. (2003)	*Macrourus carinatus*	Peer reviewed version of the CCAMLR working group paper.
2012	McMillan et al. (2012)	*Macrourus caml*	Details first recording of a fourth *Macrourus* species in the Southern Ocean and the subsequent modifications to the identification keys.
2015	Dell et al. (2015)	*Macrourus caml* *Macrourus whitsoni* *Macrourus carinatus* *Macrourus holotrachys*	Confirms the existence of *Macrourus caml* on Kerguelen Plateau, in the HIMI fishery. The cryptic nature of species-level identification of these macrourid species is noted. Von Bertalanffy parameters estimated and a sustainable catch estimated using the GYM (409 tonnes). Recommendation that the other macrourid species that have not had the same substantive study of population parameters should have a reduced catch limit.

Table 4: Research and management measures for elasmobranchs at HIMI for both trawl and longline gears.

Year	Reference	Species groups	Description
1990–1993	Williams and de la Mare (1995)	All by-catch species	Fish distribution and abundance surveys before commercial fishing commenced. Skates were one of five species seen in sufficient abundance to warrant further study.
1998	Constable et al. (1998)	*Bathyraja* spp. *Channichthys rhinoceratus,* *Lepidonotothen squamifrons*	Preliminary stock assessment for by-catch species at HIMI using a GYM model calculated basic demographic parameters and a range of sustainable catch limits for: *Bathyraja* spp. = 50–210 tonnes *Channichthys rhinoceratus* = 62–87 tonnes *Lepidonotothen squamifrons* = 7–991 tonnes.
2005	van Wijk and Williams (2005)	*Bathyraja eatonii* *Bathyraja irrasa*	First estimates of some biological parameters for *B. eatonii* and *B. irrasa* at HIMI calculated.
2013	Nowara et al. (2013)	*Bathyraja eatonii* *Bathyraja irrasa* *Bathyraja murrayi*	Skate tagging found that skates were recaptured on average only 4 n miles from their release site. The longest distance was 23 n miles.
2017	Nowara et al. (2017)	*Bathyraja eatonii* *Bathyraja irrasa* *Bathyraja murrayi*	Published study of distribution and abundance of the three commonly taken skate species at HIMI up to 2014. It includes estimates of skates caught on the line but cut off and returned to the water. The study found that catch rates of the two species commonly taken in trawl fisheries on the HIMI Plateau, *B. eatonii* and *B. murrayi*, were increasing in recent years. However, the average total length (TL) of *B. eatonii* has decreased over the duration of the fishery, suggesting that fishing may be having an effect, unless the increase is due to a pulse of recruitment. Over the same time, the smaller species, *B. murrayi*, has shown an increase in average TL. One possible explanation is that there is a shift from the larger to the smaller species, due to competitive release, as has been shown for skate species in other fisheries (Walker and Hislop 1998; Dulvy et al., 2000). *Bathyraja irrasa*, taken mainly in the longline fishery, has shown a decline in abundance, stabilised in more recent years.

Table 5: Ecological risk assessment of the HIMI fisheries. Comparison of recommendations for finfish by-catch requiring further evaluation from the first and second assessments. Coloured cells relate to the level of risk: red = high, orange = medium, green = low.

Fishery	Species of greatest concern	ERA 1 risks identified	Recommendation	AAD response	ERA2 risks recommendation	AAD response
Demersal trawl	Skates *Bathyraja irrasa* *Bathyraja eatonii* *Bathyraja murrayi*	High risk – Low fecundity/spatial uncertainty	Investigate post-capture survival, continue data collection Collect reproductive and ageing data Develop strategy in conjunction with other HIMI fisheries	Completed spatial distribution analysis and abundance estimate for skate species Recalculated length and maturity for skate species	Low risk profile. No level 2 risk issues	Continue monitoring
	Sharks Sleeper sharks (*Somniosus* spp.)	High risk – Low fecundity/spatial uncertainty	Investigate post-capture survival, develop yield estimate	Continue to collect data		Continue to collect data
	Grenadier *Macrourus holotrachys* *Macrourus carinatus* *Macrourus whitsoni* *Macrourus caml*	Medium risk Missing data Spatial uncertainty Spatial uncertainty	Improve understanding of population ecology	Complete quantitative assessment for species where suitable biological data available	Level 3 quantitative assessment already in place	Continue monitoring
	Icefish Channichthys rhinoceratus	Medium risk Spatial uncertainty	Improve understanding of population ecology	Complete quantitative assessment	Level 3 quantitative assessment already in place	Continue monitoring
	Grey rockcod *Lepidonotothen squamifrons*	High risk Low productivity Widely distributed	Improve understanding of population ecology	Complete quantitative assessment	Level 3 quantitative assessment already in place	Continue monitoring
Midwater trawl	Porbeagle *Lamnus nasus*	High risk – low fecundity/spatial uncertainty	Improve data collection to determine local productivity		Low risk profile. No level 2 risk issues	Continue monitoring

(continued)

Table 5 (continued)

Fishery	Species of greatest concern	ERA 1 risks identified	Recommendation	AAD response	ERA2 risks recommendation	AAD response
Longline	Skates and sharks *Bathyraja irrasa* *Bathyraja eatonii* *Bathyraja eatonii* *Bathyraja murrayi* *Bathyraja georgiana* *Etmopterus granulosus* *Somniosus* spp.	High risk – low fecundity/spatial uncertainty	Investigate post capture survival Collect reproductive and aging data Develop yield estimates	Completed spatial distribution analysis and abundance estimate for skate species Recalculated length and maturity for skate species	Low risk profile. No level 2 risk issues	Continue monitoring
	Grenadier spp. *Macrourus holotrachys* *Macrourus carinatus* *Macrourus whitsoni* *Macrourus caml*	Medium risk Spatial uncertainty		Completed quantitative assessment for species where suitable biological data available	Low risk profile. Level 3 assessment already in place	Continue monitoring

recognised HIMI as one of the best-ranked EEZs in the world (http://www.oceanhealthindex.org/region-scores/scores/heard-and-mcdonald-islands).

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