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Assessing changes in threatened black rockcod *Epinephelus daemelii* abundance and length over the past 15 years in New South Wales, Australia

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Abstract

Ideally, protection of a threatened fish will lead to their recovery in abundance, distribution, and size structure within the population, to a point where they are no longer considered threatened. Monitoring abundance and size is crucial to evaluate this, although low numbers associated with being threatened can strongly constrain the methods used. To assess if population recovery is occurring for the black rockcod *Epinephelus daemelii*, a large subtropical grouper endemic to shallow reefs in the southwest Pacific, surveys were undertaken across northern New South Wales and Lord Howe Island using roving diver timed counts and diver stereo-video measurements to assess relative abundance and length. Surveys in 2023 were compared with initial baseline data captured in 2009–2011 using the same methods. Relative abundance of *E. daemelii* at long-term monitoring sites has remained relatively constant or declined since 2010 rather than increasing. Comparisons between 84 broadscale sites in 2009–2011 versus 2023 (117 vs. 69 observed *E. daemelii*) indicate a recent decline in abundance. Although protected from fishing and spearfishing for over 40 years, the relative abundance of *E. daemelii* does not appear to be increasing over the past 15 years since monitoring commenced. This is a concerning trend that does not indicate recovery, although an increase in the proportion of mature females in the population from 2010 to 2023 is positive. As *E. daemelii* is slow growing, long lived, late to mature and still susceptible to incidental capture mortality, more active management may be needed to help assist with the slow recovery of this threatened species.

KEYWORDS
Cod, Grouper, Serranidae, Threatened Species, Marine Protected Areas

1 | INTRODUCTION

The impacts of fishing, both targeted and indirect, have caused numerous fish species globally to experience population declines, with many ending up on local and international threatened species lists. One group of fishes that is very susceptible to overfishing is the cods and groupers from the Serranidae family (Amorim et al., 2019; Sadovy de Mitcheson et al., 2012). Life-history traits for this group of fishes, such as slow growing, late maturity, and often being long lived, hinders the recovery of species when populations decline. Species such as the Nassau grouper *Epinephelus striatus* (Bloch, 1792), the Galapagos grouper *Mycteroperca olfax* (Jenyns, 1840), the Hong Kong grouper *Epinephelus akaara* (Temminck & Schlegel, 1842), and the Gulf grouper *Mycteroperca jordani* (Jenkins & Evermann, 1889) are just some examples of Serranids that have undergone large declines in abundance as a result of overfishing (Bacheler & Ballenger, 2018;

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Bernard et al., 2016; Sáenz-Arroyo et al., 2005; To & De Mitcheson, 2009; Usseglio et al., 2016), and have subsequently been listed as Endangered species on the IUCN Redlist. In addition to those listed as Endangered, there are numerous other Serranids listed as Vulnerable or Near Threatened (IUCN, 2024), with the primary driver of their decline being overfishing.

One such Serranid species considered to be under threat is the black rockcod *Epinephelus daemelii* (Gunther 1876), a southwestern Pacific Ocean endemic that is also commonly known in Australia as black cod and in New Zealand as the spotted black grouper (Francis, 2024). Globally, the species is currently listed under the IUCN Red List as Near Threatened (Pollard & Sadovy de Mitcheson, 2018). Over 100 years ago, this species was considered widespread and abundant across New South Wales (NSW), Australia (Roughly, 1916), the most western part of its range. However, from the 1950s through to the late 1970s, spearfishers at various locations along the NSW mainland coastline heavily targeted this species (Andrewartha & Kemp, 1968; Young et al., 2015) because it is considered an excellent eating fish (Francis et al., 2016); for example in 1976, 137 were caught in spearfishing competitions (Smith et al., 1989). Concentrated spearfishing effort, combined with line fishing impacts, led to a noticeable decline in *E. daemelii* numbers within NSW. As a result, NSW Fisheries were approached by concerned divers to protect the species in the late 1970s. Even though there was limited information on *E. daemelii* available at the time, it was recognized as being under threat, and the species was afforded total protection in NSW in 1983. This new level of protection prevented the species from being legally taken by any means of fishing.

This fish species is a large and long-lived reef-dwelling species growing up to approximately 1.7 m in total length and living for up to 65 years (Francis et al., 2016). It has a restricted distribution, occurring in the subtropical to warm temperate southwest Pacific: NSW, southern Queensland, Lord Howe Island, and Elizabeth Middleton Reefs in Australian waters, the Kermadec Islands and northern New Zealand/Aotearoa (Choat et al., 2006; Francis et al., 2016). The species is considered to be common at Elizabeth Middleton Reefs, a remote Australian Commonwealth Marine Park, where it is found occurring in the shallow lagoons and surrounding deeper waters, and is considered a key predator on these reefs (Brown et al., 2022). It is also considered abundant at the Kermadec Islands, a remote marine park in New Zealand territorial waters. They are a protogynous hermaphrodite that change sex from female to male at about 100–110 cm and females become sexually mature at about 70 cm (Francis et al., 2016). Spawning and fertilization of eggs is external in the water column, with a pelagic larval transport phase.

From 2009 to 2011, a research program for *E. daemelii* in NSW was implemented, assessing the species relative abundance and size across northern NSW and Lord Howe Island (Harasti & Malcolm, 2013). As part of the study, baseline monitoring sites for *E. daemelii* were established, as well as a subset set of key sites for more regular monitoring that were considered key locations where *E. daemelii* were found to occur. It found that adult fish are found in complex reef habitats with caves and overhangs down to depths of at least 40 m (Harasti & Malcolm, 2013). Whilst no juveniles were found in these initial surveys along the NSW coast, a study by Harasti et al. (2014) on intertidal rock pools along the NSW coast found that juvenile *E. daemelii* (up to 30 cm total length) were found to occur in these shallow dynamic environments.

In 2023, diving surveys were undertaken of the baseline monitoring sites established in 2009–2011 to assess any changes in relative abundance, relative distribution, and length structure of *E. daemelii* in mainland NSW and Lord Howe Island over the past 15 years. In addition, surveys of key monitoring sites were undertaken most years between 2010 and 2024 to assess if their size and abundance at known locations varied through time. These findings provide an insight into whether the protection measures being implemented across NSW, such as total protection from being taken by any fishing and spatial protection in no-take zones, are helping promote the recovery of this threatened species.

2 | METHODS

The initial 2009–2011 broadscale survey of 83 sites was undertaken in northern NSW (Port Stephens to Cook Island) and Lord Howe Island (Figure 1), recording a total of 117 *E. daemelii* occurring at 34 of the 83 sites (41% of sites) surveyed, as reported in Harasti and Malcolm (2013). These 83 sites were resurveyed in 2023 by the same authors to assess the relative abundance and lengths of *E. daemelii*. Based on the initial broadscale survey results in 2009–2011, a total of 12 key sites in northern NSW were selected for ongoing monitoring. These 12 key sites were monitored annually most years (11 out of 15 years) between 2009 and 2024. These years were 2010, 2011, 2012, 2013, 2014, 2018, 2019, 2020, 2021, 2023, and 2024 and the key sites surveyed included four sites in the Solitary Islands Marine Park (SIMP) (North Solitary Anemone Bay, North-West (NW) Rock, South Solitary Island west side, South Solitary north side), seven sites in the Port Stephens Great Lakes Marine Park (PSGLMP) (Latitude Rock, Forster Pinnacle, Big Seal Rock, Little Seal Rock, Outer Edith Breaker, Fingal Island north side, Little Broughton Shark Gutters and Looking Glass Island), and the cave system/southern end of Fish Rock at South-West Rocks (SW Rocks).

Surveys involved both, or either, authors swimming along each site for up to 45 min searching for *E. daemelii* and recording any individuals, as well as estimating their length, the habitat they were found in, the depth range surveyed, the depth that individual *E. daemelii* were found at, and if the fish sighting was cryptic (i.e., hidden from initial view or camouflaged) (as per Harasti & Malcolm, 2013). For some of the deeper sites (25+ m), the timed swim was limited to approximately 30 min to stay within no-decompression limits.

The Underwater Visual Census (UVC) technique of diver roving timed counts is a widely adopted method for fish surveys (Kingsford & Battershill, 1998) and has been more fully described as a successful method for *E. daemelii* (Harasti & Malcolm, 2013). It is a useful method in diving depths where a species is rare and unlikely to be detected using belt-transect UVC methods. The habitat where

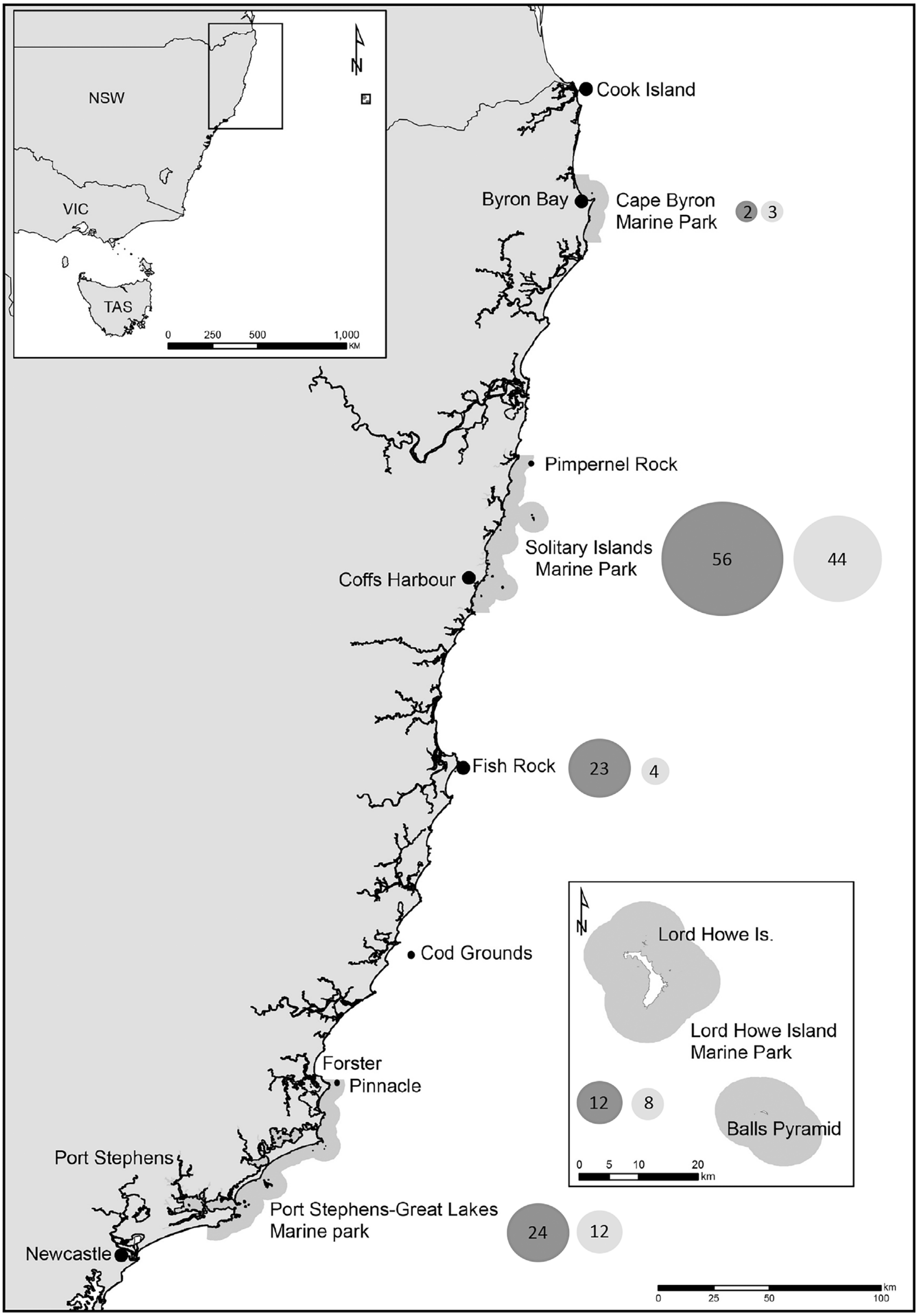

FIGURE 1 Location of Marine Parks and *Epinephelus damelii* survey locations across New South Wales (NSW), including Lord Howe Island. VIC, Victoria; TAS, Tasmania. Bubbles next to Marine Parks location and Fish Rock indicate the total number of observed *E. daemelii* on broadscale surveys in 2009–2011 (dark bubble) and 2023 (light bubble).

each fish was recorded was described based on topographic structure and this included categories such as cave, overhang, coral, swim-through, wreck, gutter, and boulders. Divers followed the topography of the reef to a maximum depth of 30 m and searched any caves or overhangs that they came across on the dive. Divers carried a dive torch to search in caves and overhangs for any hiding *E. daemelii*.

The timed swim method has proven to be much more practical for *E. daemelii* surveys compared to other methods such as transects and baited remote underwater videos (Harasti & Malcolm, 2013) because it allows divers to thoroughly search key habitats such as caves and overhangs. Notably, the same divers (both authors) have undertaken all the surveys from 2009 to 2024, thus reducing any potential observer bias between surveys. Additionally, as it has been the same divers for the surveys, the general search route for each site has been consistent to ensure the same areas of reef were surveyed each time.

For each *E. daemelii* sighting, the length of the fish was visually estimated (by both authors where possible) in centimeters. Where possible, the fish was also filmed using a diver stereo system (SeaGIS Pty. Ltd) to obtain an exact length measurement as per Harasti and Malcolm (2013). The diver stereo-video system used in 2023 consisted of two GoPro Hero 6 cameras on a base bar that had been calibrated as per standard operating procedures (Langlois et al., 2020). Measuring individual fish using the diver stereo system was only possible where a side profile was videoed with the fish stretched straight and the full image of the fish appearing simultaneously in both cameras. In many cases, this was not possible due to fish being within a constrained habitat (such as a cave or crevice) and maintaining a head-on profile to the diver, or due to the fish taking off when observed before effective video was taken. If a stereo measurement was not possible, then the diver estimated length was used as per Harasti and Malcolm (2013).

Data analyses were predominantly descriptive due to the low abundance of this species, with many sites surveyed having zero counts of *E. daemelii*. Analysis of variance was used to compare the mean abundance of *E. daemelii* per site and the total length of *E. daemelii* between the initial broadscale survey in 2009–2011 and the survey conducted in 2023. Differences in length distributions between the first and second sets of broadscale surveys were compared using the Kolmogorov–Smirnov test. This test calculates the maximum distance between two cumulative distributions (test statistic D) and determines a corresponding p value, with significant p values (<0.05) indicating differences in their relative cumulative length distributions.

Comparison of fished and no-take sites for the two broadscale surveys was carried out using PERMANOVA in PRIMER, where management type (fished and no-take sanctuary zone) was fixed and period (period 1 2009–2011, period 2 2023) was treated as fixed. In 2009–2011, there were 43 sites in the no-take sanctuary zone and 40 sites in areas that could be fished. In 2023, there were 46 sites in the no-take sanctuary zone and 45 sites in areas that could be fished. The broadscale surveys were undertaken temporally at either end of our overall 15-year monitoring study. Data were square-root transformed and analyzed using a Bray–Curtis resemblance matrix with a dummy variable added to avoid undefined resemblances between samples.

3 | RESULTS

The broadscale survey sites were resurveyed in 2023 with a total of 66 *E. daemelii* observed at 27 of the 83 original sites (32% of sites). There has been a recorded reduction of 43% in the relative abundance of *E. daemelii* at the broadscale survey sites over the past 15 years, although this decline was not significant based on the mean number observed per site ($F_{1,164} = 2.95$, $p > 0.05$). There was also an 8% reduction in the proportion of sites where *E. daemelii* were observed (40% of sites reduced to 32% of the original 83 sites). The abundance of *E. daemelii* was seen to decline across most locations over the past 15 years, with the declines most evident in the PSGLMP and at Fish Rock, located at SW Rocks (Figure 1).

The total length of *E. daemelii* significantly increased from the initial broadscale survey in 2009–2011 to the survey conducted in 2023 ($F_{1,184} = 12.18$ $p < 0{\cdot}01$). The mean length of *E. daemelii* recorded in 2023 was 90.5 ± 2.9 cm standard error (SE) compared to 77.9 ± 2.8 SE in 2009–2011. This increase was found across all marine parks surveyed and at Fish Rock (Figure 2). The mean largest fish for both surveys were of similar lengths in Cape Byron, Solitary Island, and Fish Rock in 2023, whilst the mean smallest fish were observed at Lord Howe Island for both surveys.

There was an increase in the overall proportion of larger fish from the first (2009–2011) to the second (2023) broadscale survey. The length class with the most individuals in 2009–2011 was 60–70 cm, which is subadult. In 2023, the length class with most individuals was 90–100 cm, which is large mature females (Figure 3). A Kolmogorov–Smirnov test comparing these two length frequency distributions (2009–2011 vs. 2023) indicated a significant difference between the two distributions ($p < 0.001$).

PERMANOVA comparison of fished and no-take sites for the two broadscale surveys shows a significant difference between management type (no-take vs. fished areas) where P(perm) <0.05 and where period (2009–2011 vs. 2023) is non-significant, P(perm) = 0.14, and the interaction between management type and period is non-significant, (P(perm) = 0.52). The significant difference for management type was due to a higher average abundance in the no-take zones than in fished areas. Although the average was reduced in 2023 in both management types relative to the averages in those management types in 2009–2011, the difference between management types was consistent in each survey period (Figure 4). Of interest is that the difference between 2009–2011 and 2023 is more visually apparent (standard error bars fully separated) in fished areas than no-take zones, suggesting a potential stronger decline in fished areas over that period, although the interaction was not statistically significant.

Twelve key sites were surveyed regularly in the PSGLMP and SIMP with 11 years sampled over the 15-year period from 2010 to 2024 (Figure 5). These 12 sites enable a temporal comparison of

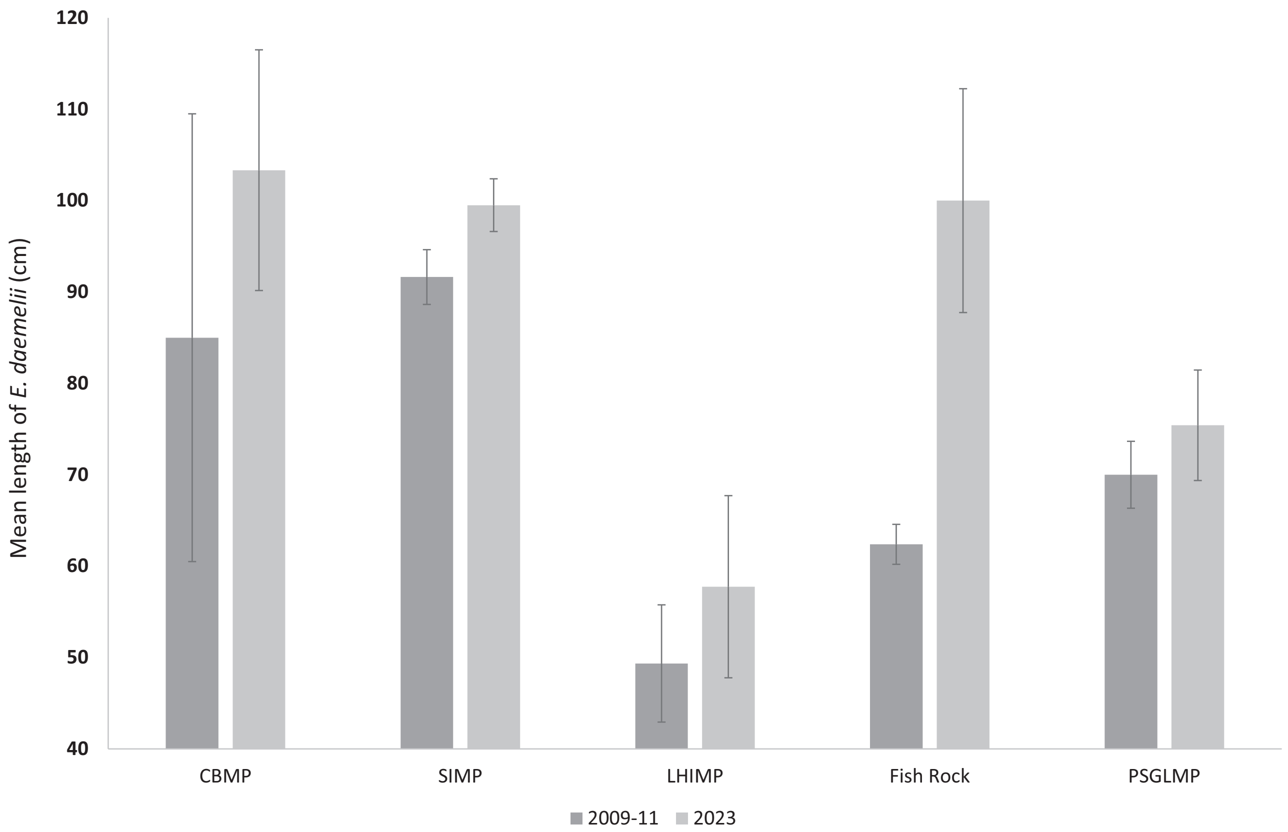

FIGURE 2 The mean length (cm, bars indicate standard error) of observed *Epinephelus daemelii* for the broadscale surveys conducted in 2009–2011 and in 2023. CBMP, Cape Byron Marine Park; LHIMP, Lord Howe Island Marine Park; SIMP, Solitary Islands Marine Park.

counts that indicate a trend in relative abundance at important *E. daemelii* sites. Relative abundance was stable across years until 2021, when it showed a slight decrease, with the lowest abundance recorded in total at these 12 sites. Numbers have started to increase again since the low record of 2021 with more in 2024 than 2023, but still less than was recorded in counts at these sites between 2010 and 2020 (Figure 5). A PERMANOVA test comparing years was not significant overall as most years did not differ. Although there was a noticeable drop in abundance in 2021, it did not cause a significant change in relative abundance over the 15-year period.

Lord Howe Island key sites have been surveyed in 4 years spanning the 15-year period and initially declined in both 2019 ($n = 6$ observed) and 2023 ($n = 8$) following the benchmark survey in 2011 ($n = 12$). However, the highest number of *E. daemelii* was recorded in the most recent survey in 2024 with 14 individuals sighted.

4 | DISCUSSION

Although *Epinephelus daemelii* has been protected in NSW since 1983, this current study indicates that the species is showing little evidence of recovery over the past 15 years. The relative abundance of *E. daemelii* was observed to decrease by 43% over the two survey periods, and the number of sites where *E. daemelii* were found to occur in the 2023 surveys had also reduced. These declines are most evident at sites within the Port Stephens-Great Lakes Marine Park (PSGLMP) and Fish Rock at SW Rocks. Whilst there was a reduction in the numbers of *E. daemelii* at Lord Howe Island in the 2023 broadscale site surveys, the abundance in 2024 of 14 observed fish was comparable with that initially observed in 2011 ($n = 12$). The highest total count at Lord Howe Island was recorded in 2024, after the lowest observed in 2019 ($n = 6$), indicating that there is hope for ongoing recovery occurring in the waters of Lord Howe Island.

When compared with observations by spearfishers and captures of *E. daemelii* from the 1950s and 1960s (Andrewartha & Kemp, 1968), the abundance of *E. daemelii* observed during the 2023 and 2024 surveys indicates that the species is a long way off from recovering to the historical abundances of over 50 years ago. Oral history records (Johnstone, 2022) and historical photographs from Lord Howe Island also suggest *E. daemelii* were considerably more abundant in the mid-twentieth century (Francis et al., 2016). Some of the highest counts for *E. daemelii* were at Fish Soup (NW Rock, Solitary Islands) in 2012, with 18 individual fish recorded and 16 recorded in 2018. However, one oral history record indicates there used to be many more individuals at this site: "…one fisherman caught 40 black rockcod at Fish Soup back in the sixties" (Johnstone, 2022).

One positive finding from the 2023 broadscale surveys is that the mean length for observed *E. daemelii* was found to significantly

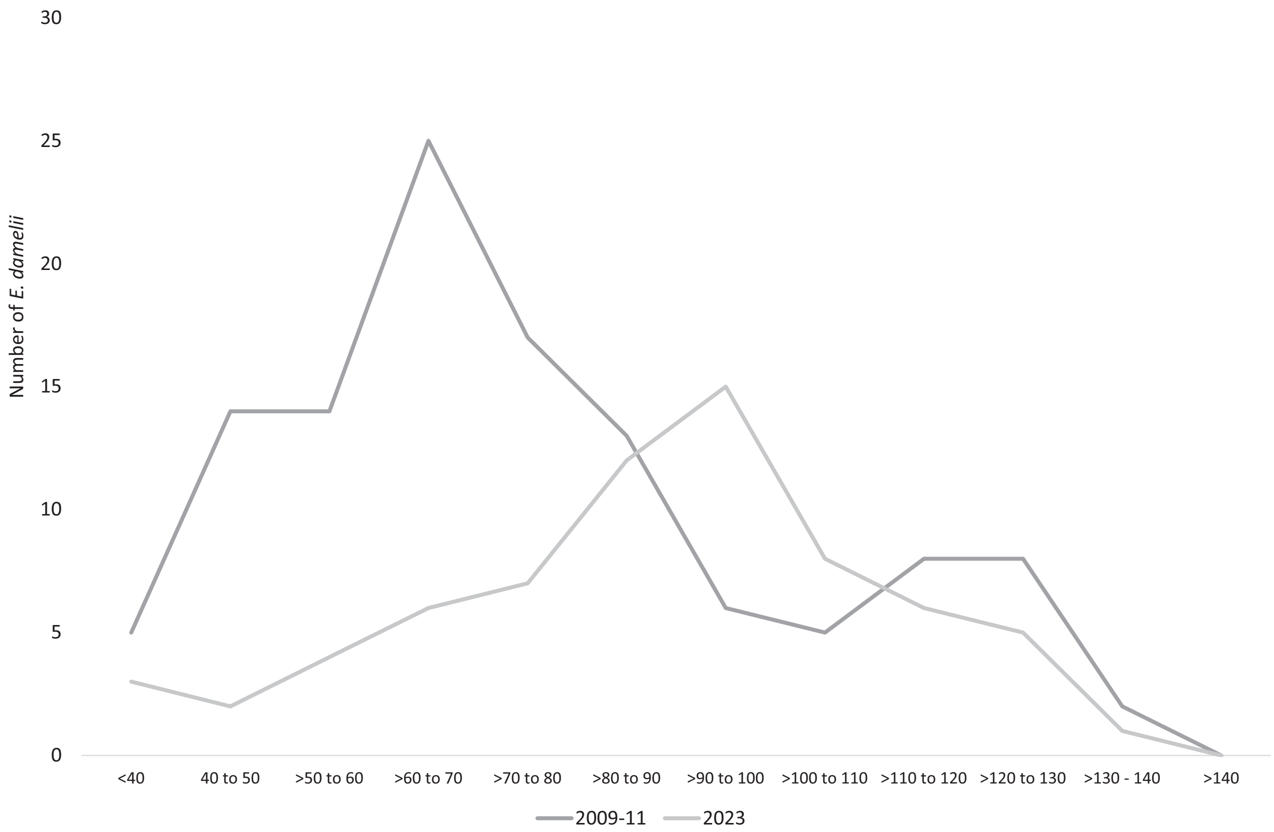

FIGURE 3 Length frequency by 10-cm bins of observed *Epinephelus daemelii* for the broadscale surveys conducted in 2009–2011 and in 2023, with the actual number of fish in each length class bin.

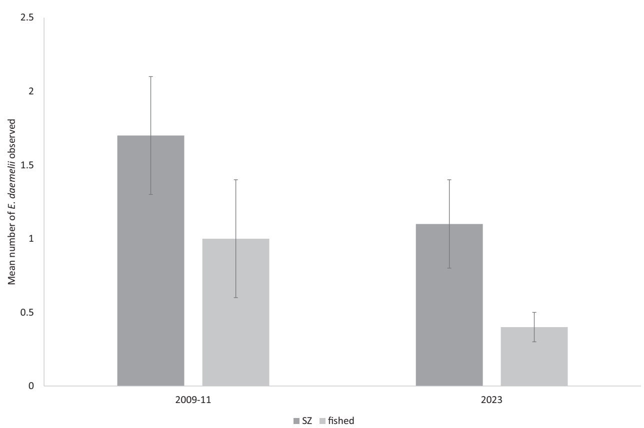

FIGURE 4 Average number (± standard error) of *Epinephelus daemelii* counted per site by management type (no-take sanctuary zone, fished areas) and by period (2009–2011, 2023).

increase from 2009–2011 to 2023. The relative proportion of mature-sized females also increased, with the peak in the length structure of observed individuals being from 90 to 100 cm. *E. daemelii* is considered to change sex from female to male at approximately 100–110 cm in length (Francis et al., 2016), and in the 2023 broadscale surveys almost half of the fish observed were greater than 100 cm in length. As more fish reach maturity, this will hopefully lead to more breeding for the species improving the likelihood of recovery.

The lack of juvenile fish seen during these surveys is not surprising given it has been shown that juvenile *E. daemelii* are found in inshore environments, particularly rock pool habitats (Harasti et al., 2014). This project did not assess the inshore habitats where juvenile *E. daemelii* are known to occur so an assessment on whether recruitment is occurring within the population is difficult to determine. However, given there were numerous observations in 2023 and 2024 of subadult fish at some locations, particularly small fish (≈18–40 cm) observed at several sites around Lord Howe Island, it is an indicator that recruitment in the species is occurring, although to provide a better understanding of recruitment in eastern Australia, juvenile habitats like rockpools and estuarine reefs and breakwalls would need to be surveyed.

The monitoring of the 12 key sites indicated that there had been no significant changes in the relative abundance of *E. daemelii* through time, although the overall trend was flat to declining. Although there was an observed strong decline in the number of fish observed in 2021, the abundances observed in 2023 and 2024 were more positive. The potential low abundance recorded in 2021 may have been related to the significant flood events along the east coast of Australia that were found to cause significant habitat declines along the NSW coast (Davis et al., 2022; Larkin et al., 2024).

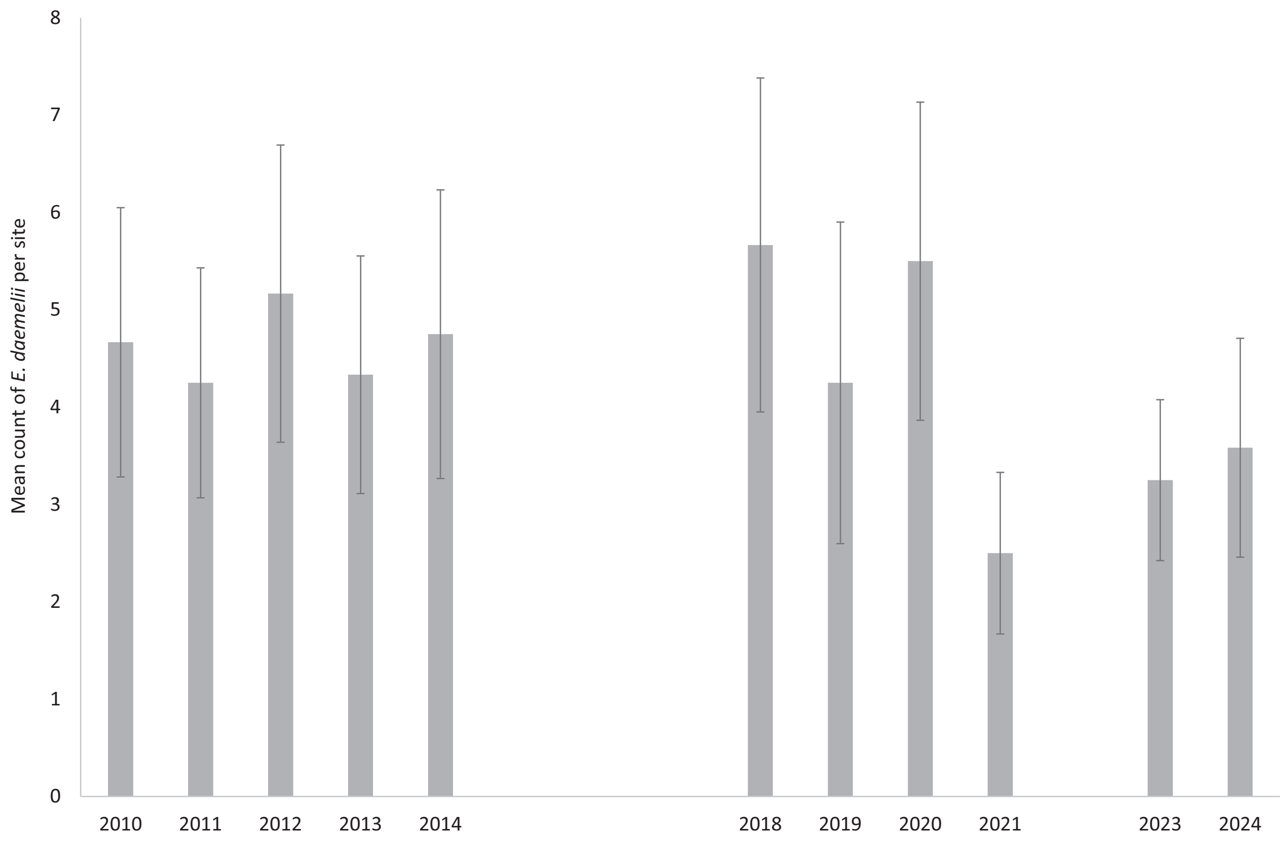

FIGURE 5 Comparative average count (± standard error) of *Epinephelus daemelii* observed at 12 key survey sites sampled in 11 years spanning the 15-year period 2010–2024.

As found in the previous research on *E. daemelii* (Harasti & Malcolm, 2013), the SIMP is considered a stronghold for the species. The largest abundances over the past 15 years have been recorded at sites in the Solitary Islands. Unlike some of the other locations surveyed in NSW, sites within the SIMP have shown stable abundances of *E. daemelii* between 2010 and 2024, with no obvious variation in annual abundance. Some of the sites where high abundances of *E. daemelii* were found to occur in the SIMP include the northern end of South Solitary Island, Anemone Bay (North Solitary Island), and Fish Soup (NW Rock), which are all located within no-take zones that provide high levels of protection for the species. As these no-take areas prevent all forms of fishing, the incidental capture of *E. daemelii* is reduced, and hence subsequent injuries or mortality from hooking injuries is limited, thus increasing the chance of *E. daemelii* to survive at these localities. However, the no-take zones mentioned above are all relatively narrow (<200 m wide), and there is potential for *E. daemelii* to move across the zone boundaries into areas where fishing is permitted.

The incidental capture of *E. daemelii* by fishers is an ongoing concern. The species is known to suffer from barotraumas when brought to the surface (Francis et al., 2016) and the likelihood of survival of the fish is considered to be low based on observations by the authors and reports by fishers. However, the number of incidental captures by recreational fishers is unknown, which prohibits an assessment of the full extent of this impact. There are also occasions where the species is caught and kept where the fisher does not know the species identification and/or that *E. daemelii* is required to be released if caught (NSW Department of Primary Industries compliance data unpublished). Research into fishing release methods to improve post-capture survival of *E. daemelii* is warranted. However, given the threatened species status of the species and its susceptibility to hook injuries, experiments would not be able to be directly conducted on *E. daemelii* so alternatives to investigate post-capture survival would need to be considered.

Overall, this research provides no indication that *E. daemelii* are becoming more abundant and more widely spread on rocky reefs in northern NSW and Lord Howe Island. Given it has been protected for 40+ years, this is concerning, as ideally signs of recovery should be evident following such long-term protection. Whilst the abundance of *E. daemelii* does not indicate recovery, the size structure of monitored *E. daemelii* has increased over the 15-year period since 2009–2011 at broadscale and key sites. There are more mature large females (90–100 cm length class), which is a positive benefit to the overall *E. daemelii* population in terms of reproductive potential.

As the species is slow-growing, long-lived and late to mature, undoubtably the recovery of this species will take more time and they are unlikely to recover to the level of an unthreatened population in the near to long (i.e., decadal scale) future. How long before strong positive signs of recovery are observed is unknown, but the above mixed indications of recovery suggest that more active management may be needed to assist the ongoing recovery of this threatened species.

Management actions that should be considered include ongoing spatial protection and education. Continued and increased spatial protection from incidental fishing impacts would help recovery of the species by reducing the chance of unintended capture by line fishing and associated potential barotrauma (Francis et al., 2016). Likewise, an increased targeted education program about the protected status of *E. daemelii* and measures that can be implemented to improve post-release survival if accidentally caught would be useful. Previously, the NSW Government had an education campaign from 2006 to 2008 for *E. daemelii* that included a tackle box sticker that helped to provide key identifying features for *E. daemelii* and how it differed from other cod species occurring in NSW. A revised educational campaign focusing on species identification and how to release if incidentally caught could help reduce any unintentional fishing-related mortalities.

Further monitoring is essential to evaluate future recovery trends, or lack of, for this threatened species. Where feasible, ongoing monitoring of the key *E. daemelii* sites should be repeated most years to assess changes in abundance and size. Further monitoring of broad-scale sites in 2028 and 2029 is essential to help evaluate the most recent upward trend in 2024 and inform ongoing management regarding future signs of population recovery.

AUTHOR CONTRIBUTIONS

Both authors (Harasti and Malcolm) had equal contributions throughout the manuscript in regard to sampling design, collection of data, interpretation and analysis of the data, and the writing of the manuscript. Both authors approve the final version of the manuscript.

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