# New opportunities for conservation of handfishes (Family Brachionichthyidae) and other inconspicuous and threatened marine species through citizen science

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## ABSTRACT

Volunteer divers participating in the Reef Life Survey (RLS) program actively assist species conservation efforts by generating data for threat assessments and population trend monitoring, through in-water restoration efforts, and through outreach of marine conservation messages. Up to 2014, standardised underwater visual survey data provided by RLS divers described densities of 495 cryptic fish species at over 1200 sites distributed around Australia. Each species was recorded on 34 separate transect blocks on average, allowing the first assessments of population trends for many species. These data highlight the threatened and data deficient status of endemic Australian handfish species. At least five shallow-water handfish species are potentially threatened, including the smooth handfish *Sympterichthys unipennis*, which has not been sighted for over 200 years, but is yet to be included on any threatened species list. RLS divers undertook directed searches at key historical locations for two handfish species, the red handfish *Thymichthys politus*, now only known from a single reef, and Ziebell's handfish *Brachiopsilus ziebelli*, with no confirmed sighting for over a decade. From a total of 100 hours of underwater search effort, only four red handfish were recorded, all at a site threatened by adjacent human activity. These and other handfish species should be considered for inclusion on the IUCN Red List given that populations are either very small or have vanished, spawning substrates have probably declined, and the species lack a larval dispersal stage. More importantly, the absence of information on the conservation status of the majority of marine species needs urgent attention, including through expanded citizen science efforts, if management intervention is to occur and extinctions minimised.

**Keywords: Population monitoring, Reef Life Survey, state-of-the-environment reporting, Tasmania, underwater visual census**

## 1. Introduction

Marine plants and animals are often considered to face much lower extinction risk than terrestrial taxa, a consequence inferred from high geographic connectivity associated with ocean currents, and generally wide geographic distributions. The low number of documented extinctions supports this contention. By contrast, objective assessment of extinction risk using the IUCN Red List of Threatened Species criteria (IUCN 2001) indicates little difference in the proportion of threatened species identified for major marine and terrestrial taxa that have been comprehensively assessed at the global level. A total of 6%, 4%, and 13% of sharks and rays, corals, and marine mammals are considered threatened (Vulnerable, Endangered or Critically Endangered), compared to 6%, 12% and 13% for birds, reptiles and terrestrial mammals, while rates for species that move between land and sea are substantially higher (57%, 39% and 14% for sea turtles, amphibious mammals and seabirds, McCauley et al. 2015).

One difference between outcomes of terrestrial and marine Red List assessments is the proportion of species ranked as Data Deficient (DD). A total of 24% of assessed marine species are considered DD because of insufficient population information for a credible threat ranking, compared to 16% of assessed terrestrial species (IUCN Red List accessed 29 June 2015). Data on population trends in animals and plants are available for very few marine species (probably <1% of the >170,000 described species, Mora et al. 2011), confounding threat assessments.

General ignorance about the threat status of marine species is highlighted by an iconic group of Australian marine fishes, the handfishes belonging to the family Brachionichthyidae. This is by far the largest fish family wholly confined to Australian waters, with 14 species recognised, most with localised distributions in Tasmania and southeastern Australia. Handfishes are colourful, crawl in preference to swim, lack a pelagic stage in the life-cycle, and possess an ancient phylogenetic lineage, with little morphological change since the fossil species *Histionotophorus bassanii* was deposited in early Eocene rock strata in Italy ~50 million years ago (Last and Gledhill 2009).

While many handfish specimens were observed in the 19th and 20th centuries, few handfishes have been observed in recent decades (Table 1). The best known species is the spotted handfish (*Brachionichthys hirsutus*), the first marine fish to be classed by the Australian Government as Critically Endangered (CR), following a rapid population decline around 1980. Whilst the ultimate cause of the population decline remains unknown, potential factors include predation of eggs by the introduced Northern Pacific seastar (*Asterias amurensis*), lack of available habitat structure for deposition of eggs, and poor environmental condition throughout the current known range of the species at the mouth of the Derwent Estuary near Hobart (Edgar 2008). The total population size of this species has been estimated to be several thousand individuals (Department of the Environment and Heritage 2004).

While scientific interest has focused primarily on the spotted handfish, other handfish species are probably closer to extinction (Table 1), including the red handfish (*Thymichthys politus*) and Ziebell's handfish (*Brachiopsilus ziebelli*), which are listed as Critically Endangered and Vulnerable, respectively, under the Australian Environmental Protection and Biodiversity

Conservation Act (Commonwealth of Australia 2015). However, neither is included on the IUCN Red List, yet both have declined greatly in range over the past century, with only one small population of a few individuals known for the red handfish, and no Ziebell's handfish reported for over a decade. Another endemic Tasmanian handfish species, the pink handfish (*Brachiopsilus dianthus*) has not been seen for over 20 years, and is not on any threatened species list. This is also the case for the smooth handfish (*Sympterichthys unipennis*), a species once sufficiently abundant to be collected in Tasmania by early French naturalists with simple sampling gear, but which has not been seen for over 200 years. If this was a mammal, bird, reptile, frog or plant species, then it would be listed on the IUCN Red List and Australian threatened species lists as Extinct, but as a poorly known marine species, it has not yet been considered for any listing.

The pivotal issue associated with assessing the true population status of most marine species, and evaluating the state of the marine environment more generally, is that the marine realm lies out of sight and is expensive to survey. Nevertheless, the limited available information unambiguously suggests that major environmental problems exist and need urgent attention. Threats associated with climate change, introduced pests, fishing, and pollution are serious and pervasive, and populations of many taxa are declining rapidly worldwide, including large fishes, higher vertebrates and sea stars (Jackson et al. 2001; Stokstad 2014). Marine ecosystems declining globally as a consequence of human activity include coral reefs (Carpenter et al. 2008), seagrass beds (Waycott et al. 2009), mangroves (Sandilyan and Kathiresan 2012), shellfish reefs (Beck et al. 2011), kelp forests (Dayton et al. 1998), and pelagic systems (Boyce et al. 2010). Moreover, analysis of historically-dated mollusc shell fragments indicates marine biodiversity can collapse catastrophically at the regional scale with no public or scientific observation (Edgar and Samson 2004).

Using the Reef Life Survey (RLS) program as a case example, this study outlines the potential for citizen science to transform threat assessment and conservation management of shallow-water marine species. The RLS model of utilising a skilled team of committed divers who donate their time and expertise, but without sacrificing scientific rigour, allows enhanced survey effort for rare and threatened species such as handfishes. By contrast, professional scientists are unlikely to receive sufficient funding to track population trends of thousands of marine species across continental scales through the long term, as is needed for informed management.

The RLS program was established through a pilot project hosted within the Commonwealth Environmental Research Facilities program from 2007 to 2010, which successfully achieved collection of quantitative data over the continental scale, without sacrificing taxonomic resolution and other detail. Subsequently, the non-profit Reef Life Survey Foundation (http://www.reeflifesurvey.com/) was formed to train committed divers in systematic underwater visual census surveys, refine data entry procedures, and operate ongoing field activities through a combination of targeted field campaigns and ad-hoc surveys of local and vacation sites by trained divers. More than 100 active RLS divers participate at present, and standardized, quantitative data have been collected at >3,000 sites in 43 countries worldwide, including >500,000 abundance records for >4,500 species. Many sites have been surveyed on multiple occasions, in some cases annually each year since 2008. Survey numbers continue to grow.

Reef Life Survey methods are based on visual census techniques applied over two decades by

University of Tasmania and tropical eastern Pacific researchers (Barrett et al. 2007; Edgar et al. 2011). They cover multiple important elements of biodiversity quantified along transect lines set on subtidal rocky and coral reefs: fishes, large mobile macroinvertebrates, sessile invertebrates, and macroalgae. Surveys include searching for small, camouflaged, or otherwise inconspicuous fish species closely associated with the bottom, which may otherwise be overlooked (hereafter referred to as cryptic fishes, see Supplementary Table 1). These are counted along 1-m wide 50-m long belts during close searches of the reef surface.

This study provides an overview of how conservation of handfishes and other cryptic fishes is assisted by RLS volunteers through:

1. Standardised surveys of the subset of cryptic fishes that is detectable by divers during seabed searches, including handfishes;
2. Targeted searches for threatened handfishes at historical locations where populations are most likely to persist; and
3. On-ground action in support of management intervention.

This assistance aligns with management priorities and is supported by national and state conservation authorities. In particular, the Australian Government Recovery Plan for Three Handfish Species identifies, amongst others, the following priority actions, where assistance by citizen scientists is fundamental (Commonwealth of Australia 2015):

- Monitor the populations and determine population size and rates of population change, by undertaking scientifically robust and repeatable population surveys;
- Identify important habitat areas and assess their quality;
- Where suitable spawning substrate for these species is lacking, encourage the introduction and maintenance of artificial spawning substrate and/or natural spawning substrate to increase reproductive success;
- Promote community awareness of the value of handfishes as part of Australia's unique biodiversity.

## 2. Methods

*2.1 Surveys of cryptic Australian fishes*

Data used for this study were obtained from surveys undertaken using standardised underwater visual census methods applied globally by Reef Life Survey (RLS) divers (Edgar and Stuart-Smith 2014). A detailed description of these methods is available on the RLS website (www.reeflifesurvey.com). All cryptic fishes sighted were counted within paired 1-m wide blocks either side of a 50-m long transect line set along a depth contour on reef habitat. Multiple depth contours were usually surveyed at each site, generally parallel at different depths when the reef was sufficiently wide. During searches in seaweed-dominated habitats, the algal canopy was brushed aside when present, and particular attention paid to crevices and undercuts, but without divers moving rocks.

Cryptic fishes comprised bottom-associated species belonging to a defined set of 88 families, as listed in Supplementary Table 1, including the handfishes. Most cryptic fishes are small in body size such as gobies and blennies, but larger crevice dwellers such as eels, groupers and rays are also included. In addition to surveys of cryptic fishes, which form the focus of this investigation, the densities of large fishes, invertebrates, and macro-algae were also recorded along the same 50 m transect lines, thereby providing contextual data on habitat and potential predators and competitors.

*2.2 Population trend analysis*

Population trends of cryptic fish species were assessed from 2008 to 2014 using RLS data from around Australia. While the best available for this purpose, these time-series data are patchy, with overlapping but different sets of sites investigated in different years. In order to accommodate this spatial and temporal variability, and the presence of numerous zero records which would complicate analysis of log response ratios, density data for each species and site were standardised relative to the year with highest abundance for the species at that site. Thus, a mean value of 1 for a species in a particular year implies that densities for that species peaked in observed values in that year at all sites, while a mean value of 0 in a particular year indicates no records of the species at any site where recorded in other years. Sites lacking records of a species across all years were excluded from calculations of population trends.

*2.3 Targeted surveys of red handfish and Ziebell's handfish*

A list of locations of confirmed historical sightings of either red handfish or Ziebell's handfish was firstly compiled from the literature, most notably from an unpublished report by M. Jacques, and personal communications with local divers. RLS divers undertook surveys directed at the majority of historical locations (Last and Gledhill 2009), as well as additional locations where habitat and local conditions suggested that these species were most likely to occur.

Surveys were conducted using the standardised RLS cryptic fish methods described above. In addition to these quantitative surveys, divers used remaining dive time after completing transects to undertake intensive searches outside of the 50 m survey area, with any handfish sightings during such searches contributing 'presence' data for a site. Due to the depth range of previous sightings of Ziebell's handfish on the Tasman Peninsula, and potential that they may be more likely to be found at depths > 20 m, considerable search effort outside of standardised transects was undertaken at depths of 20-37 m at sites in this area. For these dives, the team was generally split into two groups; one surveying quantitative transects at depths of 10-20 m, and another searching a wider depth range, from deeper reef covered in sessile invertebrates, then working their way up to shallow macroalgal dominated habitats.

Likewise, considerable search effort was spent in the various caverns within the Cathedral Cave system in southeast Tasmania (43.066$^{o}$S, 147.955 $^{o}$E), which has been the most reliable location for previous sightings of Ziebell's handfish. This additional search time in deeper habitats and caves reduced the number of standardised 50 m transects that could be surveyed, but complemented standardised transects in allowing coverage of depths at which dive time is limited. All surveys were undertaken by divers experienced in surveying cryptic fishes, and with the supervision of an experienced scientist.

## 3. Results

*3.1 Cryptic Australian fishes*

Based on survey records to 9 September 2014, a total of 6400 transect blocks (50 $m^2$) had been surveyed by RLS divers at 1225 separate sites, which were well distributed around Australia and associated offshore reefs and islands (Fig. 1). Survey records encompassed 17,066 counts of 112,554 individual cryptic fishes, comprising 495 species in 55 families.

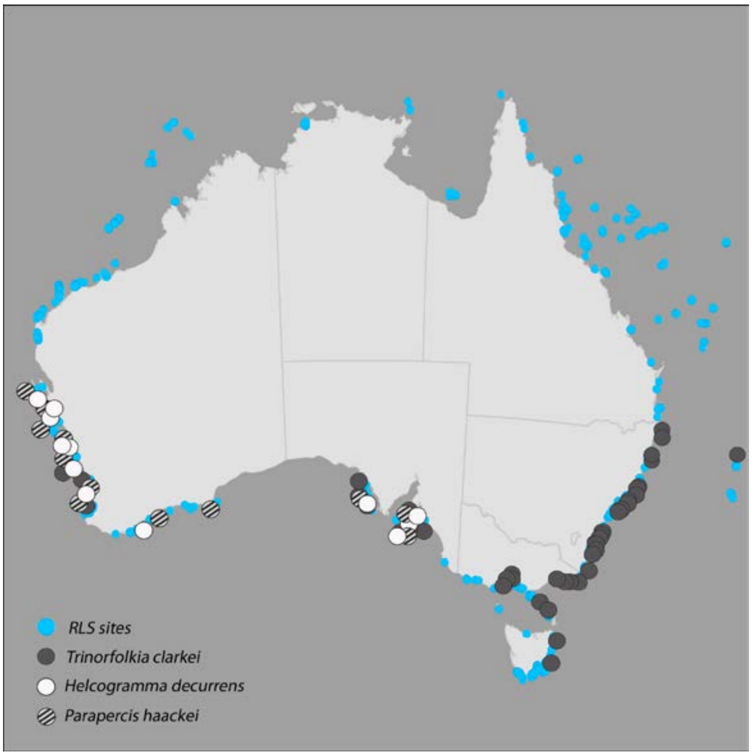



Fig. 1. Map of Australian sites where standardised cryptic fish surveys have been undertaken by RLS divers. Locations where the fish species *Parapercis haackei*, *Helcogramma decurrens*, and *Trinorfolkia clarkei* have been recorded are highlighted.

Inter-annual variation in population numbers were apparent for many common species recorded during surveys. Three examples are presented in Fig. 2: wavy grubfish *Parapercis haackei*, blackthroat threefin *Helcogramma decurrens*, and Clark's threefin *Trinorfolkia clarkei*. The first two of these species are restricted to southwestern Australia, while Clark's threefin is widespread in temperate waters, including around Tasmania (Fig. 1). *Parapercis haackei* exhibited a population trend that declined to lowest densities in 2011, while the opposite pattern was evident for *T. clarkei*. *Helcogramma decurrens* possessed a relatively stable population trend to 2012, followed by a slight decline.

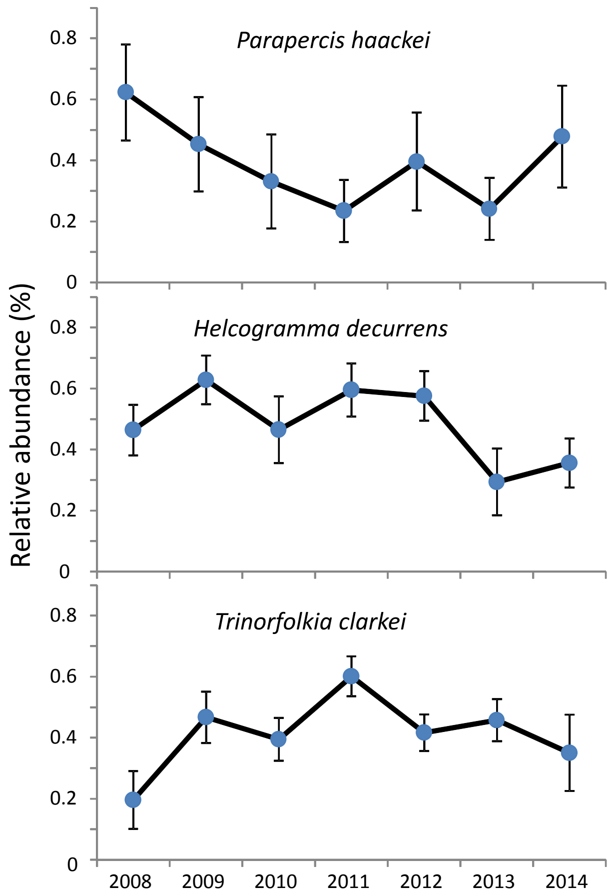
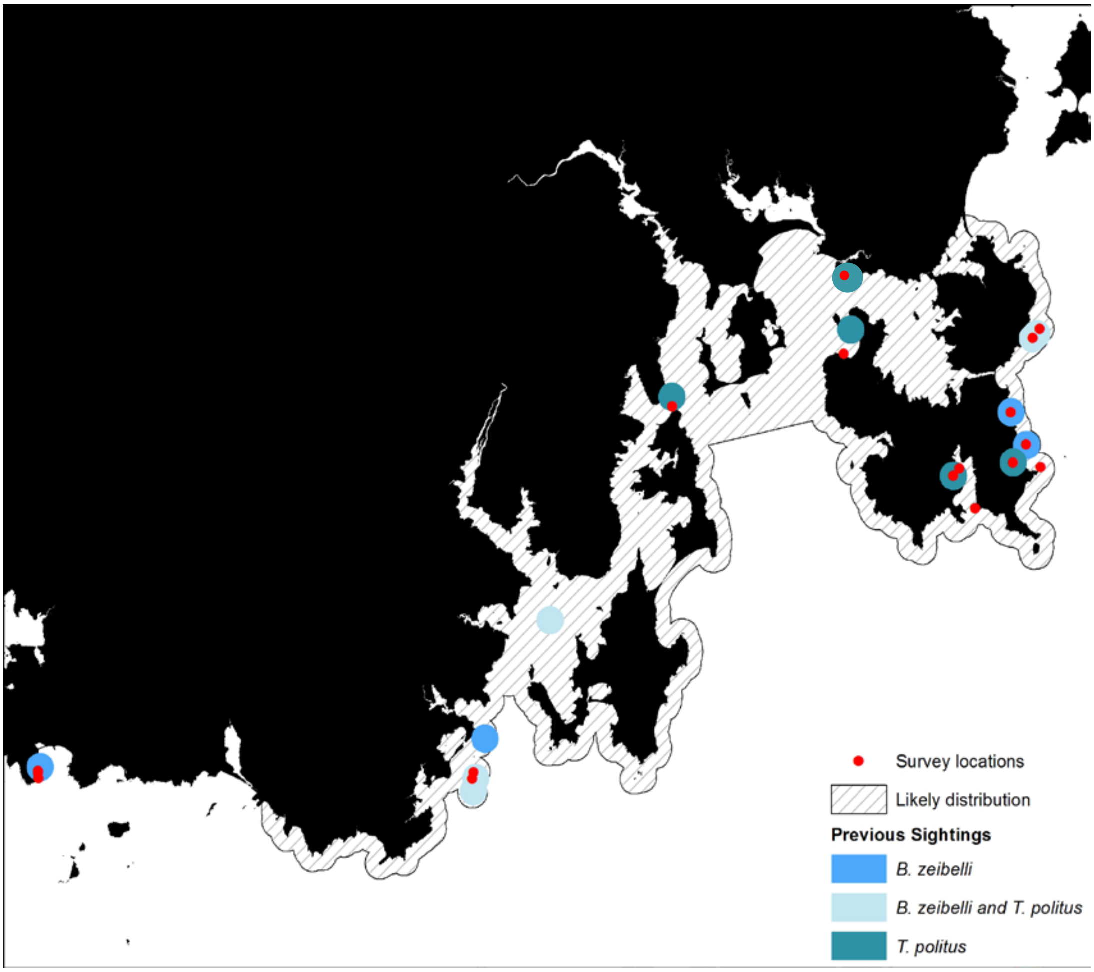



Fig. 2. Mean abundance (±SE) of three cryptic fish species relative to maximum abundance recorded for each site over the period of surveys. Mean raw abundances were 2.6, 4.2, and 1.2 individuals per 100 $m^2$ for *P. haackei, H. decurrens, and T. clarkei*, respectively, for sites with recorded presence.

*3.2 Red handfish and Ziebell's handfish*

Only one handfish species was observed during the continental-scale surveys of cryptic fishes to September 2014. Two individuals of the red handfish were recorded at the only currently-known location in Frederick Henry Bay, southeastern Tasmania, during these non-targeted surveys.

A total of 100 underwater hours was subsequently spent searching for red and Ziebell's handfishes by 19 experienced divers at 22 sites across southern Tasmania from February to June 2015 (Fig. 3). Four red handfish were recorded at the known Frederick Henry Bay site. Photographs of these individuals showed considerable differences in spot patterns (Fig. 4), suggesting four different animals.  No Ziebell's handfish was found at any of the sites surveyed.




288 Fig. 3 Southern Tasmania showing the likely distribution of Red and Ziebell's handfishes, locations of historical sightings (Last, 2009), and locations surveyed by Reef Life Survey divers in 2015.

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Fig. 4. Four red handfish (*Thymichthys politus*) photographed at Frederick Henry Bay (photographers: upper left Rick Stuart-Smith, upper right Nick Perkins, bottom Tania Mendo).

Surveys undertaken for handfishes also located other cryptic fish species that are rarely observed. Of particular interest were records of the flathead congolli (*Halaphritis platycephala*) at two locations. Only about five previous records exist of this species, which is considered a phylogenetically basal member of the toothfishes and icefishes (suborder Notothenioidei, Last et al. 2002). One of the RLS records consisted of independent sightings of the same individual by two divers in Cathedral Caves, despite being very well concealed at the back of a deep crevice in a less conspicuous offshoot of the cave network (Fig. 5). This double sighting suggests thorough search effort for handfishes, and the suitability of the divers and combination of methods applied. Despite the huge area of potential handfish habitat at this site, which is the most important location for previous Ziebell's handfish records, no handfish were observed from 690 minutes of careful searching, suggesting that the presence of any handfish in the cave was unlikely at the time of the survey.

Fig. 5 First *in situ* photo of *Halaphritis platycephala*, Cathedral Caves, Tasmania. Photo: Andrew Green.

## 4. Discussion

4.1 *Threatened handfishes*

Several handfish species appear to be highly threatened due to their unusual life-history characteristics; they lack a dispersal stage in the lifecycle, with eggs laid directly on the seabed that hatch into crawling juveniles with similar habits to adults, possess very small population sizes and highly localised distributions, lack mobility to escape predators, and suffer from ongoing decline in habitat quality (Bruce et al. 1998; Edgar et al. 1982; Last et al. 1983). Although very little reliable information exists on the distribution and movement of red handfish (*Thymichthys politus*) and Ziebell's handfish (*Brachiopsilus ziebelli*), each clearly occurs in small isolated populations. The lack of additional populations identified through RLS surveys, but continued presence of red handfish at Frederick Henry Bay, supports this contention.

The Frederick Henry Bay site is located adjacent to a small town, and is probably already adversely affected by coastal habitat degradation and anthropogenic activities; both of which are identified as key threats to handfish survival (Department of the Environment and Heritage 2004). Apart from poaching/direct removal of red handfish, the major pathways for human impacts appear likely indirect, through degradation of the seaweed habitat that appears to be important for this species. Red handfish are typically observed guarding egg masses attached to fronds of *Caulerpa* species, and individuals are also sighted sheltering directly underneath *Sargassum* fronds.

Although located on a continuous reef system, observations of red handfish persist only in an area of less than 100 m in radius. Summer observations of low seaweed cover on urchin barrens either side of the occupied area suggest that loss of seaweed habitat may represent a key threat to the long-term viability of this population. No historical data on sea urchin densities and seaweed cover on this reef are available, so it is difficult to assess whether the area of suitable habitat for handfish to shelter in, and attach egg masses to, has declined in size. However, data from other areas of similar habitat along the Tasmanian coast suggest that depletion of rock lobsters (*Jasus edwardsii*) has released the sea urchin populations on which they prey, which have in turn considerably reduced local seaweed cover (Barrett et al. 2009; Ling et al. 2009; Pederson and Johnson 2006). RLS transects at the Frederick Henry Bay site have revealed only juvenile lobsters, which are too small to consume sea urchins (Ling et al. 2009), and moderate densities of sea urchins (~120 per 50 $m^2$ within the area of handfish sightings). Very few lobsters and higher densities of sea urchins are present outside, but immediately adjacent to this area (R. Stuart-Smith, pers obs.).

An additional related potential threat to the known red handfish population is nutrient inputs from adjacent urban and rural land uses. Filamentous algal cover, an indicator of excessive nutrient inputs (Oh et al. 2015), is high at this site. Local septic system leakage could, for example, result in filamentous algal blooms that reduce the seaweed canopy, and therefore habitat for handfish to take shelter in. Pollution, siltation and turbidity have also been implicated in historical declines in the availability of natural spawning substrate for spotted handfish (*Brachionichthys hirsutus*) in the Derwent Estuary. Thus, a similar mechanism potentially threatens the even more locally-concentrated population of red handfish.

An important element of RLS data pertaining to handfishes is the availability of contextual data on cover of key algal species, and densities of lobsters, large predatory fishes, and urchin and other invertebrate grazers, in proximity to observed animals. Through the longer term, these data should prove useful in revealing factors responsible for ongoing decline or recovery in handfish populations. For the present, management recommendations arising from our study include control of urchin numbers if they become excessive at the Frederick Henry Bay site, improved control of local nutrient loadings, further surveys in suitable habitat, and consideration of *ex situ* propagation.

Cultivation of an insurance population in aquaria is a last resort option for threatened species, but appears justified in this situation, given that long-term persistence of the only known population is far from assured, and the species should survive well in aquarium conditions, as is the case for the spotted handfish. Moreover, removal of eggs from spawning masses in the field should have little impact on population numbers. On the other hand, no evidence was found during targeted surveys for persistence of any known population of Ziebell's handfish, so *ex situ* propagation of that species may already be too late for implementation.

Regardless of cultivation in aquaria, further surveys are critically needed for all shallow-water handfishes to assess if small populations persist (Table 1), particularly in apparently suitable habitat at locations along the Tasmanian southeast coast not already visited. Additional surveys should also include further searches at historical sites previously visited by divers, given that one-off surveys are unlikely to be adequate for detecting extremely rare species and handfishes possibly move seasonally for spawning. Citizen science is key to success of surveys, given the rarity of handfishes and very low probability that they will be encountered in the first instance by professional scientific teams. The near absence of handfishes in thousands of RLS surveys around Australia, including targeted surveys at sites with historical presence, highlights the extreme rarity of this group. No handfishes were sighted during two Tasmania-wide scientific monitoring surveys that covered 157 rocky reef sites around the State (Stuart-Smith et al. 2010).

In addition to monitoring, citizen science has a large hands-on role to play in population recovery, and also in educating the wider public about conservation issues associated with handfishes and other threatened species. Through a multi-institutional collaboration involving volunteer divers (RLS, the University of Tasmania Dive Club), researchers (CSIRO, the University of Tasmania), managers (Tasmanian Government, Derwent Estuary Program, Department of the Environment) and industry (Aquenal Pty Ltd, Veolia Pty Ltd), restoration efforts associated with Critically Endangered spotted handfish populations have already yielded some success. Over 1500 plastic rods have been pushed into the sediment at key locations to provide vertical substrate for deposition of handfish egg masses. These rods replace the functional role played by stalked ascidians (*Sycozoa* spp.) during handfish spawning, following major apparent losses of ascidians through predation by the introduced seastar *Asterias amurensis* (Aquenal 2008). Dive surveys of spotted handfishes indicate that, although only a small proportion of rods were utilised by handfish for egg deposition (~0.5%), nearly all handfish observed with egg masses were using these substrates (Green et al. 2012) (Fig. 6).

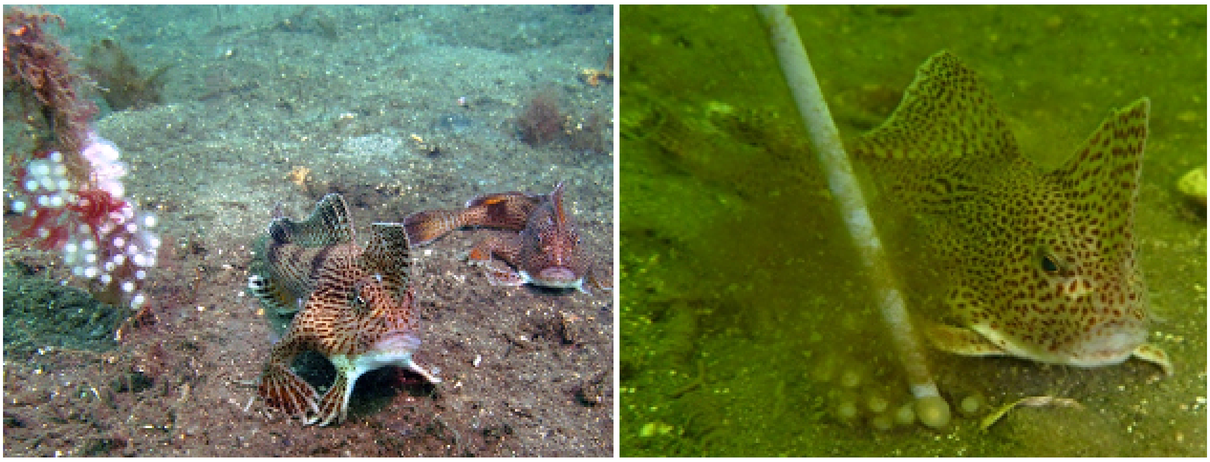

Fig. 6. Spotted handfish (*Brachionichthys hirsutus*) guarding eggs attached to artificial substrate. Photographers: left Antonia Cooper, right Joe Valentine.

## 4.2 *Citizen science and threat assessment for cryptic fishes*

Establishing a citizen science program that extends across national and global scales has entailed numerous challenges, including raising adequate finance and human resources, training, generating long-term commitment amongst participants, and database support, including appropriate quality control processes. Training, assessment and maintenance of data quality have been critical to the success of RLS (Edgar et al. 2016), with oversight by an advisory committee that includes experienced scientists, and with clearly-defined and well-tested data collection methods. The advisory team also involved managers with responsibility for marine conservation, with specific needs for the data collected. Thus, program development and ongoing activities have been guided by appropriate scientific input and end-user needs, which are important for ensuring data suitability and contribution to conservation applications (McKinley et al. 2016; Newman et al. 2016; Sullivan et al. 2016).

RLS volunteers contribute to conservation of cryptic Australian fishes in four ways. Of these, continental-scale surveys through the long term fall uniquely within the realm of citizen science, while directed surveys of handfishes, habitat restoration, and public education can equally be covered by citizen scientists and professional researchers, depending on availability of human and financial resources. With increasing spatial scale and decreasing probability of successful encounter, the cost-effectiveness of directed surveys transitions from professional researchers towards citizen science. This trade-off is not restricted to surveys of handfishes or marine species, the same applying to surveys of beetles, for example (Campanaro et al. this issue).

Similarly, the importance of the contribution of citizen scientists to habitat restoration increases with scale of restoration needed, but decreases with complexity of tasks. Public education ideally encompasses both mainstream media statements by authoritative professionals and social media engagement by citizen science organisations, which are able to disseminate messages at multiple levels within the wider community, including to parties otherwise disengaged. Natural history museums have been particularly proactive in developing citizen science programs focussed on dissemination of conservation-related information (Ballard et al. this issue). Education and public engagement also comprise a core objective of many of the larger marine citizen science programs around the world (e.g. Reef Check and REEF; http://www.reefcheck.org/; http://www.reef.org/).

Inclusion of cryptic fish and mobile invertebrate assemblages during RLS transects provides unique coverage of these two groups, which are not assessed in Australia through alternative broad-scale field programs. This is probably due, in part, to perceived difficulties obtaining reliable abundance data from non-destructive survey methodologies. Yet both assemblages include species that lack dispersing larvae and possess small and highly localised populations (e.g. egg-brooding echinoderms such as *Parvulastra vivipara* and handfishes), and are consequently particularly vulnerable to threats such as climate change, invasive species or pollution. The costs of adding a survey component to target these groups are generally fairly minimal on top of other diver-based methods (and become largely irrelevant when divers are providing skills and time at no expense). While abundance counts for cryptic fishes will likely differ substantially between divers for some species, depending on skill and visual acuity, this is highly species-specific. Abundance estimates for many cryptic species may need to be reduced to presence-absence data verified by photograph.

RLS surveys, as with all fish census methods, involve compromises and tradeoffs related to level of replication, spatial extent, range of target taxa, methodological selectivity associated with those taxa, and logistical and data processing costs. Consequently, data presented here describe a biased picture of absolute fish densities on reefs, as is also the case with other survey methods, such as baited underwater videos, timed swims, acoustic counts, or application of poisons or explosives. Because of poor detectability, some RLS fish counts may be over an order of magnitude lower than true densities; regardless, biases in data are largely systematic (Edgar et al. 2004), with a twofold difference in counts between sites or times on average indicative of a twofold difference in density. With sufficient replication, as is possible through the assistance of citizen scientists, trend data should thus generally be robust.

Overall, we are unaware of alternative methods for assessing cryptic fishes that result in similar data density and span. Explosives and poisons (e.g. rotenone and clove oil) generally provide much more accurate density estimates for cryptic fishes in small plots (Ackerman and Bellwood 2002; Lincoln Smith 1988; Willis 2001); however, these methods are unlikely to be useful when assessing population trends across the full range of a species, given very small observational grain (a few square metres at best) and time required to complete each observation. Importantly, these methods are often inappropriate given ethical issues associated with lethal sampling of threatened species. Visual surveys using wide transects or baited underwater video can provide better estimates of densities of conspicuous species, because of the larger area covered or a greater level of replication, but at the cost of non-detection of cryptic fish species closely associated with the seabed.

The potential for using data provided by citizen scientists to track annual population fluctuations of cryptic fish species across their full distributional range through the long term is shown in the population trends for *Parapercis haackei*, *Trinorfolkia clarkei*, and *Helcogramma decurrens* (Fig. 2). Data for these species are sufficiently sensitive to suggest that an extremely strong oceanographic heating event in Western Australia in early 2011 (Smale and Wernberg 2013) may have affected populations of *P. haackei*, with lowest numbers of that species sighted in 2011. Populations of *H. decurrens* and *T. clarkei*, the latter with the bulk of its distribution east of the area affected by the heating event (Fig. 1), showed no apparent affect (Fig. 2). Broad-scale ecological impacts of this heating event are well documented (Smale and Wernberg 2013; Wernberg et al. 2013), but to our knowledge no studies have examined impacts on the abundance of affected species over their full geographic range. While the trend in *P. haackei* may or may not be a direct result of anomalous heating, the data highlight the ability to examine such trends over the scale of species entire geographic ranges, and therefore global populations – an opportunity lacking through other existing means in Australia.

Data for most cryptic species in the RLS dataset are sparser than for the three species with trends figured, but population persistence over the long term can now be assessed for most species and, through data aggregation, population trends at decadal scales revealed. On average, each of the 495 cryptic fish species observed during Australian surveys has been recorded in 34 separate transect blocks (to September 2014).

Outputs from the RLS program indicate that citizen science can partially fill a void in biological data available for shallow coastal systems accessible to divers (Edgar et al. 2016). Through application of a methodology that is quantitative and standardised, RLS provides web-accessible data across spatial and temporal scales that professional researchers have been unable to cover until now. Although already unprecedented in geographic scale for quantitative species-level information, current data gathering exercises provide only a pointer to the full potential of citizen scientists for marine threatened species assessments.

Thus, through citizen science, data are now available for improved threat assessments for thousands of marine species and, for already listed species, tracking of population recovery or decline. Abundance and size-frequency transect data should also prove invaluable in providing 'before' information needed for rigorous 'before-after-control-impact' analyses of localised impacts such as oil spills, and for tracking the scale and ecological influence of global impacts such as climate change, fishing, and range expansion of introduced pests. For the first time, species-level marine ecological data can also be integrated and scaled up for tracking compliance of international environmental agreements, most notably including progress towards targets agreed under the Convention of Biological Diversity (GEO BON 2011).

## Acknowledgements

The efforts of all Reef Life Survey volunteer divers who participated in field surveys are gratefully acknowledged. Development of the RLS program was supported by the former Commonwealth Environment Research Facilities Program, while analyses were supported by the Australian Research Council and the Marine Biodiversity Hub, a collaborative partnership supported through the Australian Government's National Environmental Science Program. Policy advice was provided by Debbie Rudd and Ashley Leedman of the Australian Government's Department of the Environment, and surveys specifically targeting important handfish locations in 2015 were funded by the Department's Marine and Freshwater Species Conservation Section. Other funding has been provided to RLS activities by the Ian Potter Foundation, while the field work for spotted handfish was supported by Veolia Pty Ltd, the Derwent Estuary Program, CSIRO and Aquenal Pty Ltd. Mark Green is also thanked for leading ongoing efforts to improve recovery of spotted handfish populations, and Neville Barrett for sharing knowledge on handfishes and support. Provision of photographs by Andrew Green, Tania Mendo and Nick Perkins is gratefully acknowledged.

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Table 1. Characteristics of handfish species recorded from shallow water depths (Last and Gledhill 2009).

| Species | Common name | Most recent record | Depth (m) | No. sites | Range (km) | IUCN | Comments |
|---|---|---|---|---|---|---|---|
| *Brachionichthys australis* | Australian handfish | 2007 | 18-277 | >20 | 4000 | NA | Occasionally collected during fish surveys of south-east Australian continental shelf waters. |
| *Brachionichthys hirsutus* | Spotted handfish | 2015 | 1-60 | 8 | 300 | CR | Major population contraction during late 20th century to several micro-populations distributed over a span of ~30 km in the Derwent estuary near Hobart; total population size estimated at <5000 individuals. |
| *Brachiopsilus dianthus* | Pink handfish | 1958 | ~15-38 | 3 | 100 | NA | Known from only five specimens; shallow depth estimated from location at mouth of Huon estuary. |
| *Brachiopsilus dossenus* | Humpback handfish | 1984 | 20-226 | 3 | 400 | NA | Known from only three specimens, only one with a shallow depth record (20 m) that is probably an error given GPS location corresponds to ~100 m depth. |
| *Brachiopsilus ziebelli* | Ziebell's handfish | 2003 | 10-20 | 7 | 300 | NA | Recorded intermittently by divers (about one new sighting per year) within the southeastern Tasmanian region until about 2003, when an animal observed repeatedly by divers at Eaglehawk Neck disappeared; no subsequent reported sightings; listed as EN on Australian species list, not included on Tasmanian list. |
| *Sympterichthys unipennis* | Smooth handfish | ~1802 | shallow | 1 | 0 | NA | Known only from the type specimen collected during Peron's 1800-1804 expedition to Australia. Presumably collected in shallow water from southeastern Tasmania, and sufficiently abundant to be collected using their primitive sampling gear. |
| *Thymichthys politus* | Red handfish | 2015 | 1-20 | 5 | 400 | NA | Widely distributed around the eastern and southern Tasmania coasts in 19th century when first described, but now known from a single population of <10 individuals on one degraded southeastern Tasmania reef near Hobart; listed as EN on Australian species list, not included on Tasmanian list. |
| *Thymichthys verrucosus* | Warty handfish | 2000 | 8-230 | >20 | 2000 | NA | Occasionally collected during fish surveys of south-east Australian continental shelf waters. |

Supplementary Table 1. List of fish families classified as cryptic for Reef Life Survey data collection.

| FAMILY | COMMON NAME | FAMILY | COMMON NAME | FAMILY | COMMON NAME |
|---|---|---|---|---|---|
| Agonidae | Poachers | Cyclopteridae | Lumpsucker | Pempheridae | Bullseye |
| Ambassidae | Glassfishes | Cynoglossidae | Tonguefish | Pholidae | Gunnels |
| Anarhichadidae | Wolf eels | Dasyatidae | Stingrays | Pinguipedidae | Grubfishes |
| Antennariidae | Anglerfishes | Diodontidae | Porcupinefish | Platycephalidae | Flatheads |
| Aploactinidae | Velvetfishes | Eleotridae | Gudgeons | *Plesiopidae – excluding *Trachinops* | Longfins |
| Apogonidae | Cardinalfishes | Gnathanacanthidae | Red velvetfish | Pleuronectidae | Righteye flounder |
| Ariidae | Catfishes | Gobiesocidae | Clingfishes | Plotosidae | Catfishes |
| Aulopidae | Sergeant bakers | Gobiidae | Gobies | Priacanthidae | Bigeyes |
| Bathymasteridae | Ronquils | Grammistidae | Soapfishes | Pseudochromidae | Dottybacks |
| Batrachoididae | Frogfishes | Hemiscylliidae | Longtail carpet sharks | Psychrolutidae | Fatheads |
| Blenniidae | Blennies | Heterodontidae | Bullhead sharks | Rajidae | Skates |
| Bothidae | Lefteye flounder | Holocentridae | Squirrel and soldier fishes | Rhinobatidae | Shovelnose rays |
| Bovichtidae | Thornfish | Hypnidae | Coffin rays | Scorpaenidae | Scorpionfish, orbicular velvetfish |
| Brachaeluridae | Blind sharks | Labrisomidae | Tropical blennies | *Serranidae - excluding *Anthias*, *Pseudanthias*, *Luzonichthys*, *Caesioperca*, and *Lepidoperca* | Rockcods & Seaperches |
| Brachionichthyidae | Handfishes | Leptoscopidae | Pygmy stargazers | Scyliorhinidae | Catsharks |
| Bythitidae | Blindfishes and cuskeels | Liparidae | Snailfishes | Soleidae | Soles |
| Callionymidae | Dragonets | Lotidae | Burbots | Solenostomidae | Ghostpipefishes |
| Caracanthidae | Crouchers | Monocentridae | Pineapplefishes | Stichaeidae | Prickleback |
| Carapidae | Pearlfish | Moridae | Beardies | Synanceiidae | Stonefish |
| Centriscidae | Razorfish | Muraenidae | Moray eels | Syngnathidae | Pipefish & Seahorses |
| Chaenopsidae | Tubeblennies, flagblennies | Nototheniidae | Icefishes | Synodontidae | Lizardfishes and Sauries |
| Chironemidae | Kelpfishes | Ophichthidae | Snake and worm eels | Tetrabrachiidae | Anglerfishes |
| Cirrhitidae | Hawkfishes | Ophidiidae | Lings | Tetrarogidae | Waspfishes |
| Clinidae | Weedfishes | Opistognathidae | Jawfishes | Torpedinidae | Numbfish |
| Congridae | Conger eels | Orectolobidae | Wobbegongs | Trachichthyidae | Roughies |
| Congrogadidae | Eel blennies | Paralichthyidae | Large-tooth flounder | Tripterygiidae | Threefins |
| Cottidae | Sculpins | Parascylliidae | Catsharks | Uranoscopidae | Stargazers |
| Creediidae | Sand divers | Pataecidae | Prowfishes | Urolophidae | Stingarees |
| Cryptacanthodidae | Wrymouths | Pegasidae | Seamoths | Zaproridae | Prowfish |
| | | | | Zoarcidae | Eelpouts |