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Rapid assessment of an ocean warming hotspot reveals "high" confidence in potential species' range extensions

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ABSTRACT

Shifts in species' ranges are one of the most frequently reported and globally ubiquitous impacts of climate change, with rates of movement being particularly high in the sea. The arrival of multiple range extending species can cause serious issues for natural resource managers; some species threaten ecosystem function while others present social and/or economic opportunities. An early indication of which species are potentially extending their ranges can provide useful guidance for managers regarding future investments in impact assessment, monitoring or potential management intervention. Given that scientific monitoring data on potential range shifting species are often sparse in the marine environment a rapid assessment that utilises and assimilates disparate data sources that vary in quality, quantity and collection methods is needed. Off the east coast of Tasmania surface waters have been warming at almost four times the global average and dozens of species range shifts have already been documented. Building on existing methods used in the early detection of invasive species, we developed a cost-effective and rapid screening assessment tool that uses monitoring data from a variety of sources, particularly from the citizen science program Redmap, to classify levels of confidence in potential range extensions over a three year time period (2009–2012) for a variety of marine species. From our assessment of 47 species, eight were classified with "high" confidence as potentially extending their ranges. The "high" confidence classification of these species suggests they should be a priority when investigating potential ecosystem and socio-economic impacts.

1. Introduction

Despite lower rates of ocean warming over the past 50 years compared to terrestrial environments, both climate velocities (i.e. geographic shifts in isotherms) and shifts in the seasonal timing of temperatures have been higher in the ocean than on land (Burrows et al., 2011). This may explain why the marine environment is where some of the greatest ecological impacts of climate change are being observed (Poloczanska et al., 2013). Particularly common are shifts in the distribution of species (Burrows et al., 2011; Poloczanska et al., 2013). Many species are shifting their distributions in rapidly-warming regions (Chen et al., 2011; Last et al., 2011). This can create challenges for managers concerned with biosecurity threats and sustainable management of existing and potentially new living marine resources (Madin et al., 2012). In an environment that is difficult and expensive to observe (Richardson and Poloczanska, 2008) it is not possible to monitor movement in the geographic range of all marine species potentially being impacted. Thus a rapid screening method with minimal data requirements for prioritising on which species to focus resources is necessary. Most studies that have detected extensions in species ranges have used data intensive quantitative methods that require observations collected from a broad geographic area and over multi-decadal periods (Przeslawski et al., 2012). While predictions from these approaches are generally preferable, because they are less subjective, they require more data than qualitative methods and for many species (marine in particular) this is not available (Leung and Dudgeon, 2008). Hence rapid screening assessments of potential range extending marine species also need to accommodate limited observations/information.

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For management the benefits of knowing, with some level of confidence, that a species is potentially extending its range are similar to those benefits provided from the early detection of invasive species. The successive stages of a range extension (i.e. arrival, population increase and persistence) are broadly comparable with the final stages of an invasion pathway (Bates et al., 2014). Similarly, the ecosystem and economic consequences of a range extending species persisting can be just as serious as the persistence of an invasive species (Ling, 2008; Madin et al., 2012; Harris et al., 2007). During the initial stages of invasion (i.e. arrival and population increase) early detection and rapid response programs (EDRR) are frequently implemented in terrestrial, freshwater and marine environments (Vander Zanden et al., 2004; Westbrooks, 2004; Wotton and Hewitt, 2004). These programs commonly consist of some form of monitoring (usually low-cost), collection of any additional relevant information on the species (from literature reviews and expert knowledge) and/or the application of rapid qualitative and/or semi-quantitative analytical methods that use limited data and other available sources of information to assess the risk or classify the likely stage of invasion (Hulme, 2006).

Qualitative methods used in assessing potential invasions often enable the integration of limited and opportunistically collected data from multiple sources, and being relatively simple to understand, are more likely to be adopted by regulatory authorities (Leung and Dudgeon, 2008). Decision (or classification) trees are a systematic and transparent qualitative assessment method used to classify stages (or risk) of invasion that can include various amounts of information from a variety of sources including expert opinion, literature reviews and/or monitoring data (Maguire, 2004; Westbrooks, 2004). Because of the flexibility of this method, it is a natural candidate for assessing potential range shifting species. Consequently, this method has been developed in a range shift context, for species in the northern hemisphere to predict whether the whole range of a southern species will expand to the north, a northern species range will retreat to the north, or the species will remain or fluctuate in abundance (Hiscock et al., 2004). This assessment highlights many factors that are important in predicting a potential range shift such as "suitable habitats downstream from the existing population" and "water quality in relation to the survival of larvae". However, information on such factors is not currently available for many species and cannot generally be rapidly acquired.

Relationships between observed range shifts and species traits and/or environmental change have been explored in multiple studies (Pinsky et al., 2013; Angert et al., 2011; Przeslawski et al., 2012). Rates of environmental change, specifically ocean velocities, have thus far proven more informative and conclusive than species traits (Pinsky et al., 2013; Chen et al., 2011). Few studies that aim to predict potential range shifts have used field observations collected over shorter time-periods e.g. <10 years (Poloczanska et al., 2013). While 10–20 years of data are considered necessary to detect range shifts that are free from the biases of natural environmental variability (Poloczanska et al., 2013), this unfortunately provides evidence after the range shift has occurred. We explored the capacity to provide an early indication of a potential range extension using observations collected over a shorter period.

Pertinent factors when assessing range shifts in marine species include mobility during all life-history stages (Booth et al., 2011), detectability (Monk, 2013), information on species' historical distributions (Booth et al., 2011) and rates of environmental change (Pinsky et al., 2013; Burrows et al., 2011; Hiscock et al., 2004). Species mobility influences whether it is consistently sighted outside of its' historical range and detectability influences whether species are observed within or outside of their common or historical ranges (Monk, 2013). For most marine species in eastern Australia there are little data on historic, or even current, range limits, and very little data to assess breeding or common adult ranges (Booth et al., 2011). Qualitative information on species mobility, detectability and historical ranges can be sourced relatively rapidly from the literature and supported by expert opinion. Using this information in conjunction with expert-verified geo-referenced photographic-observations from the citizen science 'Range Extension Database and Mapping Project' (Redmap), which records observations of species that are potentially out of range, this study developed an initial screening method to rank species that are potentially extending their ranges. This will assist managers and scientists with deciding on which species may require further assessment. We apply this method in a global warming hotspot off the east coast of Tasmania where a large number of extensions in species' ranges have already been observed and more (extensions) are anticipated (Hobday and Pecl, 2014; Oliver et al., 2014).

2. Methods

2.1. Study area

Tasmania is an island located to the south-east of the Australian continent. Oceanographically it is situated at the confluence of three water masses: the East Australian Current (EAC) that carries tropical water south along the edge of the continental shelf and forms the Tasman Front (Ridgway and Dunn, 2003); the cool sub-Antarctic zone waters which move north along Tasmania's east coast when the EAC retracts north in winter and; the Zeehan current to the west that brings relatively warm and nutrient rich waters to south eastern Tasmania. This study is limited to waters off the east coast of Tasmania (Fig. 1) where warming over the past 50 years has been almost four times faster than the global average (Ridgway, 2007; Hobday and Pecl, 2014).

Climate mediated biological changes in the study region (for a summary see Frusher et al., 2014) precipitated the development of

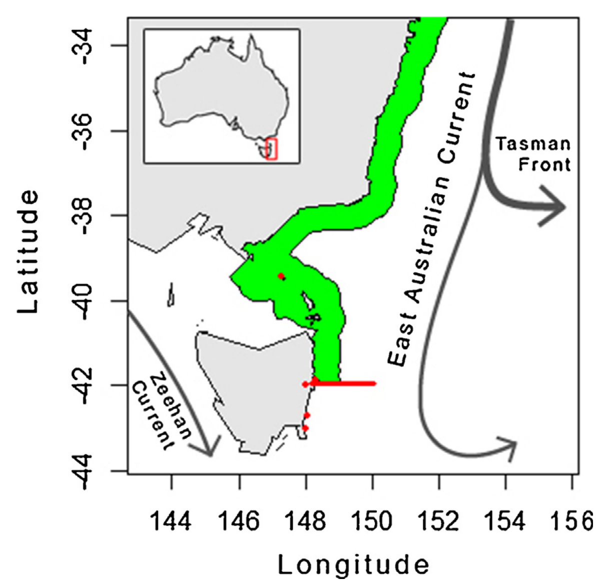

Fig. 1. The study area off the east coast of Tasmania (noted at a broader scale as the red box off the south east coast of Australia) with the prevailing directions of oceanic currents and the most poleward part of the range of one Redmap species—Halfbanded seaperch, *Hypoplectrodes maccullochi* (green polygon). The poleward range boundary (red line) used to define whether sightings from Redmap and/or other data sources (red dots) were in or out-of-range (such as the two southernmost data point). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the citizen science program Redmap, launched in December of 2009 (www.Redmap.org.au). At the time of writing Redmap was monitoring 47 marine species in Tasmanian waters (see Appendix 1), including five invertebrate, two shark, two ray, 31 fish, six turtles, and one phytoplankton species. These species were selected by Redmap researchers in consultation with recreational fishers and divers and marine taxa experts with extensive knowledge of the marine ecosystem in this region. In the selection process researchers considered which species would be monitored for range extensions, based on expert knowledge and scientific studies on species' range extensions in the study area (Johnson et al., 2011; Last et al., 2011; Ling, 2008; Pitt et al., 2010), with consideration for species of interest to different user groups, detectability and ease of identification (verification) from photographs. Hence, while species on the list varied in their detectability, there is a general biased towards those that are more detectable. For those species where range extensions had been detected in previous studies, Redmap was primarily interested in detecting further potential poleward range extensions. However, if insufficient information was available on the newly extended range of a species then the earlier historical range was used (see Appendix 1 for the references used to define species historical ranges).

2.2. Data

Field observations of the 47 preselected Redmap species (Appendix 1) were collated from four data sources. The first source was Redmap; these data were collected opportunistically by citizens participating in a range of marine recreational activities (fishing, diving, snorkelling and beach combing). Observers report potential out-of-range sightings of species on the Redmap list via an online data portal (http://www.redmap.org.au/sightings/). Potential out-of-range sightings are observations made south of a species historical poleward range boundary (Fig. 1). When registering a sighting the observer provides the species name and the location by clicking on a map or entering GPS coordinates. A photo provided with the record allows each species identification to be independently verified by an expert scientist (the list of expert scientists that verify sightings can be viewed at http://www.redmap.org.au/about/meet-the-scientists/). If the photo is verified by the appropriate expert scientist it is marked as a valid sighting, the user is notified, the record is published on the programs website and stored (with all of its associated metadata) in a database for potential use in scientific analyses. If it is not a valid sighting it is marked as inappropriate for publication and use in scientific analyses and stored in the database (see Appendix 3 for further details on the work flow of the sighting verification process and protocol). At the time of this analysis, the Redmap database consisted of three years (December 2009 to November 2012) of species presence observations. We removed data that were not scientifically photo-verified and only used potential out-of-range sightings, resulting in 44 potential out-of-range records (i.e. sightings that were located south of mapped poleward range limits) from this source.

Additional field observations were obtained for the equivalent three year time period (December 2009–November 2012) from (i) fishery-dependent catch data and (ii) scientific survey data from the Institute for Marine and Antarctic Studies, (IMAS) and (iii) data from the Reef Life Survey (RLS, www.reeflifesurvey.com). All of these sources consisted of abundance (i.e. count) data and the RLS and IMAS data were collected using scientific survey methods (for further details on IMAS and RLS data collection methods see Edgar and Barrett, 1999; Edgar and Stuart-Smith, 2009, respectively). To identify and retain observations that were potentially out-of-range for the Redmap species, data from these three sources were subjected to the same process as the Redmap data, but the abundance data were reduced to presence-only data before using the species' historical range boundaries to identify potential out-of range records. Hence, the numbers of potential out-of range records used in the assessment from each data source included: 44 from Redmap, 25 from commercial catch, 22 from IMAS, and six from RLS. (See Appendix 2 for the number of observations for each species from each data source).

2.3. Assessing overall confidence in potential range extension

To classify the level of overall confidence in a potential range extension for each species a group of expert ecologists (10 individuals, with 500+ peer-reviewed publications on marine ecology, biodiversity, species evolution and life-history, population dynamics and/or ecological impacts of climate change), experienced taxonomists (2 individuals with >10 years experience) and resource managers (2 individuals with >10 years experience) developed a stepwise assessment method:

Step 1: Classify confidence in species' historical poleward range boundaries (Fig. 2).

Step 2: Classify strength of evidence for a species being consistently detected out-of-range (Fig. 3).

Step 3: Establish level of overall confidence (high, medium, or low) that a species is potentially undergoing a range extension by combining classifications from Steps 1 and 2 (Fig. 4).

Qualitative classification trees, similar to those used in classifying early stages (or risk) of invasion from pest species (Maguire, 2004; Westbrooks, 2004), were used in Steps 1 and 2. Step 3 combined the two classifications in Steps 1 and 2 using a conservative approach that assumed the minimum confidence/evidence classification level. The methods in each step are described in more detail in the following sections.

2.3.1. Step 1: Classifying confidence in the historical poleward range boundary

Assessing confidence in species' historical poleward range boundaries was important in assessing overall confidence in a potential range extension (i.e. Step 3), because the poleward boundary (i.e. most southern latitude) of each species distribution determined whether sightings were out-of-range and included in the strength of evidence assessment performed in Step 2. The classification tree that assessed levels of confidence in species' historical poleward range boundaries included questions on availability of range maps/descriptions, whether poleward range limits were specified and whether identification and/or taxonomic confusion may have affected the accuracy of the range description (Fig. 2).

To address Question 1 (Fig. 2) literature searches for two maps and/or descriptions of species ranges were performed. Literature searches included peer-reviewed journals and books written by specialists with extensive knowledge on species in the study region. If a map or description was not available then the species was not assessed (Fig. 2). At the time of our assessment only descriptions of species historical distributions were available (see Appendix 1 for the references that provided historical distribution descriptions). Descriptions of species distributions were converted to geographic maps in ArcGIS and the assessment of all species could proceed to Question 2 (Fig. 2).

In answering Question 2 if a description of the species poleward range boundary was specified at a local scale (i.e. a landmark or region approximately <100 km in size) the assessment proceeded to Question 3. However, for species where the description of the range did not specify a poleward range boundary at a local scale (e.g. "around Tasmania") this resulted in "low" confidence.

Question 3 asked whether there has been identification or taxonomic confusion that may influence the accuracy of the

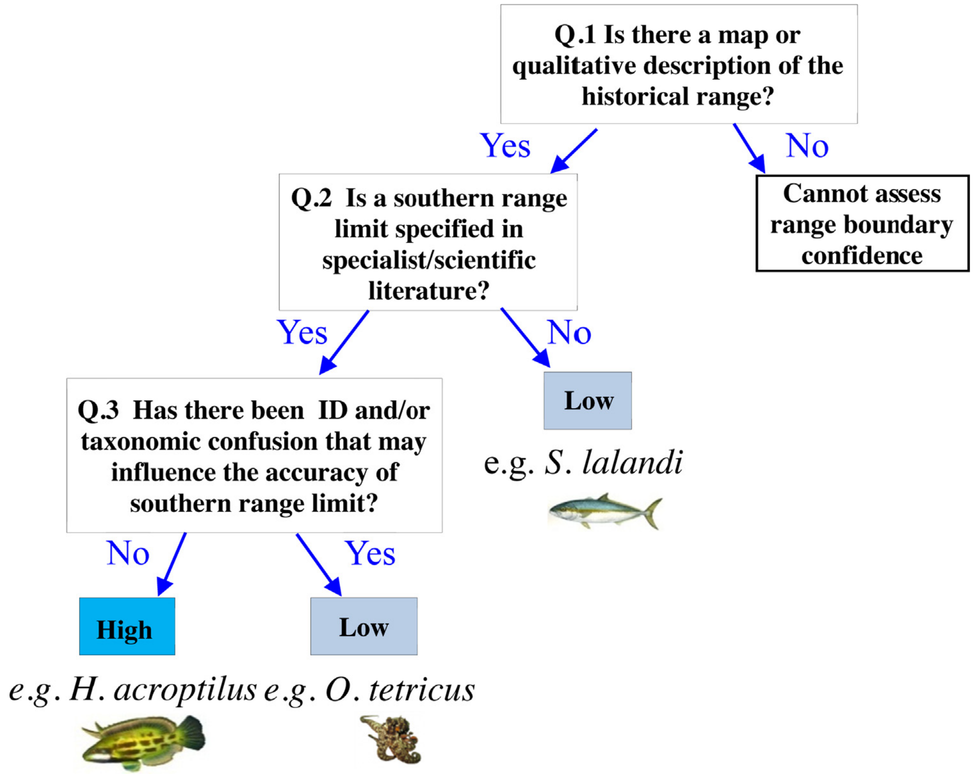

Fig. 2. Method for classifying confidence in species' historical poleward range boundaries.

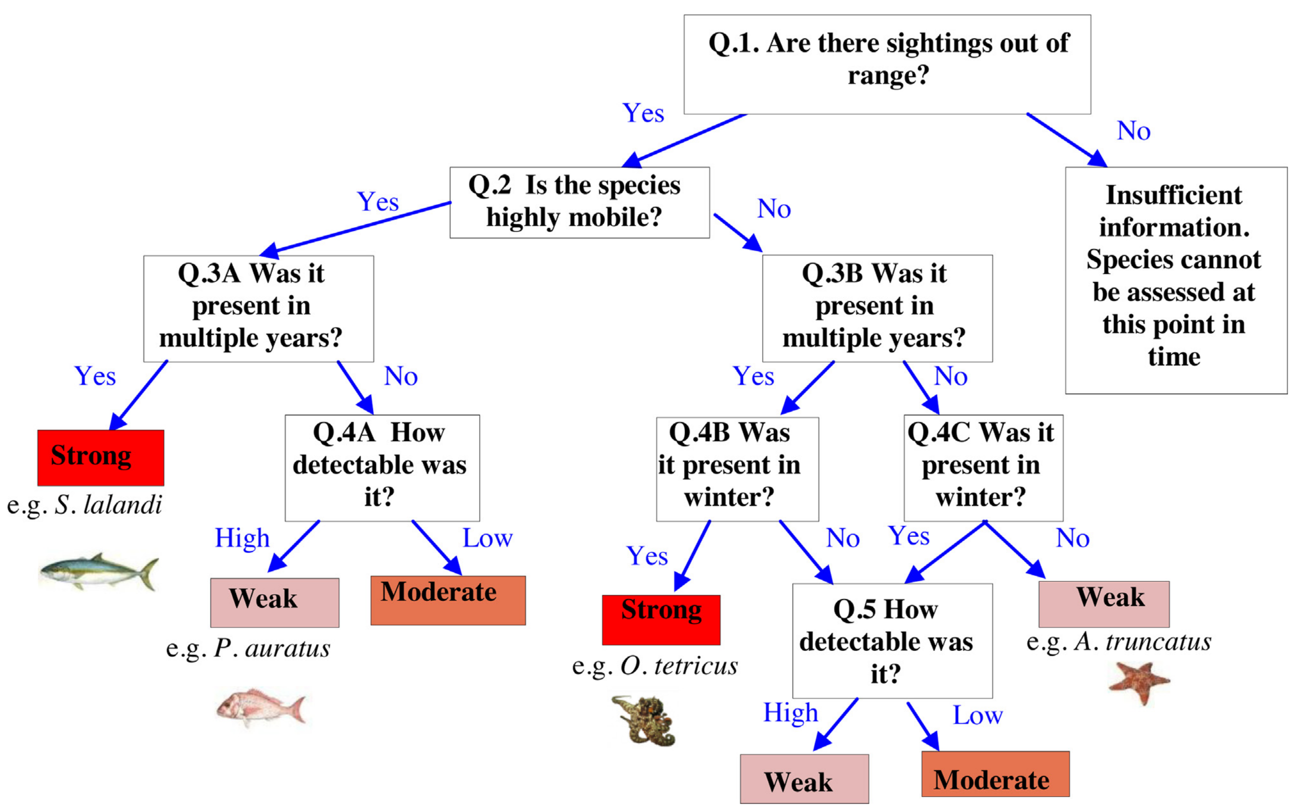

Fig. 3. Method for classifying strength of evidence for a species being consistently detected out-of-range. A sighting was potentially out-of-range if it was south of the poleward range boundary, species were considered highly mobile (in the adult life stage) if they were migratory and/or pelagic, if the species was present in multiple years there were observations in two (or more) years out of three. If it was present in the austral winter it was observed in the months of June, July and/or August. Detectability classifications were based on abundance and/or conspicuousness classifications depending on the method by which it was predominantly observed (i.e. diving vs. fishing). See below for further details.

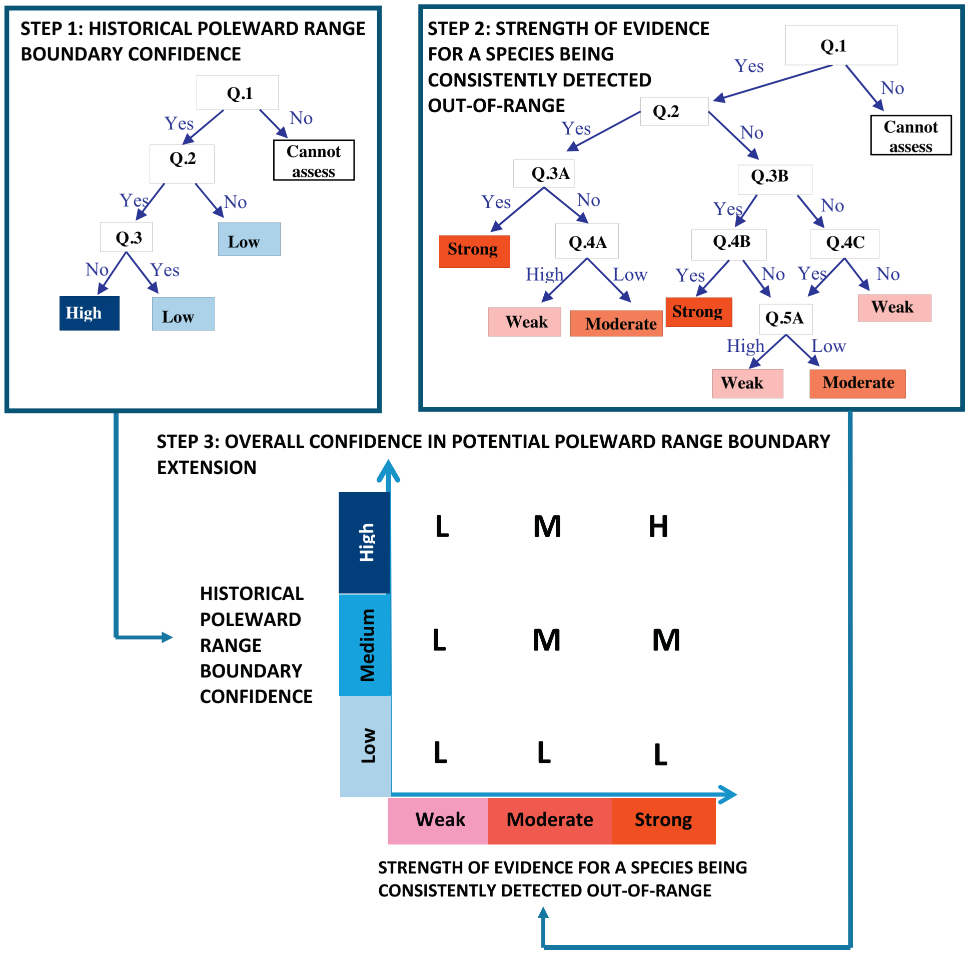

Fig. 4. Summary of how overall confidence in a potential range extension by a marine species was determined based on the combination of classifications in Step 1 (confidence in the historical poleward range boundary) and Step 2 (assessment of strength of evidence). H = high overall confidence, M = medium overall confidence and L = low overall confidence.

poleward range limit description. To determine this, taxonomic experts judged whether it was likely that specimens may have been misidentified because there are one or more similar looking species near the historic poleward boundary and whether taxonomic and nomenclature changes may have influenced descriptions and knowledge of the species' poleward range limits at the time range-maps were published.

In assessing potential taxonomic and nomenclature issues, experts considered whether recent changes in taxonomic descriptions may have influenced historic range limits (e.g. new species being described, or species being split or lumped). Changes were assessed to determine if they affected data from the poleward limits of a species range. When assessing nomenclatural confusion, consideration was given to whether this may have influenced the identification of records used to determine historic poleward range limits. Where identification or taxonomic/nomenclature issues may have compromised published poleward range boundaries, these species scored "low" confidence in the poleward range boundary, but where these issues were unlikely to have influenced the poleward range boundary the confidence was "high".

2.3.2. Step 2: Classifying strength of evidence for a species being consistently detected out-of-range

The classification tree for the strength of evidence in species being consistently detected out-of-range over the three year period first considered if potential out-of-range observations existed and then species mobility (in the adult life stage because sightings mostly consisted of adults), temporal consistency, potential overwintering and detectability were examined (Fig. 3). Question 1 in the classification process (Fig. 3) asks if there were any potential out-of-range sightings (from the combined data sources defined in Section 2.2) of species on the pre-selected list (Appendix 1). If "no", then it was deemed that there was insufficient evidence to assess the species at this point in time. If there was at least one potential out-of-range sighting this would elicit a "yes", and progression to Question 2 (Fig. 3).

In Question 2 a species was deemed highly mobile (in the adult life stage) if, based on literature searches, it was migratory, i.e. the entire population within the study area or any geographically separate part of the population was known to cyclically and predictably move in and out of distinctly different geographical regions on a seasonal basis, or the species was pelagic. If there was no reference to the species being migratory or pelagic, mobility was classified as "low".

For highly mobile species, the relative annual frequency of sightings was assessed; i.e. was it detected in multiple years? This assesses whether it was present in at least two out of three, consecutive or non-consecutive, years (Question 3A). Temporal consistency in potential out-of-range sightings across multiple years provided greater evidence for a species being detected out of range than if it was sighted in a single year. Hence, highly mobile species observed in multiple years were classified as "strong" irrespective of their detectability (Fig. 3). In Question 4A (Fig. 3) a highly mobile species that was not sighted in multiple years provided less evidence in the consistency of potential out-of-range sightings than a species that was, but if detectability was "low" this would provide "moderate" evidence (Fig. 3). However, if detectability was "high" there would be a "low" level of evidence in out-of-range sightings (Fig. 3).

For less mobile species, questions on presence in multiple years (Question 3B) and detectability (Question 5) influenced strength of evidence, but an additional question on whether species were present during winter was included (Question 4B and C). Presence during any of the austral winter months (i.e. June–August) was considered because less mobile species generally have less seasonal fluctuation in their distributions than highly mobile species. Hence their presence in winter is indicative of a consistent out-of-range presence (and potential extension) rather than temporary seasonal vagrancy. If a species was present out-of-range in multiple years (Question 3B) and during winter (Question 4B) the evidence was considered "strong". If the species was either (i) not present out-of-range in multiple years, but present in winter or (ii) present in multiple years, but not observed over winter then detectability influenced strength of evidence (Question 5). If either of these situations occurred and detectability was "low" then strength of evidence was rated as "moderate". Alternatively, if detectability was "high" the strength of evidence was "weak" (Fig. 3). Detectability did not modify the classification of species when there were no sightings in multiple years, and strength of evidence was classified as "weak" (Fig. 3).

Detectability of species were qualitatively classified as "high" or "low" based on species abundance, conspicuousness and method of detection because of the influence of these factors on detectability (Bayley and Peterson, 2001; Bozec et al., 2011). Estimates of abundance and conspicuousness were based on information obtained from the literature and expert opinion. Abundance was classified for each species using expert opinion into one of three abundance categories that included patchy, rare or common (Appendix 1). Patchy or rare species were then classified as "low" in abundance, but common species were considered "high" in abundance. Conspicuousness was either categorised as conspicuous or inconspicuous based on a score that was derived from the following formula: conspicuousness score = ability to camouflage is low + large body size + does not hide. If the total conspicuousness score was greater than or equal to two, the species was classified as "conspicuous" and less than two was classified as "inconspicuous". Camouflage (see classifications in Appendix 1) was based on the presence of body colouration strategies also defined as crypsis (Stevens and Merilaita, 2009). Hence, species that use camouflage by performing any of the following: background matching, self-shadow concealment, obliterative shading, disruptive coloration, flicker-fusion, distractive markings, motion dazzle and/or masquerade were "high" camouflage and scored a zero and those that did not possess any of these traits were "low" camouflage and scored a one. Average adult body size for a species were obtained from peer-reviewed literature or Fishbase (http://www.fishbase.org/), Average body sizes $\geq$30 cm in diameter were "large and anything smaller was "small" (Bozec et al., 2011). "Large" body sizes scored a one and "small" body sizes were scored as zero. Hiding ability was also classified by experts (Appendix 1) and was defined as whether a species generally conceals itself behind an object (i.e. rock cervices, sand and/or kelp) in their environment (Stevens and Merilaita, 2009). Species known to hide scored a zero and species that do not hide scored a one.

Given that Redmap data were collected using differing methods, the detectability of species also depended on whether records were mostly collected "in situ" (e.g. diving) or through harvest activities (e.g. fishing). Therefore, species with greater than 50% of sightings by divers were assessed for detectability in situ and all other species were assessed as harvest species. For species reported by divers, detectability was "high" if either conspicuousness or abundance were "high", as both were considered equally important in detection. If conspicuousness and abundance were "low" for in situ observations, then detectability was "low". For species mostly sighted through harvest activities we assumed detectability was equivalent to abundance i.e. "high" abundance equalled "high" detectability and "low" abundance equalled "low" detectability. Detectability influenced strength of evidence classifications that were less than "strong". Hence a species may not have been sighted consistently out of range, but rather than assuming this provides "weak" evidence we assumed that any sightings of species with "low" detectability, even if they are not consistently sighted, should provide "moderate" evidence relative to highly detectable species. A sensitivity analysis of strength of evidence classifications to the combined and independent data sources was performed (Appendix 2).

2.3.3. Step 3: Combining Steps 1 and 2 to establish overall confidence in a potential range shift

For each species, both "confidence in the historical poleward range boundary" and "strength of evidence for a species being consistently detected out-of-range" classifications were required to generate a level of overall confidence (Fig. 4). The approach used to combine the classifications from the strength of evidence and the confidence in the poleward range boundary is simple, conservative and similar approaches have been recommended (Bates et al., 2014) and used in other assessments that have combined qualitative metrics to derive an overall measure of confidence (e.g. MCCIP, 2010). The approach is conservative because the overall confidence is defined by the minimum strength of evidence or the minimum poleward range boundary confidence. Therefore, overall confidence in a potential range extension can only be 'high' when both strength of evidence is 'strong' and confidence in the poleward range boundary is 'high' (Fig. 4). When all of the necessary information for steps 1 and 2 had been collated the assessment was executed with a series of MATLAB scripts.

3. Results

3.1. Step 1: Confidence in species' historical poleward range boundaries

Confidence in the historical poleward range boundary was classified for all 47 Redmap species (see Appendix 1), but the results from 19 species that were also assessed for evidence for consistent out-of-range observations are presented (Table 1). Descriptions of the range for seven out of these 19 species did not specify poleward range limits resulting in "low" confidence classifications (Appendix 1). The poleward range boundary was not affected by identification and taxonomic/nomenclature confusion for any of the remaining twelve species (Appendix 1). Consequently, eleven species were classified with "high" confidence in the historical poleward range boundary, eight species had "low" confidence and no species had "medium" confidence classifications (Table 1).

3.2. Step 2: Strength of evidence for a species being consistently detected out-of-range

Nineteen of the forty-seven species monitored by Redmap had at least one out-of-range sighting (Table 1). Of these, two were highly mobile (*Pagrus auratus* and *Seriola lalandi*) and assessed following the Question 3A pathway (Fig. 3). *S. lalandi* were observed in at least two out of three years providing "strong" evidence while *P. auratus* were not observed in multiple years and

Table 1
Results from the confidence in historical poleward range boundaries (Step 1) and strength of evidence for a species being consistently detected out-of-range (Step 2) classification tree assessments combined to generate overall confidence in a potential range extension for each species (Step 3). Outcomes from some of the key questions/criteria from the strength of evidence (Step 2) assessment are also presented (see Appendix 1 for additional criteria classifications). Overall confidence in a potential range extensions are noted as H = high, M = medium and L = low and na means the result was not applicable to that species.

Species	Common name	Step 1	Step 2					Step 3
		Historical poleward range boundary confidence	Mobility	Present in multiple years	Present in winter	Detectability	Strength of evidence for consistent detection out-of range	Overall confidence in a potential range extension
Hypoplectrodes maccullochi	Halfband seaperch	High	Low	Yes	Yes	High	Strong	H
Parma microlepis	White ear	High	Low	Yes	Yes	High	Strong	H
Ophthalmolepis lineolatus	Southern Maori wrasse	High	Low	Yes	Yes	High	Strong	H
Notolabrus gymnogenis	Crimsonband wrasse	High	Low	Yes	Yes	High	Strong	H
Heteroscarus acroptilus	Rainbow cale	High	Low	Yes	Yes	High	Strong	H
Girella elevata	Rock blackfish	High	Low	Yes	Yes	High	Strong	H
Sagmariasus verreauxi	Eastern rock lobster	High	Low	Yes	Yes	High	Strong	H
Octopus tetricus	Gloomy octopus	High	Low	Yes	Yes	Low	Strong	H
Asterodiscides truncatus	Firebrick seastar	High	Low	No	Yes	High	Weak	L
Aulopus purpurissatus	Sergeant baker	Low	Low	No	Yes	High	Weak	L
Acanthistius ocellatus	Eastern wirrah	High	Low	No	No	High	Weak	L
Sillaginodes punctata	King George whiting	Low	Low	No	No	High	Weak	L
Seriola lalandi	Yellowtail kingfish	Low	High	Yes	Na	High	Strong	L
Pagrus auratus	Snapper	Low	High	No	Na	High	Weak	L
Girella tricuspidata	Luderick	Low	Low	Yes	Yes	High	Strong	L
Enoplosus armatus	Old wife	Low	Low	Yes	Yes	High	Strong	L
Chromis hypsilepis	Onespot puller	High	Low	No	Yes	High	Weak	L
Aplodactylus lophodon	Rock cale	High	Low	No	Yes	High	Weak	L
Eubalichthys mosaicus	Mosaic leatherjacket	Low	Low	No	Yes	High	Weak	L

because it is highly detectable, strength of evidence was "weak" (Table 1). The 17 less mobile species were assessed following the Question 3B pathway (Fig. 3). Ten of these species were observed in at least two (out of three) years and in winter and therefore classed as having "strong" evidence. Five of the seven species not observed in multiple years were observed out-of-range in winter, but were also highly detectable and consequently classed as "weak" evidence (Table 1). *Acanthistius ocellatus* and *Sillaginodes punctate* were not observed in winter and given their high level of detectability they were also classed as having "weak" evidence (Table 1). The two highly mobile species (*P. auratus* and *S. lalandi*) were mostly detected by fishers, as were *A. ocellatus, S. punctate* and *Octopus tetricus.* All other species were mostly detected by divers (Table 1). In total strength of evidence for a species being consistently detected out-of-range was "strong" for 11 species, "weak" for 12 species with no species classed as "moderate" (Table 1). The results from the sensitivity analysis of strength of evidence classifications to the aggregated vs. independent data sources revealed that classifications varied in seven out of 19 species (Appendix 2). It also revealed that Redmap data contributed to the classification of 15 out of 19 species in total and had it not been available seven species could not have been assessed.

3.3. Step 3: Overall confidence in a potential range extension

In combining the two classifications from strength of evidence for a species being consistently detected out-of-range and the confidence in the historical poleward range boundary, eight species scored "high", zero species scored "medium" and 12 species scored "low" overall confidence in a potential range extension (Table 1). The two highly mobile species were identified as having "low" overall confidence in a potential range extension (Table 1).

4. Discussion

Here we have developed and demonstrated the application of a rapid qualitative method to assess the level of confidence that species' are potentially undergoing a range extension. The method has been applied in a global warming marine hotspot off the east coast of Tasmania (Hobday and Pecl, 2014) using observations predominately collected as part of the citizen science program Redmap. Results from the assessment of fish species were comparable with a previous study that examined range extensions in some of the same species in a similar region (Last et al., 2011). The Last et al. (2011) assessment used a different assessment method and independent data collated from a range of sources (e.g. scientific surveys and spearfishing and angling competitions) from the 1800s to the 1980s and from the 1980s to the present (Last et al., 2011). The six fish species that were classified in our assessment as having overall "high" confidence in a potential range extension (*Hypoplectrodes maccullochi*, *Parma microlepis*, *Ophthalmolepis lineolatus*, *Notolabrus gymnogenis*, *Heteroscarus acroptilus*, *Girella elevata*) between 2009 and 2012 were also categorised by Last et al. (2011) as expanding their ranges south over the period 1980 to 2009. Given historical distributions (and poleward range boundaries) of *H. maccullochi*, *O. lineolatus* and *G. elevata* were similar in our study relative to those described in Last et al. (2011) our evaluation substantiates previously reported poleward range extensions in these species, but we obtained this result using a much shorter period of data collection. Importantly, for *P. microlepis*, *N. gymnogenis* and *H. acroptilus*, Last et al. (2011) defined historical range boundaries that were further north than the historical boundaries used in our assessment, so our results provide evidence of potential poleward range extension beyond previously reported extensions.

Two invertebrate species (*Sagmariasus verreauxi* and *O. tetricus*) were also classified in our assessment as having "high" overall confidence in a potential range extension. The "high" overall confidence classification for *S. verreauxi* is yet to be investigated, but the possibility of this species extending its range in Tasmania waters has been previously noted (Frusher et al., 2014; Johnson et al., 2011; Pecl et al., 2009). The "high" confidence classification for *O. tetricus* is supported by another recent study that found fast growth, small body size and associated rapid population growth may be facilitating a poleward range extension of this species into Tasmanian waters (Ramos et al., 2014).

Of the eleven species classified as having "low" overall confidence in a potential range extension, seven were also assessed by Last et al. (2011), but only *Aplodactylus lophodon* and *Eubalichthys mosaicus* were classified as expanding south and therefore relevant to our results (Last et al., 2011). For both of these fish species, the historical poleward range boundaries specified by Last et al. (2011) were further north than the boundaries used in our evaluation. Therefore, the "low" overall confidence in potential range shift classification for *Aplodactylus lophodon* and *Eubalichthys mosaicus* provides new, but "low" confidence in further poleward range extensions in both species.

Insufficient out-of-range observations limited our capacity to assess *Centrostephanus rodgersii*. Unlike the other 27 species that could not be assessed due to insufficient sightings, other evidence shows that *C. rodgersii* is in fact extending its range down the east coast of Tasmania (Ling et al., 2009). This inconsistency with Ling et al. (2009) is likely due to the differences in time periods examined and consequently the historical range boundaries from which change was assessed. Redmap commenced in 2009, just after Ling et al. (2009) completed and published their study, and consequently the most poleward point of the range extension, i.e. the Tasman Peninsula, documented in Ling et al. (2009) was used as the historical range boundary in our assessment. Had we used the same historical range boundary as Ling et al. (2009), approximately 640 km further north at the New South Wales–Victoria border (~38°S), there would have been sufficient out-of-range sightings in our assessment to classify this species as potentially extending its range.

While we have compared our findings with those of previous studies to examine whether there is consensus or disagreement, the success of the method developed here should be further evaluated as additional observations are collected and other independent assessments of species' range extensions are conducted. As Redmap and/or other monitoring programs collect more observations the consistency in results generated from this assessment can be tested. Using the same historical poleward range boundaries and any updated changes in the strength of evidence levels (Steps 1 and 2), the overall confidence levels in a potential poleward range extension should be the same or greater in any future assessments based on this method. Inconsistencies between the results presented here and results from future assessments, that use this method, may reveal biases resulting from responses to short-term environmental variability (Poloczanska et al., 2013). Additionally, results from other independent assessments of species range extensions can be compared with our results. Despite challenges in comparing results generated from using different methods that vary in their assumptions consensus among independent assessments increases confidence (Bates et al., 2014). For example, if longer term data is collected, rates in the range shifts of the species analysed here can be estimated and it may be inferred that species that shifted at a greater rate should have been classified with higher confidence than those that shifted at a slower rate.

4.1. Implications of overall confidence in potential range extending classifications for management and research

Shifts in the distribution of some species will have large flow-on effects to ecosystems and/or significant implications for natural resource management, while impacts from other species will be imperceptible (Madin et al., 2012). Results from our assessment have implications for managers and researchers as they can be used to prioritise species for impact assessments and/or detailed quantitative analyses. The probability of establishment and the potential impact of species are two components commonly evaluated in invasive species organism risk assessments (Leung and Dudgeon, 2008). Hence, the level of confidence that a species is potentially extending its range, derived from our assessment, could provide half of the information required for an ecological risk assessment.

Definitions of risk vary depending on the context (Burgman, 2005; Hobday et al., 2011). Ecological risk assessments, in an invasive species context, are a logical and systematic process for objectively defining the probability of an adverse effect of an organism on other organisms and or the ecosystem (Leung and Dudgeon, 2008). However, in a range extension context, there are potential risks associated with the recreational and/or commercial exploitation of a new resource as well as those that arise from impacts on an ecosystem and/or individual species.

The potential ecological impacts of most of the species examined in our study are currently unknown. An exception is *C. rodgersii*, where the potential impacts on the ecosystem and associated fisheries have been formally assessed (Johnson et al., 2014; Marzloff et al., 2013; Ling et al., 2009). The strong quantitative evidence that this species has extended its range (Ling et al., 2009) in conjunction with the negative biodiversity and productivity impacts on the marine ecosystem has resulted in the development of several possible management responses (Johnson et al., 2014; Marzloff et al., 2013).

There is limited information available on the impacts of other species examined in our study, but some potential positive and/or negative impacts of *O. tetricus*, *S. verreauxi*, *P. auratus* and *S. lalandi* have been noted. For example, a range extension in *S. verreauxi* could have a potential positive impact as its increasing presence may support a new lobster fishery (Pecl et al., 2009). *P. auratus* and *S. lalandi* have also been recognised as having potential positive social and economic impacts for recreational and commercial fishers (Last et al., 2011; Madin et al., 2012; Frusher et al., 2014). Additionally, for those species for which potential impacts are completely unknown, our assessment could be used to guide research efforts on potential impacts. Hence, species classified as having "high" overall confidence in a potential range extension (i.e. *S. verreauxi, O. tetricus, H. maccullochi*, *P. microlepis*, *O. lineolatus*, *N. gymnogenis*, *H. acroptilus* and *G. elevata)* could be prioritised for impact assessment and if there are no imminent negative or positive impacts, then information on the impacts of the lower priority "medium" or "low" confidence species could be collected and assessed.

Once the potential impacts of species are identified, appropriate management responses can be developed and implemented relatively rapidly. In an invasive species context decision/classification tree methods have included rapid management responses (Vander Zanden et al., 2010; Westbrooks, 2004; Wotton and Hewitt, 2004). If a non-native species is detected or classified as an "arrival" then rapid responses in such programs commonly suggest eradication and/or control because the impact of the species is either known or assumed to be negative (Bax et al., 2003; Crall et al., 2012). In applying this method to assessing potential range extending species it is important to note that an absence of information on the potential impact of species may limit management responses. It would therefore be more sensible to use the confidence classification levels from our assessment to prioritise species for impact assessment (e.g. Pecl et al., 2014) before developing and initiating any management responses or actions.

4.2. Improving and extending the method for early detection and rapid assessment of potential range shifting species

While the classification trees developed here provide a solid base for qualitatively assessing potential range extensions in marine species, further modification and/or development of a number of elements may further improve confidence in the results. One modification that may improve classification accuracy is explicit consideration of the environmental conditions. The assessment for the strength of evidence for a species being consistently detected out-of-range included a question on the temporal consistency of sightings; "was the species present out-of-range for multiple (i.e. at least two) years?" In addressing this question, without explicit consideration of the environmental conditions during the three year period, we assumed if the species was present out-of-range for two or more years, its presence was unlikely to be related to anomalous or extreme annual climatic/ oceanographic events. To ascertain whether this is likely or not the temperature and current strength over the three year assessment period could be compared against the mean conditions over the past decade to provide a more explicit indication of whether observations may be related to unusual and potentially short-term environmental conditions. An examination of sea surface temperature over the three years assessment period, relative to previous years, showed that conditions were not anomalous and were consistent with the rising trend in sea surface temperature over the past decade (Hobday unpublished data). However, in some regions or time periods, explicitly including an analysis of SST into the strength of evidence classification tree may not be necessary and instead the addition of a question asking "Was the species only observed in extreme year(s)?" may suffice. If the answer to this question is "yes" (and it was only present during the time when extreme conditions prevailed) then lower confidence for potential range extension is likely. Alternatively, presence in potential out-of range sightings across an increasing number of years would result in higher confidence.

Assessing the overall confidence in a potential poleward range extension is strengthened by incorporating multiple independent sources of evidence (Bates et al., 2014). Multiple independent data sources were included in our assessment, but these data were aggregated due to the small number of observations from each source in isolation (but see the sensitivity analysis of strength of evidence classifications to independent data sources in Appendix 2). When more data becomes available from each of these sources (or any additional sources of field observations), which is likely within the next five years, there may be a sufficient number of potential out-of range sightings to use the data from each source independently in the strength of evidence classification tree. The level of agreement among strength of evidence classifications from the different data sources would provide an additional rating of confidence in rating.

The addition of biological and ecological traits (such as body size, dispersal potential, reproductive strategies and thermal tolerance) in determining the overall confidence in a potential range extension assessment may be useful (Hiscock et al., 2004). While some information is readily available for some species (e.g. body size was acquired for all species in the classification of species' detectability in our assessment), for many species and regions details on most physiology and life-history traits are lacking. Given the time and expense of obtaining such details, inclusion may be patchy across species and thus limit the effectiveness of a method designed to provide a rapid and early assessment of potential range extension. If trait-based information becomes readily available in the future it would be possible to incorporate this information by modifying the assessment developed here. Additionally, changes in climatic conditions such as rates of warming and species-specific climate velocities have generally been stronger indicators of range shifts than species traits (Pinsky et al., 2013; Poloczanska et al., 2013), so the inclusion of climate velocities and rates of warming in future assessments may be a valuable addition to supplement information on traits. However, within the same region, these physical rates will be similar, suggesting limited value in resolving observed differences in range shift between species.

5. Conclusion

Given the observations and ongoing likelihood of species extending their ranges under climate change (e.g. Last et al., 2011; Poloczanska et al., 2013) and the potential impacts associated with those shifts (Madin et al., 2012) there is a need for systematic guidance on where research efforts should be focused (Frusher et al., 2014). In response, we have developed a practical, simple and rapid method to facilitate this process. This method may be applicable to the Australia-wide Redmap program (initiated in 2012), other citizen science programs monitoring potential range extensions, and analysts or mangers who require an early indication of potential range extending species in situations where there are many species with limited data. There is ample opportunity for further testing, modification, extension and advancement of this method in other geographic regions experiencing rapid climatic change. Due to the large number of species range extensions that are anticipated in warming hotspots globally (Frusher et al., 2014; Hobday and Pecl, 2014), this rapid assessment method provides a useful tool in assisting researchers and managers with identifying species that could present potential threats or opportunities with sufficient lead time to perform further research and take effective action.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.12.003.

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