

High recruitment associated with increased sea temperatures towards the southern range edge of a Western Australian endemic reef fish *Choerodon rubescens* (family Labridae)

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Abstract *Choerodon rubescens* is a subtropical wrasse endemic to Western Australia which has recently recruited in high abundance into lagoonal habitats at the southern end of its distribution. Abundance, size structure and habitat associations of juvenile *C. rubescens* were assessed during summer and autumn 2013 (January–May) via underwater visual census across available shallow water habitats towards the southern range edge of their distribution (32°S, 115°E). High abundances of juveniles (up to 14 fish/40 m²) were found in areas where they were previously absent or in low abundance. Lagoonal habitats presented abundances three to eight times higher than seagrass beds or rocky reef, indicating preference of *C. rubescens* for mixed lagoonal habitats as settlement grounds. Such habitats contain open sandy areas with small rocks and rubble that are important feeding grounds for juveniles. Based on the size structure of populations encountered, recruitment was estimated to occur during summer 2011–12 and 2012–13. This coincides with water temperatures 1 to 2 °C higher than long-term averages in the region, making conditions more favourable for recruits to survive in greater numbers. We conclude that the high abundance of

C. rubescens recruits towards the southern end of their distribution together with trends of increasing water temperature and the availability of suitable settlement habitat to the south of their present range, indicate a capacity for the species to shift its distribution southwards. Monitoring of future recruitment events will be crucial to determining range expansion capacity and guiding management efforts for this endemic and important fisheries species.

Keywords Range extension · Recruitment · Juvenile habitat · Climate change · Tuskfish · Baldchin groper

Introduction

The geographic distribution of a species reflects the range of habitats in which it may successfully settle, grow to maturity and reproduce. In reef fishes, the majority of which have dispersive larvae, geographic limits to their range are most commonly set by constraints on the establishment of recruits (Feary et al. 2013). This is apparent at the southern margins of the ranges of tropical to subtropical species in which larvae may disperse into higher latitudes, settle and metamorphose, but fail to survive through winter periods (Kimball et al. 2004; Figueira et al. 2009). It is clear that distributional limits to a species range will vary over time in response to changes in the prevailing physical and biotic environments, particularly temperature (Pörtner and Peck 2010). For this reason changes in recruitment patterns at range margins of species during

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periods of environmental change represent unique opportunities to identify the factors operating at range margins that constrain distribution patterns.

Research documenting recent range shifts by either extension or contraction of long-term geographic range continues to accrue, especially in relation to climatic changes along latitudinal gradients (Perry et al. 2005; Last et al. 2011; Przeslawski et al. 2012; Poloczanska et al. 2013). Such shifts are most obvious at subtropical and temperate locations, where warm water pulses and intensified pole-ward currents are enhancing the possibilities of tropical recruits to reach new localities, overwinter, survive, and become established (Figueira and Booth 2010). The east coast of Australia is a well-studied example, with reports of tropical species recruiting into temperate waters off Sydney (Booth et al. 2007; Figueira et al. 2009; Figueira and Booth 2010) and Tasmania (Last et al. 2011) as a result of higher temperatures and increased intensity of the East Australian Current.

Along the west coast of Australia a number of marine fishes display latitudinal distributions that extend from the tropical to subtropical-temperate region, including several endemics (e.g. *Thalassoma septemfasciatum*, *Chaetodon assarius*) (Fox and Beckley 2005; Langlois et al. 2012). Recent changes to the distributions of both fish and benthic communities along this coast have been reported as a result of ocean warming and intensification of the poleward flowing Leeuwin Current (Pearce and Feng 2007; Caputi et al. 2009), especially after a 2011 marine heat wave (Wernberg et al. 2011, 2012). In addition, models based on current climate change scenarios predict that fish distributions will shift their centroids southwards, leading to a “tropicalization” of fish communities along the Western Australia (WA) coastline (Cheung et al. 2012). Such shifts could result in range contraction rather than expansion, especially for coral reef associated species which rely on resources centred across a tropical-subtropical latitudinal belt and are therefore limited in their capacity to shift (Munday et al. 2008). Range contractions could ultimately lead to population decline and/or extinction in these species, especially for endemic species of restricted range near the latitudinal margins of coral reef development, and/or experiencing multiple stressors (e.g. fisheries species) (Last et al. 2011).

Baldchin grouper, *Choerodon rubescens* (Günther, 1862), is a subtropical wrasse (family Labridae) endemic to ca 1,700 km of the WA coast between the tropical

Ningaloo Reef (ca 22°S) and subtropical Geographe Bay (ca 33°S) (Edgar 2000). It occurs on both coral and rocky reef of 2–40 m depth, with adults usually inhabiting deeper reefs and juveniles living in shallower waters (<3 m) on sand and weed areas (Hutchins and Swainston 2008; Fairclough et al. 2011). The species is a protogynous hermaphrodite with females reaching maturity at 274 mm total length (TL) (2.7 years) and sex change to males occurring at 479 mm TL (11.9 years) (Fairclough 2005). *Choerodon rubescens* spawns mainly during spring, with peaks in gonadosomatic index during November and recruits expected to appear during the late summer (February) (Fairclough 2005). Maximum size is 700 mm TL (Hutchins and Swainston 2008) and they can live up to 22 years (Fairclough 2005; Nardi et al. 2006).

Choerodon rubescens is reported to be most abundant at the Houtman Abrolhos Islands (ca 28°S), at approximately the centre of its distribution. Its abundance tends to decrease steadily towards the northern and southern limits, where they are typically rare (Hutchins 2001; Langlois et al. 2012). *C. rubescens* is an important commercial and recreational fisheries target throughout its distribution, but mainly along the central areas of its range. Angling club records indicate that the species has become more common in recent years in recreational catches in the southern part of its range.

The Rottneest-Mandurah region is located near the southern range edge of *C. rubescens* (Hutchins 2001). Regular monitoring at Rottneest Island (Parker Point) over the past three decades has revealed both an increase in the number of juvenile tropical fish and increased abundances of some subtropical species over the past 2 years (B. Hutchins pers. comm.). Recently (November 2012), one *C. rubescens* juvenile (TL—12 cm) was recorded at this monitoring site for the first time, although adult *C. rubescens* (>27 cm) have been occasionally found here (B. Hutchins pers. comm.). At the same time, local anglers and divers reported seeing or catching juvenile *C. rubescens* at locations around the Rottneest-Mandurah region, where they were not typically caught or seen.

The above data together indicate that *C. rubescens* may have increased in abundance towards the southern extent of its range in recent years and warrant an assessment of whether the species distribution is shifting southwards. If the distribution is shifting southwards, then we expected higher numbers of individuals towards

the southern parts of the range as a result of increased recruitment and over-winter survival during years with warmer than average sea temperatures, such as experienced recently along the coast of WA.

The aim of this study was to investigate the apparent increase in abundance of juvenile *C. rubescens* in Metropolitan waters (ca 32°S) towards its southern range limit. To do this, the following was examined: (1) the relative abundance and size distributions of *C. rubescens* in shallow waters in this region, and (2) the habitats used by juvenile *C. rubescens* in the same area. We then assessed whether increases in recruitment and abundance occurred during years of warmer than average water temperatures. Evidence of a strong recruitment pulse of *C. rubescens* in the Rottne-Mandurah region, along the southern range of the species geographic distribution, is presented.

Materials and methods

Data collection

Abundance and size structure of juvenile *C. rubescens* were assessed via underwater visual census (10×4 m transects) in shallow water habitats at three locations towards the southern range edge of the species (Garden Island, Rottne Island and Mandurah area), during January to May 2013 (Fig. 1). Underwater visual census has been used successfully to survey adult and juvenile *Choerodon* in the past (Fairclough et al. 2008). Lengths were estimated to the nearest cm and estimates were always conducted by the first author, who has been trained in fish length estimations following the methods of Bell et al. (1985). Locations were selected based on anecdotal reports of *C. rubescens* juveniles in areas where they had not previously been encountered, but represented similar habitat types and depths to those where this species has been recorded further north in its range (Fairclough et al. 2008, 2011). At each location several sites were randomly surveyed based on available habitat ($n=4$ at Mandurah and Garden Island, $n=6$ at Rottne). At each site, three different habitats (outer reef, lagoon and seagrass; 1 to 3 m depth) were surveyed. These habitats were less than 1 km apart, and represented a range of available habitats in which *C. rubescens* had the potential to settle into, given that this species recruits into shallow and protected lagoonal habitats (Hutchins and Swainston 2008; Fairclough

et al. 2011). For each habitat, benthic composition was quantified via the point intercept method which consisted in recording microhabitat observed directly under the transect line every 50 cm (see McCormick 1994; Wilson et al. 2007). Recordings were done whilst returning along the same transects used to assess abundance of juvenile *C. rubescens* (10 m). Number of points per microhabitat were later converted to percent cover per transect for each microhabitat category. Microhabitats for assessing benthic composition were classified into ten categories: sand, rubble, brown algae, turf algae, *Sargassum* spp., red algae, seagrass, kelp (*Ecklonia* sp.), green algae and coral.

Additional length data for *C. rubescens* were collected during timed swims (30 min) at each site in areas adjacent to where UVC were conducted. Estimates for the age of recruits encountered were then produced, based on von Bertalanffy growth curves available for the species (Fairclough 2005; Nardi et al. 2006).

To obtain ‘*a priori*’ estimates of juvenile *C. rubescens* density in the region, footage from previous surveys conducted on snorkel using diver operated stereo-video systems (DOVs) (50×5 m transects) along similar shallow water habitats (<2 m) in Rottne Island (16 sites; 107 transects; July–August 2011) and Garden Island (2 sites; 12 transects; March 2012), were obtained (A. Ferguson: University of Western Australia). Footage from these surveys was analysed to determine previous abundance and size structure of *C. rubescens* at two of the areas surveyed in this study (Parker Point—Rottne Island and GI001/GI002—Garden Island, see Fig. 1), using the software ‘EventMeasure (Stereo)’ (SeaGIS Pty Ltd., see <http://www.seagis.com.au/event.html>). The use of different methodologies for assessing fish density could result in biases inherent to the method of choice and its power of detectability (i.e. detecting presence/absence of juvenile fish), and is therefore not ideal. However, high definition stereo-video has been shown to be capable of detecting and measuring small (2 cm) damselfish (family Pomacentridae) as well as larger fishes (Cappo et al. 2006; Harvey et al. 2010). Furthermore, there is evidence for the equivalence of stereo-video and visual census surveys in estimating both species richness and fish abundance at Rottne Island (Holmes et al. 2013), where this study was conducted. For this reason and because previous visual census data were unavailable at the sites studied, we decided to use stereo-video data for obtaining a general indication of juvenile density at these sites.

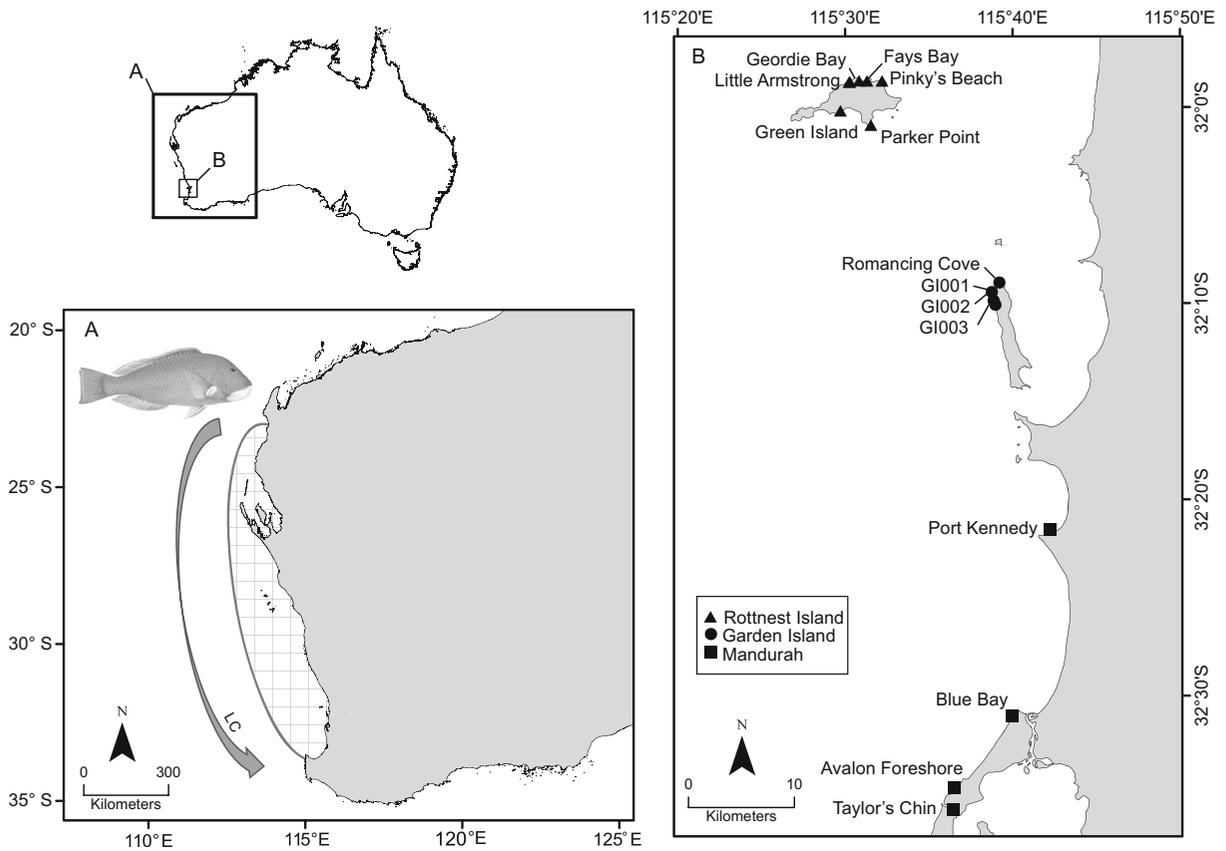


Fig. 1 Location of *C. rubescens* geographic range along the coast of Western Australia (A) and juvenile survey sites along the southern end of *C. rubescens* range (B). Sites were located along each of three

fixed locations: Rottneest Island (triangles), Garden Island (circles) and the Mandurah area (squares). LC: Leeuwin Current. Map source: National Geoscience Datasets, Geoscience Australia

Historical water temperature data (Reynolds Optimum Interpolation SST) (Reynolds and Smith 1994) were obtained via the Integrated Marine Observing System (IMOS) from satellite data for a square grid of two by two degrees centred along the Perth metropolitan region, and available at <http://www.marine.csiro.au/remotesensing/imos/aggregator.html>.

Data analyses

Abundance of *C. rubescens* juveniles ($\log(x+1)$ transformed) was analysed using a permutational univariate analysis of variance (PERMANOVA) based on a Euclidean dissimilarity matrix constructed for the univariate dataset (juvenile abundance) (Anderson 2001; Anderson and Millar 2004). PERMANOVA was chosen because it assumes no particular distribution, and data on *C. rubescens* density presented significant departures from both normality and homogeneity of variance, which were

not resolved by transformation. A two-way PERMANOVA design with location (three levels) and habitat (three levels) as fixed factors was run with a minimum of 9,999 permutations, type III sums of squares, and permutation of residuals under a reduced model (Anderson et al. 2008).

To highlight the differences between the three surveyed habitats, the microhabitat multivariate data from the point-intercept transects were characterised using principal coordinates analysis (PCO), based on a Bray-Curtis similarity matrix generated from square root transformed data on percent cover. Vectors representing each of the most important variables were overlaid on the PCO (Anderson et al. 2008).

Results

Choerodon rubescens juveniles were found in high abundances during surveys in January to May 2013 at

areas towards the southern edge of the species geographic range. Across all locations, the mean density of *C. rubescens* was 0.54 ± 0.09 per 40 m^2 (mean \pm SE, $n=262$), whereas previous surveys in 2011 and early 2012 along the same area (Parker Point—Rottneest Island and GI001/GI002—Garden Island, see Fig. 1) did not detect any individuals despite sampling a total area of $30,000 \text{ m}^2$. In this study, only juvenile *C. rubescens* were seen ($TL < 270 \text{ mm}$). The density of juvenile *C. rubescens* varied significantly between the three locations (PERMANOVA, $F_{(2,253)}=26.64$, $P=0.001$) and three habitats (PERMANOVA, $F_{(2,253)}=84.68$ $P=0.001$) surveyed; however differences between locations were dependent on the habitat surveyed (PERMANOVA, location \times habitat, $F_{(2,253)}=25.522$, $P=0.001$, Fig. 2). Overall, the density of juvenile *C. rubescens* was typically highest in lagoonal habitats, with very few encountered in seagrass and outer reef habitats. The highest density of *C. rubescens* was recorded in lagoonal habitats at Mandurah (mean \pm SE: 4.20 ± 0.88 fish per 40 m^2 , $n=15$, Fig. 2). One of the sites at this location (Taylor’s Chin) was located in the Dawesville Cut, a man-made channel that connects the Peel-Harvey Estuary and the Indian Ocean.

The microhabitat composition of lagoonal habitats, where the highest *C. rubescens* densities were found,

was dominated by a mixture of brown algae, turf algae, sand and rubble (Figs. 2 and 3). The seagrass habitat was more homogenous (mean \pm SE: 76.41 ± 3.78 % seagrass, $n=64$) and the outer reef habitat was dominated by kelp (*Ecklonia* spp.) (mean \pm SE: 36.19 ± 2.40 %, $n=105$) and *Sargassum* spp. (mean \pm SE: 17.23 ± 1.84 %, $n=105$). Habitats sampled showed distinct separation across both PCO axes (Fig. 3). The separation between habitats dominated by seagrass and habitats showing a mixture of microhabitats was the greatest (45 % of the variation in the data explained, PCO1, Fig. 3), followed by the separation between habitats containing a mixture of kelp, red algae, *Sargassum* spp. and green algae vs. habitats consisting of a mixture of turf, brown algae, rubble, sand and coral (24.1 % of the variation in the data explained, PCO2, Fig. 3).

Analysis of the size structure of *C. rubescens* found across all locations and habitats, revealed two distinct modes in the size-frequency distribution (6 and 12 cm approximately), indicative of two separate recruitment events (Fig. 4). Based on length at age data for the Abrolhos Islands, the southernmost location for which length at age data are available for the species, observed size peaks correspond to fish of approximately 6 and 16 to 18 months of age respectively (Fairclough 2005; Nardi et al. 2006). This places the settlement of

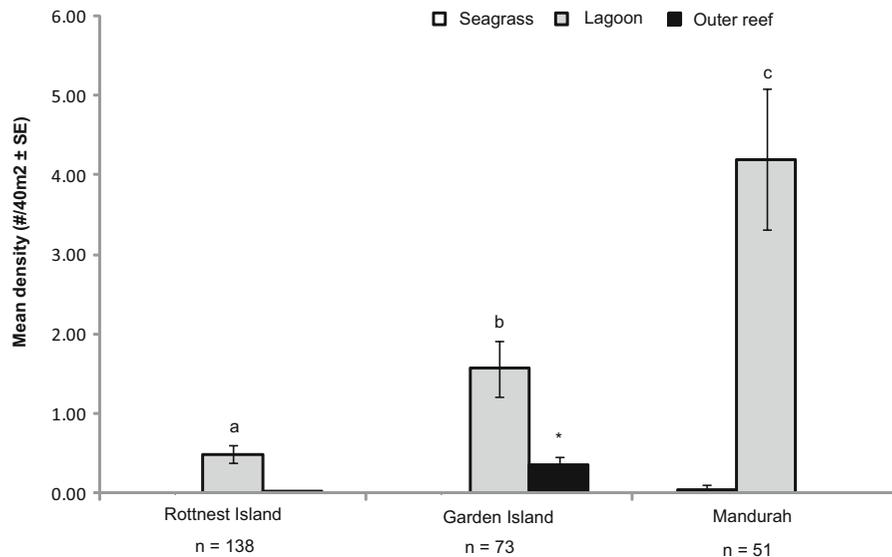
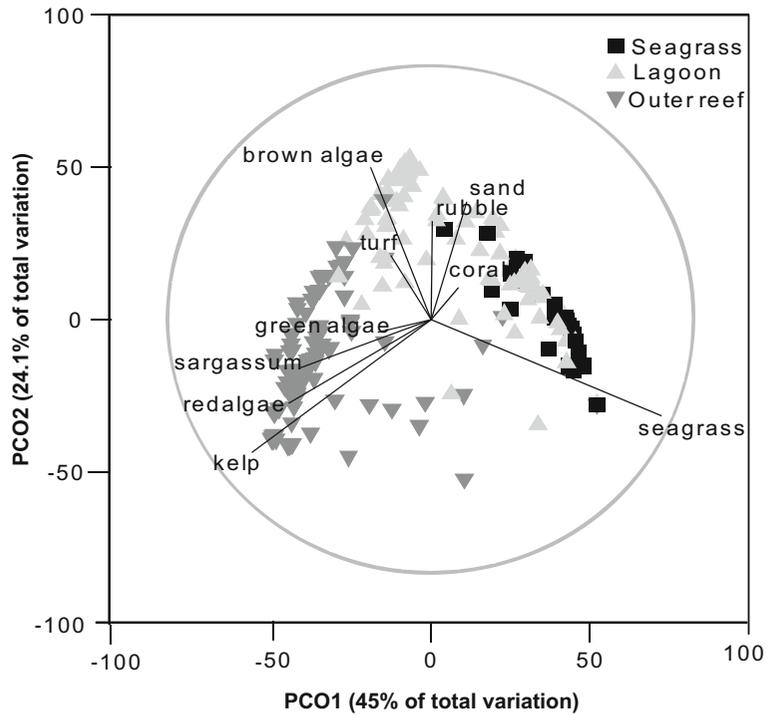


Fig. 2 Mean (\pm S.E.) density of juvenile *C. rubescens* ($TL < 20 \text{ cm}$) at each habitat sampled (seagrass, lagoon and outer reef), at three locations along the southern range edge (Rottneest Island, Garden Island and Mandurah). Significant differences in juvenile

density between locations are represented by lower case letters at lagoon habitat ($P < 0.001$) and an asterisk at outer reef habitats ($P < 0.05$). Note that values are zero for seagrass at Rottneest and outer reef at Mandurah

Fig. 3 Principal coordinates analysis (PCO) showing micro-habitat differences at the three habitats sampled (seagrass, lagoon and outer reef) during juvenile *C. rubescens* surveys, via vector overlay of benthic variables (% cover) on habitats sampled



observed recruits onto the reefs surveyed around the summer of 2011–12 (December 2011 to February 2012) and 2012–13 (December 2012 to February 2013).

During the past 2 years when recruitment of *C. rubescens* towards the southern end of their

distribution increased, average sea surface temperatures around Perth metropolitan areas were 1 to 2 °C higher (Fig. 5). This pattern was particularly evident during the summer months (December to February), when water temperature was up to 2 °C higher (mean±SE=22.88±

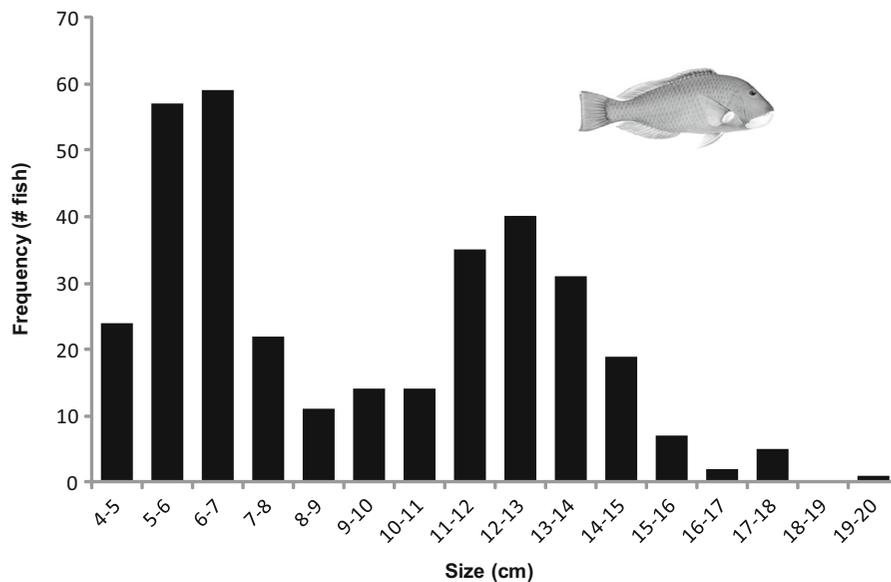


Fig. 4 Size frequency distribution of juvenile *C. rubescens* at sites surveyed along their southern range edge. Data are combined across sites and for observations on both visual census and long swims

0.59 °C, $n=3$ for 2011–12) than the long-term average of the previous 30 years (mean±SE=21.46±0.10 °C, $n=89$) (Fig. 5a). The average water temperature for winter 2012 (June to August) (mean±SE=20.48±0.72 °C, $n=3$) was also higher than the long-term average winter water temperatures (mean±SE=20.08±0.10 °C, $n=90$) (Fig. 5b).

Discussion

Choerodon rubescens has recruited in higher than usual abundance during the past two summers at sites in the southern part of its distribution where they were previously either absent or in low abundance. This pulse in recruitment coincides with warmer than long-term average water temperatures (Pearce and Feng 2007; Caputi et al. 2009; Pearce et al. 2011b) along the Western Australian coastline. Warmer temperatures extended into the winter months, which would favour survival and growth of young recruits (Figueira et al. 2009) typically limited by a failure to withstand the low winter temperatures at subtropical and temperate locations (Figueira and Booth 2010). Since *C. rubescens* is mostly distributed between the tropics and subtropics, it is expected that recruits are limited in their expansion to temperate southern reefs by the physiological constraints associated with low winter temperatures.

The high juvenile abundances found in this study have also coincided with increased intensity of the poleward flowing Leeuwin current along the WA coastline, which usually brings recruits from northern locations into southern reefs (Caputi et al. 1996; Beckley et al.

2009; Pearce et al. 2011a). A combination of warmer waters and stronger currents has thus probably resulted in a higher proportion of larvae being dispersed southwards along the coast, recruiting and surviving at southern range locations and adding to the local recruitment pool. Equally high recruitment pulses are likely to be maintained in the future if: (1) the new recruits encountered reach adult size and contribute to greater abundance of reproductive individuals at the southern end of the range and (2) water temperatures continue to increase as predicted. Whether these recruitment pulses reach the true southern range edge will largely determine the capacity of the species to shift its distribution southwards and expand its current range. Close monitoring of recruitment around the Rottnest-Mandurah region and extending into Cape Naturaliste to the south is recommended.

A potential factor limiting *C. rubescens* from expanding its geographic distribution southward is the availability of suitable settlement habitat. Microhabitat surveys confirmed earlier observations that *C. rubescens* recruits are associated with shallow in-shore seagrass and algal beds (Edgar 2000; Fairclough 2005; Fairclough et al. 2011). However, this study clarified that the greatest density of recruits and juveniles specifically occurs in mixed lagoonal habitats, where both brown algae and seagrass are present, together with bare areas of sand and rubble. Importantly, recruits and juveniles were rarely observed in areas dominated by one type of benthos such as large seagrass beds, and kelp dominated rocky reef. The recognition of such specific recruitment micro-habitats for *C. rubescens* can help locate potential nursery grounds for the species,

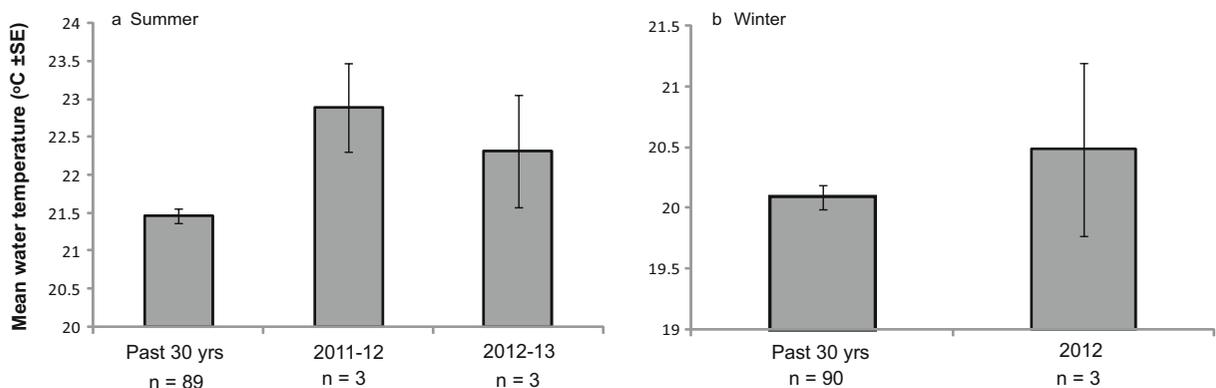


Fig. 5 Comparisons of monthly average sea-surface temperatures (mean±SE) over the past 30 years vs. the past 2 years for: **a** summer (December, January and February), and **b** winter (June, July, August)

which can be incorporated into the design of marine protected areas across the species distribution, to guarantee protection of this important fisheries resource.

Behavioural observations at the survey sites revealed that the mixed lagoonal habitats contain open sandy areas with small rocks and rubble that are important feeding grounds for juveniles. Many juveniles were observed using a feeding technique involving pectoral fin flapping to displace sand and find invertebrate food (Lek 2004). Mixed habitats also contained very small *C. rubescens* (<5 cm TL), which indicates that *C. rubescens* are preferentially settling into these mixed lagoonal habitats. Although *C. rubescens* appears to settle to a specific habitat, this type of habitat is present south of the Capes region (S. Bennett, pers. comm.) where the southern boundary of the species current distribution lies, indicating that settlement habitat would not limit southward range expansion.

Understanding changing recruitment variation in time and space across a species' range has important implications for the future of endemic species. Western Australia is a global hotspot for endemic marine species, including reef fishes (Roberts et al. 2002; Allen 2008), and conserving endemics is a management priority (Fox and Beckley 2005). Endemic species may be particularly vulnerable to increasing seawater temperatures because they may have limited physiological tolerances as a consequence of evolving within a narrow set of environmental conditions within their restricted geographic range (McKinney 1997; Somero 2010). Consequently, endemic species may be more responsive to rising sea temperatures and more likely to exhibit range shifts and geographic changes in abundance (Wernberg et al. 2012).

This study documented high abundance of *C. rubescens* new recruits at three locations towards its southern range edge where it has historically been absent or in low abundance. This increase in abundance of this WA endemic was associated with elevated sea temperatures and may be indicative of current or future changes in the abundance and distribution of other marine species endemic to WA. The increase in *C. rubescens* abundance towards its southern range edge was facilitated by the availability of appropriate recruitment habitat. Future range shifts of endemic species may depend not only on the relationship between physiological tolerances and increasing sea temperatures, but also the availability of suitable resources (food and habitat). The recent increases in abundance of tropical

fishes at their southern range edge on WA coast (also see Wernberg et al. 2012) mirrors the well-established patterns observed on the east coast of Australia (Booth et al. 2007; Figueira et al. 2009; Figueira and Booth 2010; Last et al. 2011). Changes in abundance associated with poleward range shifts of tropical marine species are likely to continue with rising sea temperatures. Management strategies for the conservation of biodiversity and fisheries resources should adapt to the risks this possibility poses, especially for fished species.

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References

- Allen GR (2008) Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquat Cons Mar Fresh Ecosyst* 556:541–556
- Anderson MJ (2001) A new method for non-parametric multivariate analysis of variance. *Aust Ecol* 26:32–46
- Anderson MJ, Millar RB (2004) Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. *J Exp Mar Biol Ecol* 305:191–221
- Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA + for PRIMER: Guide to software and statistical methods, 2nd edn. PRIMER-E Ltd
- Beckley LE, Muhling BA, Gaughan DJ (2009) Larval fishes off Western Australia: influence of the Leeuwin Current. *J R Soc West Aust* 92:101–109
- Bell JD, Craik GJS, Pollard DA, Russell BC (1985) Estimating length frequency distributions of large reef fish underwater. *Coral Reefs* 4:41–44
- Booth DJ, Figueira WF, Gregson MA et al (2007) Occurrence of tropical fishes in temperate southeastern Australia: role of the East Australian Current. *Estuar Coast Shelf Sci* 72:102–114
- Cappo M, Harvey ES, Shortis M (2006) Counting and measuring fish with baited video techniques—an overview. In: Lyle JM, Furlani DM, Buxton CD (eds) Cutting-edge technologies in fish and fisheries science, p 101–114. Australian Society for Fish Biology Workshop Proceedings. Hobart, Tasmania, August 2006, ASFB. 225 pp
- Caputi N, Fletcher WJ, Pearce A, Chubb CF (1996) Effect of the Leeuwin Current on the recruitment of fish and invertebrates along the Western Australian Coast. *Mar Freshw Res* 47: 147–155

- Caputi N, de Lestang S, Feng M, Pearce A (2009) Seasonal variation in the long-term warming trend in water temperature off the Western Australian coast. *Mar Freshw Res* 60:129
- Cheung WWL, Meeuwig JJ, Feng M et al (2012) Climate-change induced tropicalisation of marine communities in Western Australia. *Mar Freshw Res* 63:415
- Edgar GJ (2000) *Australian Marine Life: the plants and animals of temperate waters*. Reed New Holland Publishing, Sydney, 544 pp
- Fairclough DV (2005) The biology of four tuskfish species (Choerodon: Labridae) in Western Australia. PhD Thesis, Murdoch University, Western Australia. 204 pp
- Fairclough DV, Clarke KR, Valesini FJ, Potter IC (2008) Habitat partitioning by five congeneric and abundant Choerodon species (Labridae) in a large subtropical marine embayment. *Estuar Coast Shelf Sci* 77:446–456
- Fairclough DV, Potter IC, Lek E et al (2011) The fish communities and main fish populations of the Jurien Bay Marine Park. Centre for Fish and Fisheries Research, Murdoch University, Western Australia, 363 pp
- Feary DA, Pratchett MS, Emslie MJ et al (2013) Latitudinal shifts in coral reef fishes: why some species do and others do not shift. *Fish Fish*. doi:10.1111/faf.12036
- Figueira WF, Booth DJ (2010) Increasing ocean temperatures allow tropical fishes to survive overwinter in temperate waters. *Glob Chang Biol* 16:506–516
- Figueira W, Biro P, Booth D, Valenzuela V (2009) Performance of tropical fish recruiting to temperate habitats: role of ambient temperature and implications of climate change. *Mar Ecol Prog Ser* 384:231–239
- Fox NJ, Beckley LE (2005) Priority areas for conservation of Western Australian coastal fishes: a comparison of hotspot, biogeographical and complementarity approaches. *Biol Conserv* 125:399–410
- Harvey ES, Goetze J, McLaren B, Langlois TL, Shortis MR (2010) The influence of range, angle of view, image resolution and image compression on underwater stereo-video measurements: high definition and broadcast resolution video cameras compared. *Mar Technol Soc J* 44(1):75–85
- Holmes TH, Wilson SK, Travers MJ, Langlois TJ, Evans RD, Moore GI, Douglas RA, Shedrawi G, Harvey ES, Hickey K (2013) A comparison of visual- and stereo-video based fish community assessment methods in tropical and temperate marine waters of Western Australia. *Limnol Oceanogr Methods* 11:337–350
- Hutchins BJ (2001) Biodiversity of shallow reef fish assemblages in Western Australia using a rapid censusing technique. *Rec West Aust Mus* 20:247–270
- Hutchins B, Swainston R (2008) *Sea fishes of Southern Australia*, 2nd edn. Swainston Publishing, Western Australia, 180 pp
- Kimball M, Miller J, Whitfield P, Hare J (2004) Thermal tolerance and potential distribution of invasive lionfish (*Pterois volitans/miles* complex) on the east coast of the United States. *Mar Ecol Prog Ser* 283:269–278
- Langlois TJ, Radford BT, Van Niel KP et al (2012) Consistent abundance distributions of marine fishes in an old, climatically buffered, infertile seascape. *Glob Ecol Biogeogr* 21: 886–897
- Last PR, White WT, Gledhill DC et al (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. *Glob Ecol Biogeogr* 20:58–72
- Lek BE (2004) Diets of three carnivorous fish species in marine waters of the west coast of Australia. Hons. Thesis, Murdoch University, Western Australia. 99 pp
- McCormick MI (1994) Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Mar Ecol Prog Ser* 112:87–96
- McKinney ML (1997) Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annu Rev Ecol Syst* 28:495–516
- Munday PL, Jones GP, Pratchett MS, Williams AJ (2008) Climate change and the future for coral reef fishes. *Fish Fish* 9:261–285
- Nardi K, Newman SJ, Moran MJ, Jones GP (2006) Vital demographic statistics and management of the baldchin groper (*Choerodon rubescens*) from the Houtman Abrolhos Islands. *Mar Freshw Res* 57:485
- Pearce A, Feng M (2007) Observations of warming on the Western Australian continental shelf. *Mar Freshw Res* 58:914
- Pearce A, Slawinski D, Feng M et al (2011a) Modelling the potential transport of tropical fish larvae in the Leeuwin Current. *Cont Shelf Res* 31:2018–2040
- Pearce A, Lenanton R, Jackson G, et al. (2011b) The “marine heat wave” off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, Western Australia. 40 pp
- Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. *Science* 308:1912–1915, 80-
- Poloczanska ES, Brown CJ, Sydeman WJ et al (2013) Global imprint of climate change on marine life. *Nat Clim Chang* 1–7
- Pörtner HO, Peck MA (2010) Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. *J Fish Biol* 77:1745–1779
- Przeslawski R, Falkner I, Ashcroft MB, Hutchings P (2012) Using rigorous selection criteria to investigate marine range shifts. *Estuar Coast Shelf Sci* 113:205–212
- Reynolds RW, Smith TM (1994) Improved global sea surface temperature analyses using optimum interpolation. *J Clim* 7:929–948
- Roberts CM, McClean CJ, Veron JEN et al (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295:1280–1284
- Somero GN (2010) The physiology of climate change: how potentials for acclimatization and genetic adaptation will determine “winners” and “losers”. *J Exp Biol* 213:912–920
- Wernberg T, Russell BD, Moore PJ et al (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. *J Exp Mar Bio Ecol* 400:7–16
- Wernberg T, Smale DA, Tuya F et al (2012) An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. *Nat Clim Chang* 3:78–82
- Wilson SK, Graham NAJ, Polunin NVC (2007) Appraisal of visual assessments of habitat complexity and benthic composition on coral reefs. *Mar Biol* 151:1069–1076