Tropicalisation of reef fish at Rottnest Island

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Abstract

Rising ocean temperatures are forcing a poleward shift in species distributions creating a tropicalisation of temperate reef fish assemblages. This study aimed to assess the extent to which tropicalisation has occurred in fish assemblages at Rottnest Island and to determine the importance of different habitats to the tropical species now residing there. We used a novel technique that combined visual and video survey methods in an assisted diver operated stereo-video (ASD) to complete a comprehensive assessment of Rottnest Island's inshore fish assemblage. We recorded a higher proportion of tropical species than any previous study, with tropical fish making up 36.2% of all recorded species. While many tropical species were associated with coral habitat, tropical species were also found to be associating with turfing algae, macroalgae and seagrass. The occurrence of tropical species *Scarus psittacus* (Palenose Parrotfish) and *Siganus fuscescens* (Mottled Spinefoot) as mature individuals and across locations suggest they have experienced a poleward range extension. We found the tropical herbivores *Siganus fuscescens* (Mottled Spinefoot) and *Scarus ghobban* (Blue-bar parrotfish) have increased in relative abundance and are now the 4th and 5th most abundant species in the assemblage. Comparison with long term data suggests that, rather than displacing temperate herbivores, these species are occurring as an additional biomass. This additional biomass is likely to increase grazing pressure and may be the first step in a habitat phase shift away from macroalgae dominated reefs. The potential for long term ecological change means ongoing monitoring of Rottnest Island's tropical fish and macroalgal assemblage is necessary, and may help in predicting future changes along Australia's south-west coast.

Key words: tropicalisation, tropical, temperate, fish, distribution, herbivory, habitat phase shift

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1. Introduction

Species distributions are controlled by a combination of biological and physical factors that represent a niche in which a species can continuously occur (Figueira and Booth, 2010; Goh and Lai, 2013; Preston et al., 2008). For marine fish, temperature is a major limiting factor in defining distributions as they require water temperatures within a species specific thermal window to undergo all their biological functions (Portner et al., 2010; Wood and McDonald, 1997). Larval and post settlement juvenile fish are less thermally robust than adults and species distributions can be limited to areas where temperatures fall within their larval thermal window (Hurst, 2007; Ling et al., 2009). Increasing oceanic temperatures are creating new areas suitable for the survival of larval fish, creating a pole-ward shift in species' distributions (Cure et al., 2014; Perry et al., 2005; Last et al., 2011). This distribution shift is leading to a tropicalisation of temperate fish assemblages as warm water species become increasingly abundant (Cheung et al., 2012).

In south-west Australia, temperature is the most important abiotic factor influencing fish assemblages (Lanlgois et al., 2012). The Leeuwin Current is the dominant oceanographic force in this region and plays an important role in defining the distributions of tropical fish species. The current flows from tropical to temperate climatic zones, often transporting tropical larvae well south of their distribution (Maxwell and Cresswell, 1981). When these larvae settle on reefs they generally exist only as transient individuals, experiencing high rates of mortality when minimum winter temperatures fall below lethal limits (Hutchins, 1994, 1979; Maxwell and Cresswell, 1981). As such, winter temperatures provide an important limit on the distribution of tropical fish towards the southern edge of their range (Figueira and Booth, 2010).

Western Australia has experienced an increase in oceanic temperatures between 0.6-1°C over the last 50 years (Pearce and Feng, 2007), causing a southward shift in the distribution of some species (Cure et al., 2014). Modelling suggests as temperatures continue to rise over the next 40 years the distributions of some West Australian tropical finfish will shift south at a rate of 19 km per decade (Cheung et al., 2009). Despite south-west Australia's inshore systems not having the same strong herbivore mediated effects as systems on the east coast of Australia (Johnson et al., 2011; Wernberg et al., 2011), recent predictions suggest increasing water temperatures and tropicalisation may threaten local macroalgal assemblages (Verges et al., 2014;Wernberg et al., 2011). A predicted range extension of the tropical herbivore *Siganus fuscescens* (Mottled Spinefoot, synonym: *Siganus canaliculatus* (Hsu et al., 2011)), may act with increased rates of herbivory from temperate *Kyphosus* spp. (Sea Chubs) to promote overgrazing of macroalgae in temperate regions. Once overgrazing has occurred, a diversity of feeding techniques by tropical herbivores can inhibit the ability of macroalgae to recover, which could result in its permanent removal from reefs in south-west Australia (Verges et al., 2014). Already an overlap of tropical and temperate herbivores in Jurien Bay, Western Australia, has created a diversity of feeding techniques which has reduced the ability of macroalgal assemblages to recover from an environmental perturbation (Wernberg et al., 2013). Canopy loss can also inhibit macroalgae recovery through increased light stress, further increasing the likelihood that a loss of macroalgae would result in a permanent habitat phase shift (Bennet et al., 2015). While distribution shifts are predicted to increase commercial catch potential in southern Australia, a loss of important macroalgal assemblages could result in a decrease in the biomass of commercially fished species (Cheung et al., 2010; Lozano-Montes et al., 2011).

The impacts of warming oceans may not occur as a gradual process (Wernberg et al., 2012). In 2010/2011 a marine heatwave produced a large mass of warm water which extended along much of the Western Australian coast (Pearce and Feng, 2013). It created a rapid tropicalisation of some fish assemblages (Pearce and Hutchins, 2014; Wernberg et al., 2013) and in Cockburn Sound, just south of Perth, the tropical species, *S. fuscescens* (referred to as *S. canaliculatus* by Caputi et al. (2014)), was recorded for the first time (Caputi et al., 2014). While previously not target commercially in south-west Australia, *S. fuscescens* have high quality flesh and have commercial value across Asia (Jaikumar, 2012; Soliman et al., 2008). A rapid population increase meant the following year it had become a target species for commercial fisherman in Cockburn Sound and in 2012 made up 800 kg of commercial catches (Caputi et al., 2014).

Rottnest Island, at 32°S, 115°30’E, is located in a temperate climate 18 km off-shore from the Western Australian coast. Its off-shore location means it is influenced by eddies that regularly shoot off from the Leeuwin Current, carrying with them tropical recruits and the warm water they need to survive (Pearce et al., 2011). While water temperatures closer to the mainland quickly drop during winter and spring, Rottnest Island’s most westerly bays experience relatively stable year-round temperatures, with mean winter temperatures of 18°C (Hutchins and Pearce, 1994). These stable temperatures more closely imitate tropical temperature regimes than other marine environments at this latitude and have created conditions suitable for the establishment of tropical corals (Mscience, 2012; Portner et al., 2010). Both these tropical corals and the influence of the Leeuwin Current are thought to play an important role in the occurrence of over 98 species of tropical fish which make up ~27% of species found at Rottnest Island (Hutchins, 1979, 1991; Pearce et al., 2011). Despite the influence of the Leeuwin Current, many tropical species still occur only as transient individuals. These species rarely survive beyond juvenile life stages before suffering either temperature induced mortality or predation due to decreased fitness and a lack of suitable habitat (Pearce et al., 2011). For the tropical species which can persist over winter, most are not considered to be breeding, with recruits likely to be arriving from the Houtman Abrolhos Islands with the Leeuwin Current (Pearce et al., 2011). Before breeding activity can take place, these fish require a combination of specific temperatures with a minimum density of fish (Figueira and Booth, 2010).

During the heatwave, Rottnest Island experienced record recruitments of tropical species which included several new species records (Pearce and Hutchins, 2014). The warm water during this time may have acted to increase the growth rates of tropical recruits, resulting in larger recruits that have an increased ability to avoid predators, forage for food and are more thermally robust (Grorud-Colvert and Sponaugle, 2011; Hurst, 2007). As these recruits are likely to have experienced increased survivorship, post heatwave there may now be a higher abundance and diversity of tropical species persisting at Rottnest Island. This study aimed to assesses the degree to which tropicalisation has occurred at Rottnest Island by completing a comprehensive assessment of fish assemblages around its inshore bays.

We hypothesised that:

1) There has been an increase in the abundance and diversity of tropical reef fish.

2) Tropical fish will be primarily associated with coral habitats.

2 Materials and Method

2.1 *Study sites and sampling design*

Our 18 study sites were chosen to cover areas surveyed during baseline assessments of tropical fish and to spatially cover the whole island (Fig. 1). To assess of habitat associations we chose sites that had the three dominant habitat types of seagrass meadows, reef dominated by large macroalgae and sand, as well as capturing as much of the limiting habitat of coral as possible (Harvey, 2009). Each site was first sampled during a trip from the 30th November – 6th December 2014, and re-sampled during a trip from the 1st March – 8th March 2015.

The majority of tropical species residing at Rottnest Island are not heavily targeted by fisherman and the small size of the sanctuaries suggests they may not increase the abundance of targeted species (Bellchambers et al., 2008). As such, sanctuaries were not incorporated into our design.

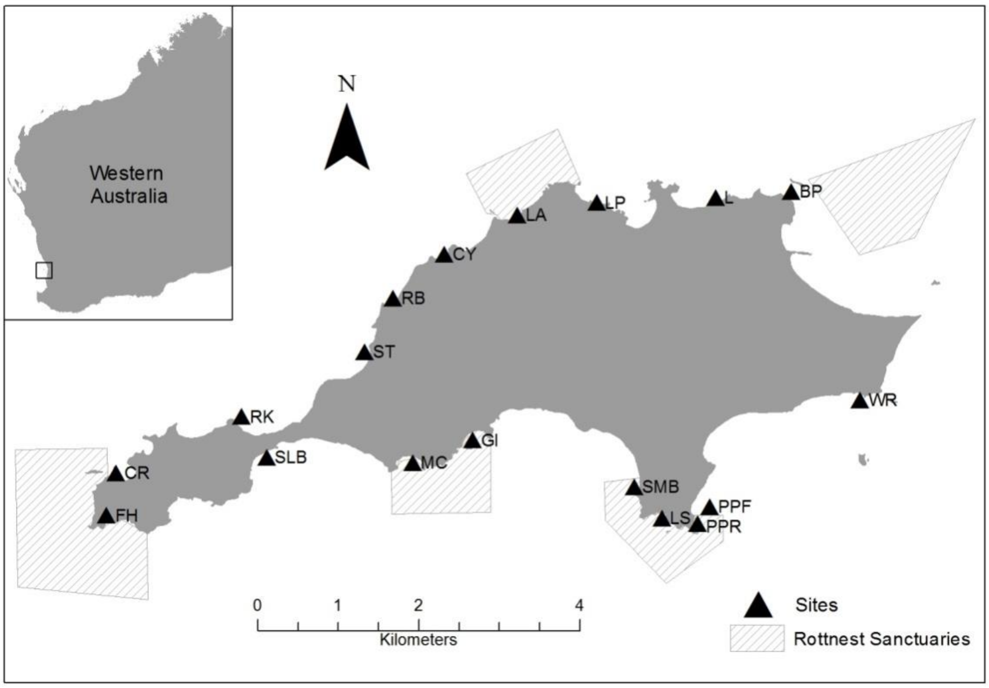

Fig. 1. Map of our 18 study sites at Rottnest Island.

2.2 *Assisted Stereo-DOV (ASD) using a Roving Diver Technique (RDT)*

Due to the low abundance of many tropical species at Rottnest Island, a technique that maximises sightings of rare species was required. The Roving Diver Technique (RDT) has been proven as a highly effective method to locate rare species as it maximises time spent surveying and gives the diver autonomy on where the search is directed (Schmitt et al., 2002). It is also comparable to the technique used in long term assessments of tropical fish assemblages at Rottnest Island (Hutchins and Pearce, 1994). While RDT often targets specific species, our surveys targeted habitat types. Our roves involved observers exploring a predetermined area for one hour along a general pre-planned route, however autonomy was given to change the route to ensure target habitats were covered. The rove routes were planned to capture equal portions of the three most dominant habitats of sand, macroalgae and seagrass, as well as capturing as much coral habitat as was available. Due to the shallow depths being assessed, observers were snorkelling.

The inherent biases in both video and visual techniques mean they produce different information when assessing fish assemblages (Goetze et al., 2014; Holmes et al., 2013). While stereo-DOV can allow for more accurate information on species identification and sizes when compared to visual surveys (Harvey et al., 2002), one limitation is a decreased ability to detect cryptic species (Holmes et al., 2013; Watson et al., 2005). These include species that are small in size (>5cm), have a preference to hold up under ledges and some that are targeted by fisherman (Holmes et al., 2013). To overcome these technique specific biases it has been recommended that a combination of survey techniques are used (Watson et al., 2005).

For this study we used a combination of video (stereo-DOV) and visual (underwater visual census) techniques in an assisted stereo-DOV (ASD) to create one comprehensive dataset. ASD involved one snorkeler completing a roving snorkel using stereo-DOV while a second snorkeler swam abreast completing a UVC (underwater visual census), targeting cryptic species. Snorkelers used a stereo-DOV system that was made up of two Canon digital camcorders in underwater housings mounted 0.7 m apart on a metal cross bar and angled in at 7 degrees.

One trained observer conducted all UVC’s at an average of 3.5 m depth (maximum of 6 m). They were swum at a slow pace, averaging 550 m per rove, to allow the UVC diver to record cryptic fish that may have been missed by the stereo-DOV. Species that were sighted whilst swimming back to shore were classified as opportunistic sightings and were used for species occurrences but not in abundance calculations. Both observers used stopwatches to synchronise observations and water temperate was recorded at each site. The temperatures (Table 1) were recorded at the half way point of the dive to reduce the effect of air temperature.

Table 1
The range of water temperatures (°C) recorded across all sites.

	Maximum	Minimum	Average
Trip 1	22	20	21.1
Trip 2	27	23	24.7

2.3 Analysis

2.3.1 *Video analysis*

Calibration of Stereo-video imagery was conducted following the technique used by Harvey and Shortis (1998) with the calibration software CAL (SeaGIS Pty Ltd., see http://www.seagis.com.au/bundle.html). All videos were processed by one trained observer with the software, EventMeasure (http://www.seagis.com.au/bundle.html), and data were collected on species type, size, abundance and the habitat they were associated with. Habitat was defined by the most dominant substrate during any point of the video and was broken into five benthic categories: reef dominated by macroalgae, reef dominated by turfing algae, sand (including rubble), seagrass meadows and coral reef. Total time in each habitat was recorded and fish were determined to be associated to the most dominant habitat at the time of their identification.

2.3.2 *Combination of stereo-DOV and UVC data*

Due to the use of total length by UVC observers and fork length during video analysis, lengths were standardised to total length using conversion rules from Fishbase (www.fishbase.org). The R program (R Development Core Team, 2009) was used to clean data with the packages; reshape2 (Wickham, 2007), gtools (Warnes et al., 2015) and plyr (Wickham, 2009).

While both observers completed the roves together, constant duck diving by the UVC observer meant it was not possible for both techniques to record fish at the exact same time, introducing the possibility of double counts. To reduce this effect, we took a conservative approach which used two tests to assess the time between measurements and differences in measured lengths when combing UVC and stereo-DOV data (Fig. 2).

Time Test

We determined that if a UVC measurement had occurred within 20 m of a stereo-DOV measurement there was a possibility the two measurements were of the same individual. An average swimming speed of ~10 m per minute allowed the 20 m potential double up distance to be translated into a two minute time period (one minute before and after a UVC measurement).

Length Test

A fish that was recorded on UVC within two minutes of a stereo-DOV measurement was only deemed to be a double up if its length fell within the error adjusted UVC and stereo-DOV lengths. The error adjusted length measurements for UVC is +/-4.6 % of the recorded length (Bellwood and Alcala, 1988) and based on a precision estimate for each individual length, that is calculated in EventMeasure, for stereo-DOV. When a double count was identified, the UVC measurement was removed from the combined data set.

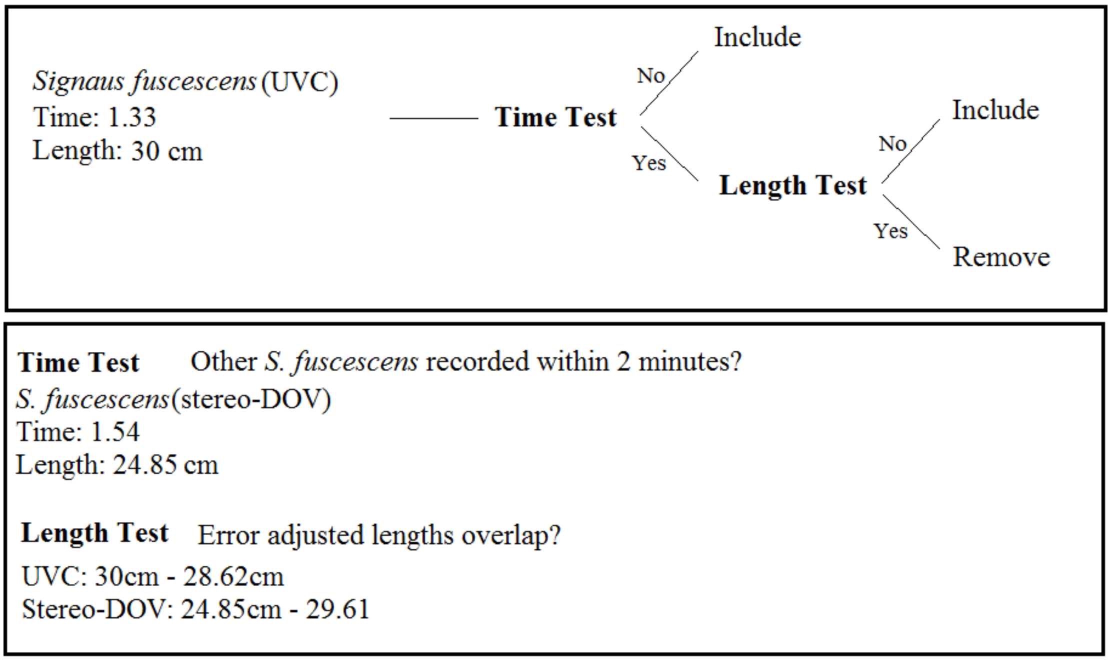

Fig. 2. Graphical representation of the two test process used to combine UVC and STEREO-DOV

measurements. In this case the UVC recorded individual was a double up and removed from the final data set.

2.3.3 *Species classification and comparison*

Species were defined as being temperate, subtropical or tropical based upon their distributions as described in the relevant literature (Allen and Swainstone, 1988; Fishbase, (www.fishbase.org); Hutchins, 1991, 1994). Recordings of transient species that were chance encounters were not included when defining species' distributions (Hutchins, 1994). We compared our combined data to a list of species seen at Rottnest Island prior to 1994 (Hutchins, 1994) and with baseline records of herbivore abundance (Jones and Andrew, 1990). When assessing habitat associations, tropical species were grouped into schooling and non-schooling fish to reduce the effect of highly abundant fish masking the habitat associations of less abundant species. Schooling fish were defined as fish that were seen on either trip in schools of 15 individuals or more.

2.3.4 *Statistical analysis*

Due to the large variations in the abundance of species the data underwent a 4th root transformation. A repeated measures analysis of variance using the PRIMER-E package was run with 9,999 permutations (PERMANOVA+; Anderson et. al., 2001) with trip (two levels) and site (18 levels) as fixed factors to determine if there were differences in the data collected between the two trips. A principle coordinates analysis (PCO) was used to highlight these differences.

Habitat associations were assessed using the statisticXL add on to Excel. A goodness of fit test was run on groups of species to assess the habitats with which they were most associated. This test assumed all habitats were utilised equally by fish and used the total number of fish seen and the time spent observing each habitat to calculate an expected number of fish per habitat. This was compared with the number of fish observed in each habitat (observed - expected) to identify habitats with which fish had positive associations.

3 Results

3.1 *Descriptive results*

The stereo-DOV observed 17,893 individuals from 100 species with UVC adding 3,014 individuals (including 23 species only recorded on UVC) to give a total of 20,907 fish from 123* species (*127 including opportunistic sightings).

3.2 *Differences between trips*

Assemblages varied significantly between the two trips (PERMANOVA, F= 3.4804, P= 0.0002) with a principle coordinates analysis highlighting grouping of the two trips and a shift between them (Fig. 3).

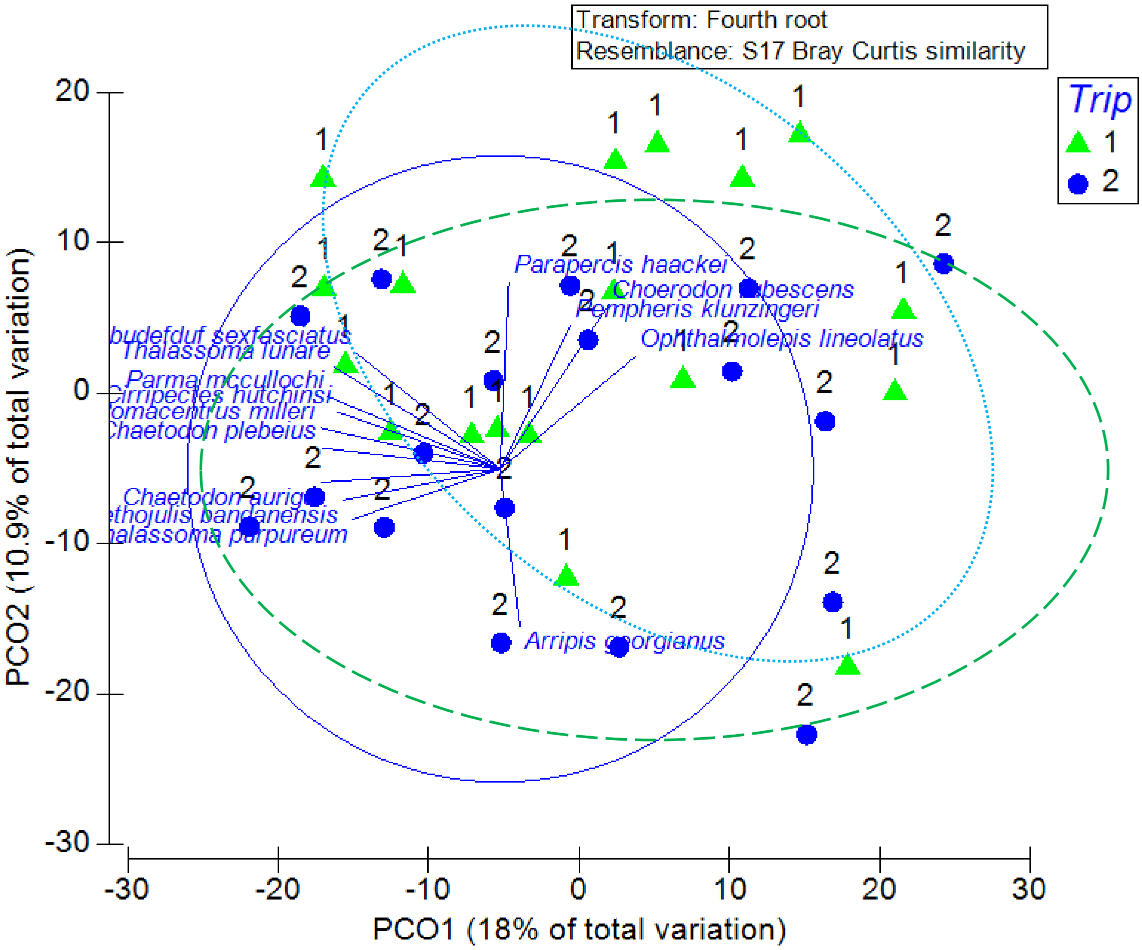

Fig. 3.
A principle coordinate analysis (PCO) highlighting the differences between trips via a vector overlay of correlated species.

A univariate analysis (using trip and site as factors) for the tropical species *Chaetodon auriga*, *Stehojulis bandenensus* and *Thalassoma pupureum* (Fig. 3) found changes in their abundance to be non-significant (P>.05). They were likely correlated with habitat which could not be separated by site.

The amount of macroalgae surveyed in each trip varied with 161 minutes less surveyed on trip two, which surveyed 179 minutes more turfing alage habitat (Table 2).

Table 2

Total time surveying each habitat over both trips. Bolded habitats had large changes in the time spent surveying between the trips.

Trip1(December)

Habitat	Total time in habitat (mins)
Macroalgae	**262.6695**
Turfing Algae	**119.3913**
Coral	23.8339
Seagrass	324.9731
Sand and Rubble	349.9672
Total time surveying	1080.835

Trip 2 (March)

Habitat	Total time in habitat (mins)
Macroalgae	**100.7585**
Turfing algae	**299.2362**
Coral	35.4113
Seagrass	315.7386
Sand and Rubble	331.5423
Total time surveying	1082.687

3.3 *Number of tropical species*

Tropical fish made up 36.2% of recorded species with 46 tropical, 30 subtropical and 51 temperate species. Of the 46 tropical species recorded in our surveys, 20 were first sighted at Rottnest Island sometime between 1979 and 1994 (Hutchins, 1979, 1994). We also recorded six additional tropical species (Table 3) which, according to the published literature, are new sightings since surveys in 1994 (Hutchins, 1994).

Table 3
Species we observed that had not been sighted at Rottnest Island before 1994 (Hutchins, 1994) and their abundance on both trips.

Species/common name	Trip 1	Trip 2
Abudefduf bengalensis (Narrow-Banded Sergeant Major)	0	3
*Chaetodon speculum** (Mirror Butterflyfish)	0	1
Diagramma labiosum (Painted Sweetlip)	1	2
Paracirrhites forsteri (Freckled Hawkfish)	0	1
*Plectroglyphidodon johnstonianus** (Johnston Damsel)	3	1
*Pomacanthus sexstriatus*** (Sixbar Angelfish)	0	1
Scarus psittacus (Palenose Parrotfish)	3	5

*Indicates fish first seen during the heatwave in 2011 (Pearce and Hutchins, 2014).

**Indicates fish identified during opportunistic sightings

3.4 *Biomass of species*

Fish assemblages at Rottnest Island were dominated by four species making up 69.6% of the total biomass (Fig. 4). These were the temperate herbivores *Kyphosus cornelii* (Western Buffalo Bream) and *Kyphosus sydneyanus* (Silver Drummer) and the tropical herbivores *S. fuscescens* and *Scarus ghobban* (Blue-bar parrotfish). In total 26.5% of the relative biomass was made up by tropical species, 21.2% of which were tropical herbivores.

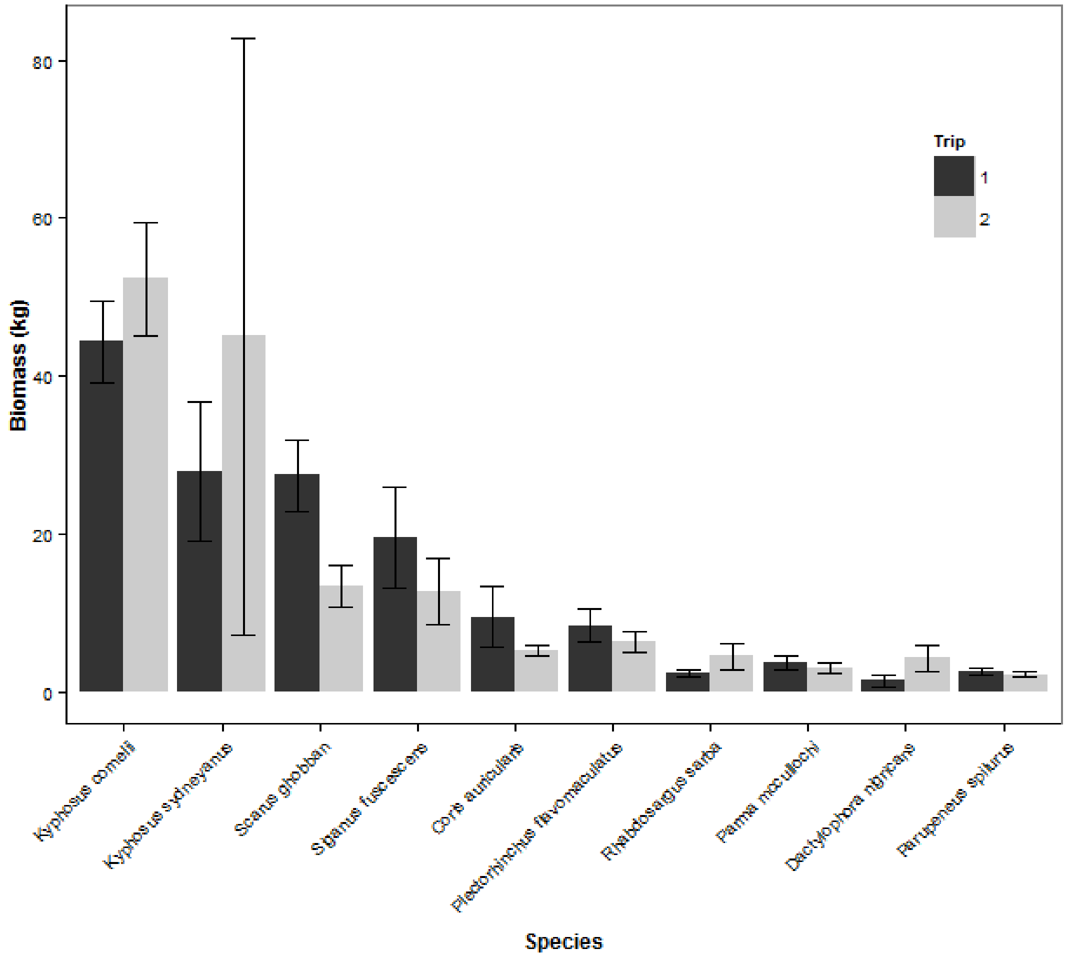

Fig. 4. The mean biomass and standard error for the ten species with the highest biomass across our 18 sites.

3.5 *Abundance of species*

Three tropical species were identified in the top ten most abundant species including tropical herbivores *S. fuscescens* and *S. ghobban* as the 4th and 5th most abundant species (Table 4). *S. fuscescens* individuals averaged 27.9 cm in length (maturity reached at 18 cm (www.fishbase.org/)) and were recorded at 16 of the 18 study sights while *S. ghobban* were found at all 18 study sights and averaged 28.4 cm in length (maturity reached at 40 cm (Venkataramani and Jayakumar, 2006). Herbivores made up 45.6% of the fish assemblage, with 29.1% temperate and subtropical and 16.5% tropical species. Parrotfish, family: *Scaridae*, were prominent in the assemblage with 1,825 individuals detected from seven species making up 8.73% of individuals. *Scarus psittacus* (Palenose Parrotfish) made up eight of these individuals and averaged 28.9 cm in length (maturity reached at 19 cm (Page, 1998)).

Table 4

The 10 most abundant species ranked in order of abundance with *Kyphosus corelii* being the most abundant and *Notolabrus parilus* being the 10th most abundant species.

Species		Distribution
Kyphosus cornelii	(Western Buffalo Bream)	Subtropical
Coris auricularis	(Western King Wrasse)	Subtropical
Arripis georgianus	(Australian Herring)	Temperate
Siganus fuscescens	(Mottled Spinefoot)	Tropical
Scarus ghobban	(Blue-bar parrotfish)	Tropical
Parma mccullochi	(Mcculloch's Scalyfin)	Temperate
Trachinops brauni	(Bluelined Hulafish)	Subtropical
Rhabdosargus sarba	(Tarwhine)	Subtropical
Plectorhinchus flavomaculatus	(Goldspotted Sweetlip)	Tropical
Notolabrus parilus	(Brownspotted Warsse)	Temperate

3.6 *Habitat associations of tropical species*

The abundance of fish recorded varied significantly with habitat type ($P<.0001$) with schooling tropical fish (*S. fuscescens* and *S. ghobban*) having a positive association with macroalgae and seagrass habitats (Table 5). Non-schooling fish (all other tropical species) were associated with coral, macroalgae and turfing algae habitats (Table 6).

Table 5

The habitat associations of tropical schooling fish. Bolded habitats indicate habitats that fish were positively associated with.

Habitat	Observed	Expected	Obs - Exp
Coral	10	85.24541	-75.2454
Macroalgae	**818**	**522.9212**	**295.0788**
Seagrass	**1438**	**921.8929**	**516.1071**
Turfing algae	247	602.3454	-355.345
Sand and rubble	600	980.5951	-380.595

Table 6

The habitat associations of non-schooling tropical fish. Bolded habitats indicate habitats that fish were positively associated with.

Habitat	Observed	Expected	Obs - Exp
Coral	**283**	**56.84853**	**226.1515**
Macroalgae	**475**	**348.7261**	**126.2739**
Seagrass	367	614.7927	-247.793
Turfing algae	**672**	**401.6926**	**270.3074**
Sand and rubble	279	653.9401	-374.94

4 Discussion

Hutchins describes a species to be within its distribution if conditions are suitable for all its life stages (Hutchins, 1994). While many tropical species were observed in low abundances, their maximum recorded size is significant and indicates conditions are suitable for survival of individuals up to that size (Figueira and Booth, 2010). If mature individuals of a species are seen, then the conditions are considered suitable for all life stages of that species**.** The size, abundance and location of sightings of *S. psittacus* (described distribution as far south as Ningaloo) and *S. fuscescens* (described distribution as far south as Houtman Abrolhos (Hutchins, 1994)) may represent a shift in their distributions. Recordings of these species were not considered to be chance encounters, with both being sighted on numerous occasions, as mature individuals and across locations. As accurate and up to date data on the distribution of these species is not available, it is difficult to say with certainty that these records indicate a recent shift, however they do suggest a poleward extension of their range since 1994.

The current assumption that coral is an important habitat for tropical species at Rottnest Island is an over generalisation. While there are numerous species that are highly associated with coral habitats, many of the most abundant tropical species are not. *S. ghobban* is one such species which, despite assumptions it associates with coral habitat (Hutchins, 1979), had no positive association with coral. This assumed association came from the species historically only occurring in bays with significant coral habitat. Given our findings, the warmer temperatures generally experienced by these bays is likely to have been the factor responsible for their historical occurrence. As temperatures have risen over the last few decades, more bays have attained temperatures suitable for tropical species, allowing these species a wider choice of habitats. This may be resulting in a clearer picture of the habitat associations of tropical species, and shows the importance of assessing a variety of habitats when surveying tropical fish in temperate environments.

We identified three tropical species in the top ten most abundant fish which, given surveys in 1994 (Hutchins, 1994) identified no tropical species in the ten most abundant species, indicates an increase in the relative abundance of tropical species at Rottnest Island. These included tropical herbivores *S. fuscescens* and *S. ghobban* as the 4th and 5th most abundant species whose recent proliferation (B. Hutchins pers. comm.) is reflected in an increase in the relative abundance of herbivores from 28.3% of fish in 1990 (Jones and Andrew, 1990) to 45.6% in 2015. The similar abundance of temperate herbivores to levels in 1990 suggests that rather than displacing them, tropical herbivores may exist as an additional 21.2% biomass on Rottnest Island's reefs. As temperatures continue to rise, this increased dominance of herbivores may promote overgrazing of macroalgae. The dominance of Parrotfish, whose feeding technique removes macroalgae recruits, means that macroalgal assemblages that have suffered overgrazing may fail to recover.

While they pose a threat to macroalgal assemblages, the establishment of *S. ghobban* and *S. fuscecens* may represent a new fisheries resource with potential economic value. While there are no commercial finfish fisheries at Rottnest Island, recreational fishing is popular in the area. Both these fish are considered good eating and targeting of these species may provide value for fisherman whilst reducing herbivory pressures on macroalgae. Though the Department of Fisheries have stated that where range extensions have been made management strategies will be reviewed (Lenanton et al., 2014), as little is known about their recruitment at Rottnest Island, it would be difficult to create a management plan based upon sustainable extraction. Also, before any fisheries management solutions are incorporated, more information is needed on changes at the northern margins of these species' distributions to help identify the importance of these new southern populations to the population.

While we found the proportion of tropical species to be 9% higher than three previous studies, variations in the methods used between studies make it difficult to identify if this increase has been caused by tropicalisation (Huthcins 1979, 1994; Watson and Harvey, 2009). Despite identifying six tropical species that were not recorded in any of these studies, the transient nature of many species means it is difficult to establish changes in overall proportions of species. While both studies by Hutchins (1979, 1994) found tropical species to make up at least 26% of recorded species, the study by Watson and Harvey (2009) found that tropical species only made up 2% of the assemblage. As this study was the only one that did not survey inshore areas (depths less than 6 m), a large amount of the variation between these studies may have arisen from differences in the depth ranges they assessed. The results from our study suggest inshore areas are providing an important habitat and future surveys assessing tropical species assemblages at Rottnest Island should incorporate inshore waters as well as deeper waters.

Previous studies have shown that the choice in survey method can create a range of biases (Goetze et al., 2014; Holmes et al., 2013;Watson et al., 2005). ASD overcomes some of these issues by combining both techniques, making the most of their unique advantages. The 23 species only detected by UVC represent a large number of cryptic fish that would have otherwise been missed using only stereo-DOV. While the stereo-DOV provided habitat data that could be linked to fish and a permanent record. Whilst the combination of ASD data required an extra step, the efficiency created in the field by combining the two techniques meant that overall there was no added time cost compared to utilising both techniques separately. The use of ASD should be considered for future fish surveys as it creates a data set that allows for a more detailed assessment of fish assemblages.

On one instance during our second trip we witnessed breeding behaviour by *Abudefduf sexfasciatus* (Scissortail Sergeant) which has previously not known to be occurring at Rottnest Island (Pearce and Hutchins, 2014; pers. obv.). Nesting males are known to show courtship colouration when presenting to females whereby they lose their disruptive colour bars (The atlas of living Australia, 2015). We witnessed a male present itself to females in its courtship colouration (including a white spot on its body between its dorsal and tail fins) (Fig. 5). After presenting to a female it would shoot back down to a crevice in the reef (presumably its nest) before repeating the process several times.

Fig. 5. The same *Abudefduf sexfasciatus* individual pictured first with courtship colours, which when approached (second picture) returned to normal disruptive camouflage bars.

While breeding activity is not a prerequisite for a distribution shift (Hutchins, 1994), it suggests conditions are becoming increasingly suitable for tropical species. If breeding activity by tropical species is successful, it may further accelerate tropicalisation and provide a stepping stone for the export of tropical recruits to new locations south of where they could have previously been transported.

The decrease in macroalgae surveyed on trip two is likely to be related to the perennial life cycle of *Sargassum* whereby after reproduction in late summer, it loses its thali (Kendrick and Walker, 1994). This natural decrease in *Sargassum* biomass is likely to have been reflected by the increase in turfing algae habitat on trip two. This natural decrease in *Sargassum* biomass has been shown to influence fish abundances on reefs in other parts of the world (Ornellas and Coutinho, 1998) and further assessment of this process could identify links to changes in fish assemblages at Rottnest Island.

5 Conclusion

This paper provides a comprehensive inshore assessment of fish assemblages at Rottnest Island. It supports our hypothesis that Rottnest Island is undergoing a tropicalisation with an increase in the diversity and abundance of tropical fish leading to an overall increase in their dominance in the assemblage. It also provides evidence of a change in the assemblage structure of species with an increase in the abundance of tropical herbivores likely to placing increased grazing pressure on macroalgal assemblages. This, combined with the dominance of Parrotfish, may be the first step of a habitat phase shift away from macroalgae dominated reefs. The potential for long term ecological changes means ongoing monitoring of Rottnest Island’s tropical fish and macroalgal assemblages is essential. Rottnest Island's unique habitats and offshore location means it is likely to experience a more rapid tropicalisation than areas at similar latitudes closer to the mainland which may be used in predicting future changes along Australia's south-west coast.

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Appendices

Appendix I: Images for taxa not seen at Rottnest before 1994

Paracirrhites forsteri

(Freckled Hawkfish)

Michael Tropiano

*Plectroglyphidodon johnstonianus***

(Johnston Damsel)

http://www.fishbase.org/

*Pomacanthus sexstriatus**

(Sixbar angelfish)

http://www.fishbase.org/

Scarus psittacus

(Palenose Parrotfish)

Michael Tropiano

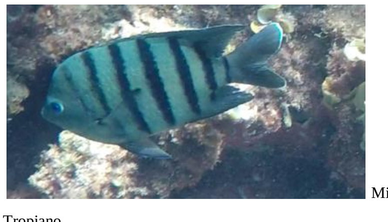
Chaetodon speculum

(Mirror butterflyfish)

Michael Tropiano

Abudefduf bengalensis

(Narrow-Banded Sergeant Major)



Michael Tropiano

Diagrammalabiosum

(Painted Sweetlip)

Michael Tropiano

*Indicates fish identified during opportunistic sightings

** Indicates fish first seen during the heatwave

Appendix II: Full names of survey sights

Abreviation	Official site name
BP	Bathurst Poin
L	Longreach Bay
LP	Little Parakeet
LA	Little Armstrong
CY	City of York
RB	Ricey Bay
ST	Stark Bay
RK	Rockey Bay
CR	Cathedral Rocks
FH	Fish Hook Bay
SLB	Strickland bay
MC	Mary Cove
GI	Green Island
SMB	Salmon Bay
LS	Little Salmon Bay
PPR	Parker Point Sanctuary
PPF	Parker Point Fished
WR	Wallace reef

Appendix III: Journal Format – JEMBE

Journal of Experimental Marine Biology and Ecology 400 (2011) 17–32

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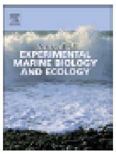

Climate change cascades: Shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania

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ABSTRACT

Several lines of evidence show that ocean warming off the east coast of Tasmania is the result of intensification of the East Australian Current (EAC). Increases in the strength, duration and frequency of southward incursions of warm, nutrient poor EAC water transports heat and biota to eastern Tasmania. This shift in large-scale oceanography is reflected by changes in the structure of nearshore zooplankton communities and other elements of the pelagic system; by a regional decline in the extent of dense beds of giant kelp (*Macrocystis pyrifera*); by marked changes in the distribution of nearshore fishes; and by range expansions of other northern warmer-water species to colonize Tasmanian coastal waters. Population-level changes in commercially important invertebrate species may also be associated with the warming trend.

Over-grazing of seaweed beds by one recently established species, the sea urchin *Centrostephanus rodgersii*, is causing a fundamental shift in the structure and dynamics of Tasmanian rocky reef systems by the formation of sea urchin 'barrens' habitat. Formation of barrens represents an interaction between effects of climate change and a reduction in large predatory rock lobsters due to fishing. Barrens realize a loss of biodiversity and production from rocky reefs, and threaten valuable abalone and rock lobster fisheries and the local economies and social communities they support. This range-extending sea urchin species represents the single largest biologically mediated threat to the integrity of important shallow water rocky reef communities in eastern Tasmania.

In synthesizing change in the physical ocean climate in eastern Tasmania and parallel shifts in species' distributions and ecological processes, there is evidence that the direct effects of changing physical conditions have precipitated cascading effects of ecological change in benthic (rocky reef) and pelagic systems. However, some patterns correlated with temperature have plausible alternative explanations unrelated to thermal gradients in time or space. We identify important knowledge gaps that need to be addressed to adequately understand, anticipate and adapt to future climate-driven changes in marine systems in the region.

Contents

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