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Storm-induced changes in environmental conditions are correlated with shifts in temperate reef fish abundance and diversity

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ABSTRACT

We studied the effects of regularly occurring non-destructive storm events on a temperate Australian reef fish assemblage. We collected 78 remote underwater stereo-video samples during four storms. The relative abundance and species richness of fishes were compared to environmental data (significant wave height, water motion, temperature, light intensity and mean surface level pressure) collected during each storm. As wave height and water motion increased, there was a general decline in abundance of fishes and species richness within the assemblage. The variation in the total number of individual fishes was best explained by a combination of water motion, mean surface level pressure, and temperature. Species richness decreased at the height of the storms, and was best explained by significant wave height and mean surface level pressure. Certain fish species were observed to be highly sensitive to fluctuations in different environmental variables, while others proved more resilient to the changing conditions. Sensitive species such as *Austrolabrus maculatus* disappeared from the recorded assemblage when wave height reached ~3 m. In contrast, more resilient species such as *Parma mccullochi* persisted until the occurrence of more severe conditions (wave height > 5 m). In addition to wave height and water motion, temperature, light intensity and mean surface level pressure all contribute to models explaining variation in the abundance of fish species during these storm events. We suggest that environmental changes during storm events have an influence on the behaviour of fishes depending on their morphological and physiological characteristics, and that sensitive species may migrate from the area or seek refuge in the reef substrate to weather the storm. Our results suggest that it may be important to consider meteorological conditions when conducting fish surveys, and further work should examine the susceptibility of different species to rapid changes in environmental conditions.

1. Introduction

Marine ecosystems vary along a wide range of spatial, temporal and organisational scales (Levin, 1992). This variability creates predictable oscillations in community structure that are driven by a number of physical and biological factors (Ballantyne et al., 2011). Shifts in the composition of fish assemblages can occur over fine temporal scales in response to altered environmental conditions that affect feeding patterns, predator–prey interactions and other behavioural processes (Chabanet et al., 2012). Natural disturbances in environmental conditions resulting from events such as storms, cyclones, coral bleaching, predator outbreaks and mass mortalities of keystone species can induce stochastic shifts in fish assemblages (Adjeroud et al., 2002). These disturbances alter biological interactions and have a structuring effect on communities.

Physical environmental factors play an important role in determining the structure of fish assemblages. Water movement can influence the biological composition of marine communities (Dower et al., 1997). Increased wave height and water motion during a storm could reduce the swimming speed of some fishes (Lupandin, 2005; Liao, 2007). Consequently, certain species will choose to spend time in areas with lower levels of water movement to conserve energy (Johansen et al., 2007; Tritico, 2009). Extreme wave energy during storm events has the ability to displace individuals from an area if they do not seek refuge (Turpin and Bortone, 2002; Lassig, 1983; Hill and Grossman, 1987), although certain species may endure short periods of extreme wave energy (Walsh, 1983) or return once the event has subsided (Cheal et al., 2002). Temperature fluctuations may be increased during storm events due to enhanced mixing processes. Fish and other aquatic species are more sensitive to temperature fluctuations than terrestrial ectotherms (Beitinger and Fitzpatrick, 1979), as they are not generally subject to abrupt changes in temperature (Montgomery and Macdonald, 1990). Light level may be decreased during storm events due to cloud cover and turbidity from agitated bottom sediment or detached marine foliage. Light level and visibility

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conditions can alter behavioural processes such as foraging and feeding in fishes (Townsend and Risebrow, 1982; Puvanendran and Brown, 2002) as well as refuge seeking (Emery, 1973; McCartt et al., 1997). Low pressure systems associated with the onset of a storm event cause a decrease in mean surface level pressure. Some species of marine invertebrates and fish display depth-regulatory behaviour in response to changes in hydrostatic pressure from tidal and weather cycles (Fraser and Shelmerdine, 2002).

Habitat type and structure have important effects on the spatial distributions of reef-associated fish species (Anderson and Millar, 2004), and influences assemblages at both local (Hyndes et al., 2003; Jenkins and Wheatley, 1998) and regional scales (Tuya et al., 2011). Different components of habitat complexity (e.g., rugosity, percentage of live cover, presence of refuge holes) have been suggested to affect the composition of fish assemblages through providing shelter from the influence of predation (Anderson, 1994; Levin and Hay, 1996; Walsh, 1983) and wave energy (Beukers and Jones, 1998). Fishes exhibit a preference for particular habitats that may reflect their functional morphology (Keast and Webb, 1966; Motta et al., 1995) and tolerance for particular environmental conditions (Bellwood et al., 2002; Romer, 1990). Due to differences in species body size, morphology and swimming ability, wave energy and water motion have a significant influence on the structure of fish assemblages (Fulton and Bellwood, 2005). The availability of shelter for smaller-bodied reef fish may be important in providing areas of reduced water movement where they may expend less energy (Santin and Willis, 2007) and endure storm periods.

With the exception of nocturnal shifts (Hobson, 1965; Metcalfe et al., 1998; Harvey et al., 2012; Fitzpatrick et al., 2013), there are very few studies of fine-scale temporal variability in temperate reef fish assemblages that result from environmental changes. Additionally, the majority of current literature on the effects of storms on fish populations refers to large, destructive, cyclonic events (Walsh, 1983; Lassig, 1983; Cheal et al., 2002; Paperno et al., 2006; Rousseau et al., 2010). Our study aimed to evaluate the effects of changes in environmental variables on a temperate reef fish assemblage during regularly occurring storm conditions at levels where habitat destruction does not occur. We investigated correlations between fine-scale, storm-induced changes in environmental conditions and the number of species and individuals recorded in a reef fish assemblage. Remote underwater stereo-video systems (stereo-RUVs) were used to collect video data of a temperate reef fish assemblage each day as wave height increased from calm conditions through storm conditions and returned to calm over the duration of four storm events in South-West Australia.

2. Materials and methods

2.1. Study site

This study was conducted in an area of reef offshore from Warnbro Sound, South-West Australia (Fig. 1). The study reef was characterised by rocky limestone areas with turfing and coralline algae and abundant large plate corals. As we standardised for this habitat, any stereo-RUV deployments that were not on the target habitat were discarded. The depth of the deployments ranged between 19 and 24 m. To capture temporal variation in the fish assemblage, but reduce spatial variation, four storms were studied at the same reef.

2.2. Sampling technique

2.2.1. Stereo-RUVs

Remote underwater stereo-video systems (stereo-RUVs) (Fig. 2) were used to collect fish assemblage data during four storm events that occurred between June and September 2013. Stereo-RUVs are a non-extractive sampling technique (Harvey et al., 2007) that facilitates the identification of fish species as well as the collection of data on their relative abundance and lengths. This technique also allows accurate measurements of the direction and distance of the fish from the centre of the systems. This information can be used to standardise the field of view or to calculate swimming speeds and distance between fish (Harvey et al., 2004). For this study, each system used two Sony Handycam® HDR CX12 video cameras recording full high definition 1920 × 1080 pixel resolution. Each system included a pre-programmed timer and a 16 V battery pack that allowed recording at specified intervals for each day of deployment. The frame of each system was fitted with galvanised steel weights to ensure stability during storm events. Stereo-RUVs were placed at least 100 m apart to reduce the risk of fish overlap between cameras and ensure sample independence without bait (Cappo et al., 2001, 2003, 2006).

2.2.2. Environmental loggers

The environmental variables collected for the modelling procedure were significant wave height (m), mean wave period (s), water motion ($m\,s^{-2}$), temperature (°C), light intensity (Lux) and mean surface level pressure (MSLP, measured in hPa). Environmental loggers were attached to each system to collect water motion, light intensity and temperature data. Water motion data was collected using HOBO Pendant G acceleration data loggers as described in Evans and Abdo (2010) configuration C (Onset Computer Corporation; www.onsetcomp.com/products/data-loggers/ua-00464, accessed 13/05/2014). These three-channel devices record acceleration on three axes (x = up/down, z = back/forth and y = side/side) and can record both static and dynamic acceleration. The measure of water motion that we used was a measure of acceleration along the x and y axes. Temperature and light intensity data was collected using HOBO Pendant Temperature/Light data loggers (Onset Computer Corporation; http://www.onsetcomp.com/products/data-loggers/ua-002-64, accessed 13/05/2014). Light was recorded in lux (lumens m^{-2}). The HOBO loggers were attached to a float on a flexible rope. Significant wave height (m), mean wave period (s), and mean surface level pressure (hPa) data was obtained from the Western Australian Government Department of Transport's Rottnest wave buoy which is located less than 20 km from the study site, with no shallow reef lines between. Therefore, the two locations are likely to experience similar sea states.

2.3. Camera calibration

Each camera system was calibrated prior to deployment using CAL (Seager, 2011) to allow for accurate measurements during video analysis. Calibration involves collecting video footage of a point-marked calibration cube of known dimensions and using the CAL software to calculate lens distortion, camera spacing and orientation (Hardinge et al., 2013), a process detailed by Harvey and Shortis (1995, 1998).

2.4. Video analysis

After collection, the video imagery was converted from HD MTS2 video files to AVI format using Xilisoft Video Converter Ultimate software (http://www.xilisoft.com/video-converter.html, accessed 13/05/2014) prior to image analysis. EventMeasure Stereo software (Seager, 2011) was used to analyse the video data. Fish were identified to species level and counts of their relative abundance were made using the MaxN approach. A MaxN count records the time and the maximum number of fish of one species that are observed in the field of view during any one frame throughout the duration of the recording (Cappo et al., 2003). MaxN is used to avoid repeated counts of the same individuals that may re-enter the field of view (Cappo et al., 2001, 2003, 2006; Hardinge et al., 2013). For every fish a 3D position was allocated using 3D points in EventMeasure. The range component of this 3D position allowed standardisation of the field of view.