Marine Pollution Bulletin 122 (2017) 259–262

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Linking fish species traits to environmental conditions in the Jakarta Bay-Pulau Seribu coral reef system

Daniel F.R. Cleary

Department of Biology, CESAM, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

ARTICLE INFO

Keywords:
Indonesia
Java
Ordination
RLQ

ABSTRACT

Coral reefs around the globe have been subjected to a wide range of stressors. In the present study, fish species were recorded across a pronounced in-to-offshore gradient in the Jakarta Bay-Pulau Seribu reef system. In addition to this, fish species traits were obtained from FishBase. RLQ analysis revealed a significant association between fish species traits and environmental variables. Fish species associated with perturbed, inshore waters were resilient to disturbance, had higher mortality rates, higher growth rates and mainly consumed animals. In contrast, fish species associated with less perturbed, mid- and offshore waters had greater life expectancy, higher age at maturity, greater life span, greater generation time and mainly fed on plants or plants and animals. Eutrophication, pollution and physical destruction of coral substrate in inshore waters has thus selected for a low biomass and depauperate fish community characterised by fast growing and short lived species.

Coral reefs are one of the most diverse marine ecosystems. They also provide a wide range of ecosystem goods and services including coastal protection, tourism and food (Rees et al., 1999; Hughes et al., 2003; Green and Bellwood, 2009). Despite this, coral reefs have been subject to substantial unsustainable exploitation including overfishing and coral mining. Their proximity to the coast has also subjected them to land-based pollution including untreated sewage, agricultural and industrial runoff and increased sedimentation following the loss of coastal forests and mangroves (Jackson et al., 2001; Williams et al., 2000; Green and Bellwood, 2009; Farhan and Lim, 2012). Inshore waters in particular have over time become eutrophied, which has led to poor water visibility and quality.

An area that exemplifies all the problems faced by coral reef systems is the Jakarta Bay-Pulau Seribu system (hereafter referred to as JBTI). The reefs are relatively well studied (Cleary et al., 2006; Rachello-Dolmen and Cleary, 2007; Cleary et al., 2014; Cleary et al., 2016) and a prime example of a still intact albeit perturbed coral reef system adjacent to a megacity, namely Jakarta, the capital of Indonesia. Jakarta is a major conurbation housing more than > 26 million inhabitants (Demographia, 2012). Sewage and storm water are transported over a 2000 km^2 catchment area to the bay, which is defined by two flanking delta systems with considerable sediment input (Rees et al., 1999; Williams et al., 2000; Rinawati et al. 2012). River discharge in JBTI contains (excessive) nutrients, pollutants, heavy metals and household litter (Willoughby, 1986; Uneputty and Evans, 1997; Willoughby et al., 1997; Hosono et al., 2011; Baum et al., 2015). Previous studies have reported on the pronounced in-to-offshore gradient in environmental conditions in JBTI. Inshore, JBTI has been shown to have poor to very poor water transparency, heavy nutrient loads and depauperate coral assemblages. Offshore, coral cover and diversity is much higher and water transparency and quality better than inshore (DeVantier et al., 1998; Cleary et al., 2008, 2014). Mean annual precipitation is 1700 mm yr^{-1} with a ‘wet’ season during the northwest monsoon (November–March) and a ‘dry’ season during the southeast monsoon (May–September) (Rees et al., 1999).

In the present study, fish species were recorded and habitat and water quality parameters measured in order to link fish species traits to environmental conditions using RLQ analysis, a three-table ordination method that directly relates species traits to environmental attributes (Dolédec et al., 1996). Scores of species in RLQ axes can, furthermore, be used to define functional groups, which can aid conservation management. Changes in disturbance regimes can thus be directly related to changes in species traits instead of being indirectly related via taxonomic composition (Ribera et al., 2001).

One can ask what traits species of disturbed inshore reefs share and what traits species of the less disturbed offshore reefs share. Identifying the sets of traits associated with both types of reefs can help us to understand how disturbance affects the coral reef fish community. If species at multiple sites are affected by the same perturbation then species that survive should possess traits promoting persistence whereas species that disappear or decline in abundance should possess traits that promote susceptibility. The identification of these traits can help in identifying how the perturbation affects communities and can be used to develop effective conservation strategies (Lips et al., 2003).

E-mail addresses: cleary@ua.pt, dfrcleary@gmail.com.

http://dx.doi.org/10.1016/j.marpolbul.2017.06.054
Received 8 December 2016; Received in revised form 19 June 2017; Accepted 19 June 2017
Available online 26 June 2017
0025-326X/

In particular, understanding the relationship between sets of traits and environmental conditions can help us to understand which traits are associated with increased sensitivity to disturbance (Ribera et al., 2001). The aim of the present study was to test for significant associations between fish species traits and environmental variables in relation to the in-to-offshore disturbance gradient in JBTI.

Sampling for the present study occurred from September 7th – 23rd 2005 mainly on the northwestern sides of surveyed reefs (see Cleary et al., 2016 for a map and table of the reefs sampled). Fishes were visually assessed by scuba diving along six transects (30 m long) at each of two studied depths (3 and 5 m). Individuals observed within 5 m on either side of the transect were identified to species, if possible, and recorded. Individuals that left the transect area and re-entered were not counted again (Hoey and Bellwood, 2008; Dickens et al., 2011). In total, 28 sites were surveyed. For the purposes of this study, the two depth transects were pooled per site. During sampling, the cover of coral and other benthic cover categories was estimated along each transect using the line intercept transect survey method (English et al., 1997). This included the cover of *Acropora* corals, branching corals, encrusting corals, foliose corals, massive corals, submassive corals, mushroom corals, turf algae, macroalgae, dead coral, rubble and sand. In line with earlier studies of JBTI (DeVantier et al., 1998; Cleary et al., 2006; Cleary et al., 2008), sample sites were assigned to specific zones along an in-to-offshore gradient, namely: an inshore zone (zone 1) to the south of -5.97° latitude, a midshore zone (zone 2) between -5.77° and -5.97° latitude, and an offshore zone (zone 3) to the north of -5.77° latitude. The offshore zone is largely contained within the Pulau Seribu National Marine Park, the first marine park established in Indonesia (Farhan and Lim, 2012). Raw fish counts per site and values for benthic cover are provided as supplementary tables to Cleary et al. (2016).

In addition to assessing the benthic substrate, water quality was also quantified using an aqua Troll water quality instrument (In situ Inc., Fort Collins, CO, USA) to measure temperature (Tmp), pH, dissolved oxygen (DO; Clark DO μgs l^{-1}) and salinity (Sal: parts per thousand [ppt] or ‰). This was supplemented with water transparency, measured once in each site using a Secchi disk, and satellite imagery to measure four water quality variables. These variables were: coloured dissolved organic matter index (CDOM), near-surface chlorophyll-a concentration (Chla), sea surface temperature (SST) and remote sensing reflectance at 645 nm (Rrs_645). They were assessed following previously described methods (Polónia et al., 2015). Rrs_645 is a proxy for total suspended sediments (Miller and Mckee, 2004; Chen et al., 2007) and CDOM largely consists of humic and fulvic substances from runoff containing decaying plant material from areas with high vegetation productivity or originating from mangroves and seagrasses (Carder et al., 1999; Martin, 2004; Richardson and LeDrew, 2006). Given that satellite data accuracy is often higher with long-term averaging (Patt et al., 2003), a single mean value per sample site was generated for the previously mentioned parameters for the years 2002–2005.

Data on selected fish traits were obtained from the species ecology matrix of the Indian Ocean in the FishBase database (Froese and Pauly, 2016). The fish species traits used in the present study are the population means of: maximum length (Lmax; cm), L infinity (Linf; cm), the von Bertalanffy growth function K (K; 1/year), life span (Years), natural mortality (M; 1/year), generation time (Gen; years), age at first maturity (AgeM; years), length at maturity (Lm; cm), length at maximum yield (Lopt; cm), resilience (Res), trophic level (Trop) and dummy variables for the food items animals, plants and both. Detailed descriptions of the variables can be found at http://fishbase.us/manual/English/Key%20Facts.htm. In summary, L infinity (Linf) is the length that a fish would reach if it were to grow indefinitely, the von Bertalanffy growth function K is the rate at which asymptotic length is approached and generation time is the average age of parents at the time their young are born. Length at maximum yield is the length class with the highest biomass. Resilience (or productivity) is a categorical variable defined as high, medium, low and very low in response to disturbances. Data for certain variables were not available for all species. Generic mean values were then used instead in order to avoid missing values.

Species traits were directly linked to environmental variables with a three-table ordination method known as RLQ analysis, (Dolédec et al., 1996; Ribera et al., 2001) using the ADE4 software package (http://pbil.univ-lyon1.fr/ADE-4/) within R (http://www.r-project.org/). See Rachello-Dolmen and Cleary (2007) and Cleary et al. (2007) for detailed descriptions of the method. In summary, R is a table of environmental variables at a set of sites, L is a table of the species composition at corresponding sites and Q is a table of traits for the species in table L. Prior to RLQ analysis, three separate tables were constructed using correspondence analysis (CA) for species composition and principal components analysis (PCA) for environmental and traits variables. R was subsequently linked with L using row weights (site scores) obtained with CA and Q was linked with L using column weights (species scores) obtained with CA. RLQ combines these three analyses by maximising the covariation between environmental variables and species traits whereby site scores in the R table constrain site scores in the L table and species scores in the Q table constrain species scores in the L table. The relationship between the R and Q tables was tested for significance with a permutation test using 1000 random permutations in which the inertia was compared with the total inertia in the dataset. The constrained ordination resulting from the three tables was finally compared with each of the unconstrained separate analyses whereby the percentage of the variation calculated by the RLQ analysis was subsequently compared to the variation explained by the separate analyses.

There was a highly significant (Permutation test; $P < 0.001$) association between fish species traits and environmental variables. The first two axes of the RLQ analysis explained 86% and 8% respectively of the total variance in the matrix crossing the environmental variables and traits. The first two RLQ axes also accounted for 82% of the variation in the separate analysis of environmental variables, 69% of the variation in trait variables and 23% of the variation in species composition. Less variation is generally explained in the species composition table because RLQ analysis rearranges species and site scores to maximise covariance between species traits and environmental variables. A detailed examination of the covariation of environmental variables and species traits is presented in Fig. 1 showing the first two RLQ axes.

Along axis 1 (eigenvalue: 0.179; covariance: 0.423), fish species associated with inshore waters, characterised by higher Chlorophyll-a values, higher sand cover and higher SST among other things (see Cleary et al., 2016), were resilient, had a higher mortality rate, higher growth rate (K), consumed animals and thus had a higher mean trophic level. In contrast, species associated with mid- and offshore waters characterised by higher transparency, live branching and *Acropora* coral cover and CDOM, among other things, (Cleary et al., 2016) had a greater life expectancy, higher age at maturity, greater life span, greater generation time and fed mainly on plants or plants and animals. Along the second axis (eigenvalue: 0.017; covariance: 0.128), fish species associated with sites with higher turf algae cover were longer (Lm, Linf, Lmx and Lopt) than fish species associated with sites with higher dead coral, encrusting coral, foliose coral and massive coral cover.

Previous studies of JBTI showed that there was a pronounced in-to-offshore gradient in environmental conditions and concomitant pronounced variation in the composition of a number of taxa including fishes, corals and sponges along the gradient (Cleary et al., 2008; Cleary et al., 2014; Cleary et al., 2016). Significant associations between environmental variables and coral species traits have also been previously demonstrated using RLQ analysis (Rachello-Dolmen and Cleary, 2007). In the present study, this also holds true for fish species. Fish species in perturbed inshore waters are thus relatively fast growing and short-lived compared to their offshore counterparts. This includes species