4. Rukai, L., Xiaoming, W., Huoming, W. and Gang, Z., Research on adhesive dosage of porous polyurethane gravel pavement. *Highway Eng.*, 2015, **40**, 105–108.
5. Qiushi, L. and Dongpo, H., Comparative study of porous concretes using naturaland recycled aggregates. *J. Beijing Univ. Technol.*, 2015, **41**, 89–94.
6. Zhang, P., Zhao, Y. N., Li, Q., Wang, P. and Zhang, T. H., Flexural toughness of steel fiber reinforced high performance concrete containing nano-SiO_2 and fly ash. *Curr. Sci.*, 2014, **106**, 980–987.
7. Blissett, R. S. and Rowson, N. A., A review of the multi-component utilization of coal fly ash. *Fuel*, 2012, **97**, 1–23.
8. Berez, A., Schäfer, G., Ayari, F. and Trabelsi-Ayadi, M., Adsorptive removal of azo dyes from aqueous solutions by natural bentonite under static and dynamic flow conditions. *Int. J. Environ. Sci. Technol.*, 2016, **13**(7), 1625–1640.
9. Gao, Y., Zhu, B., Yu, G., Chen, W., He, N., Wang, T. and Miao, C., Coupled effects of biogeochemical and hydrological processes on C, N, and P export during extreme rainfall events in a purple soil watershed in southwestern China. *J. Hydrol.*, 2014, **511**, 692–702.
10. Li, L. and Davis, A. P., Urban stormwater runoff nitrogen composition and fate in bioretention systems. *Environ. Sci. Technol.*, 2014, **48**, 3403–3412.
11. Zinger, Y., Blecken, G. T., Fletcher, T. D., Viklander, M. and Deletić, A., Optimising nitrogen removal in existing stormwater-biofilters: benefits and tradeoffs of a retrofitted saturated zone. *Ecol. Eng.*, 2013, **51**, 75–82.
12. Liu, J. and Davis, A. P., Phosphorus speciation and treatment using enhanced phosphorus removal bioretention. *Environ. Sci. Technol.*, 2014, **48**, 607–620.
13. Wang, B., Li, T., Meng, Y., Ren, Z. and Cao, B., Distribution from of nutrients in roof runoff. *Environ. Sci.*, 2008, **29**, 3035–3042.
14. Jeppu, G. P. and Clement, T. P., A modified Langmuir-Freundlich isotherm model for simulating pH-dependent adsorption effects. *J. Contam. Hydrol.*, 2012, **129**.
15. Phetphaisit, C. W., Yuanyang, S. and Chaiyasith, W. C., Polyacrylamido-2-methyl-1-propane sulfonic acid-grafted-natural rubber as bio-adsorbent for heavy metal removal from aqueous standard solution and industrial wastewater. *J. Hazard. Mater.*, 2015, **301**, 163–171.
16. Park, C. M., Chu, K. H., Heo, J., Her, N., Jang, M., Son, A. and Yoon, Y., Environmental behavior of engineered nanomaterials in porous media: a review. *J. Hazard. Mater.*, 2016, **309**, 133–150.
17. Mahmoodian, H. *et al.*, Enhanced removal of methyl orange from aqueous solutions by poly HEMA–chitosan-MWCNT nano-composite. *J. Mol. Liq.*, 2015, **202**, 189–198.
18. Latour, R. A., The langmuir isotherm: A commonly applied but misleading approach for the analysis of protein adsorption behavior. *J. Biomed. Mater. Res. A*, 2015, **103**, 949–958.
19. Ghosal, P. S. and Gupta, A. K., Determination of thermodynamic parameters from Langmuir isotherm constant-revisited. *J. Mol. Liq.*, 2016, **225**, 137–146.
20. Xia, L. X., Shen, Z., Vargas, T., Sun, W. J. and Ruan, R. M., Attachment of Acidithiobacillus ferrooxidans onto different solid substrates and fitting through Langmuir and Freundlich equations. *Biotechnol. Lett.*, 2013, **35**, 2129–2136.
21. Nakkeeran, E. *et al.*, Hexavalent chromium removal from aqueous solutions by a novel powder prepared from Colocasia esculenta leaves. *Int. J. Phytoremediation*, 2016, **42**, 812–821.
22. Saranya, N., Nakkeeran, E., Shrihari, S. and Selvaraju, N., Equilibrium and kinetic studies of hexavalent chromium removal using a novel biosorbent-Ruellia patula Jacq. *Arab. J. Sci. Eng.*, 2017, **18**, 1545–1557.
23. Çınar, S. *et al.*, An efficient removal of RB5 from aqueous solution by adsorption onto nano-ZnO/Chitosan composite beads. *Int. J. Biol. Macromol.*, 2017, **96**, 459–465.
24. Guangxing, Z. *et al.*, Adsorption and desorption of ammonia-nitrogen wastewater by modified bentonite. *Chin. J. Environ. Eng.*, 2017, **11**, 1494–1500.

ACKNOWLEDGEMENTS. We acknowledge the funding support from the Major Science and Technology Program for Water Pollution Control and Treatment of China (2010ZX07302-002) and the technology support obtained from the Key Laboratory of Urban Stormwater System and Water Environment (Beijing University of Civil Engineering and Architecture), Ministry of Education.

Received 11 January 2017; accepted 8 July 2017

doi: 10.18520/cs/v114/i02/378-384

Climate change-induced coral bleaching in Malvan Marine Sanctuary, Maharashtra, India

K. Diraviya Raj[1,*], G. Mathews[1], M. Selva Bharath[1], Rohit D. Sawant[2], Vishal Bhave[3], Deepak Apte[3], N. Vasudevan[2] and J. K. Patterson Edward[1]

[1]Suganthi Devadason Marine Research Institute, 44-Beach Road, Tuticorin 628 001, India
[2]UNDP Sindhudurg Project and Mancrove Cell, Mumbai 400 051, India
[3]Bombay Natural History Society, Mumbai 400 001, India

Malvan Marine Sanctuary (MMS), Maharashtra, India is rich in coral reefs and the associated resources, which provide livelihood for the people involved in fishing and tourism. The elevated sea-surface temperature triggered by climate change had caused the coral reefs around the world to undergo severe bleaching during 2014–2016. Scientists have declared this as the third global coral bleaching event. Two underwater surveys during December 2015 and May 2016 were conducted in MMS to assess the intensity and trend of coral bleaching. A high prevalence of coral bleaching, i.e. 70.93% (SD = 4.53) was recorded inside MMS during December 2015, with a mortality of about 8.38% (SD = 0.91). After a lapse of six months, corals were found to recover. This is borne out by the reduction in the bleaching prevalence to 6.77 ± 0.12% during May 2016. Climate change being a global issue, reduction in the local stressors such as fishing and tourism is highly recommended in order to allow the corals to recover and enable sustainable utilization of coral reef resources around MMS.

*For correspondence. (e-mail: diraviyam_raj@yahoo.co.in)

Keywords: Climate change, coral bleaching, mortality, marine sanctuary, sea surface temperature.

CORAL reefs are the most diverse marine ecosystems with rich biodiversity and they are known for their beauty, diversity and productivity. About 500 million people around the world are benefited by coral reefs by way of fishing, recreation and tourism. On monetary terms, loss of coral reefs may amount to US$ 1 trillion globally[1]. Corals are animals which respond to any variation in the environment they live in, especially to temperature fluctuations. Coral bleaching or whitening is a general response by corals to elevated sea-surface temperature. Coral bleaching refers to the loss of symbiotic unicellular algae called zooxanthellae from coral tissue. Since the zooxanthellae give colour to the corals, their absence makes the corals look white or bleached. Bleaching happens when corals are exposed to increased sea-surface temperature, say, about 1–2°C. Corals would recover if the normal temperature range is restored within a short period, but if the temperature stress continues for a long time, the corals would die[2]. During 2014–2016, the longest ever known global coral bleaching driven by climate change and El Niño was reported in many countries[2]. The US National Oceanic and Atmospheric Administration (NOAA) had declared this event as the third global coral bleaching because the phenomenon was witnessed in all three ocean basins, namely Indian, Pacific and Atlantic[3,4]. Global coral bleaching has been declared twice before – in 1998 and during 2010 (refs 3, 5).

The Malvan coast in Maharashtra is one of the important tourist attractions in the west coast of India. It is marked by islands, rocky areas and sandy beaches. Corals in Malvan have been reported to be attached to the rocks and are dominated by *Porites* spp.[6]. Malvan Marine Sanctuary (MMS) in the Malvan taluka, Sindhudurg district between 16°15′–16°50′N lat and 73°27′–73°31′E long encompasses an area of 29.22 sq. km (refs 7, 8). It was declared as a Wildlife Sanctuary in 1987 by the Maharashtra Government with a view to protect the coral patches and other important marine ecosystems. The present assessment on coral bleaching was carried out twice during December 2015 and May 2016. Coral bleaching was first noticed during December 2015 while scuba diving around MMS (Figure 1). Corals appeared bleached or white because of the absence of symbiotic zooxanthellae. Detailed assessment on coral bleaching was carried out immediately inside the Sanctuary in December 2015 in areas ranging in depth between 2 and 5 m. The assessment protocol involved scuba diving. The benthic community structure was assessed with twelve 20 m line intercept transects (LIT)[9] around the famous Sindhudurg Fort, with high tourist activity. Twelve 20 m belt transects were laid to assess the prevalence of coral bleaching inside MMS[9]. Each transect covered an area measuring 20 × 2 m (2 m on each side of the transect line) and 20 m distance was allowed between each transect. Underwater documentation of coral bleaching was done using underwater digital camera. The survey was carried out again in May 2016 using the same protocols to assess the trend of bleaching. Sea-surface temperature was measured during both the surveys using a digital thermometer.

LIT results showed that benthic community structure was dominated by corals in MMS during December 2015 with 35.07% (SD = 6.69) followed by sand, rock and algae with 29.36% (SD = 9.4), 24.97% (SD = 5.61) and 10.59% (SD = 4.15) respectively. In May 2016, coral cover was 35.64% (SD = 7.1), while sand, rock and algae were 27.68% (SD = 5.26), 26.37% (SD = 9.78) and 10.31% (SD = 3.8) respectively. The result of belt transects showed massive bleaching of 70.93% (SD = 4.53) during December 2015, and only 29.07% (SD = 4.53) corals were found intact. A total of 11 genera of corals were found bleached. They are *Pavona*, *Coscinaraea*, *Goniastrea*, *Favites*, *Favia*, *Cyphastrea*, *Leptastrea*, *Montastrea*, *Turbinaria*, *Goniopora* and *Porites*. *Favia* (98.61%) and *Favites* (95.9%) were the most affected coral genera by bleaching and *Turbinaria* (17.34%) was found to be least affected. In May 2016, the prevalence of bleaching had come down to 6.77% (SD = 0.12) and 84.84% (SD = 1.03)

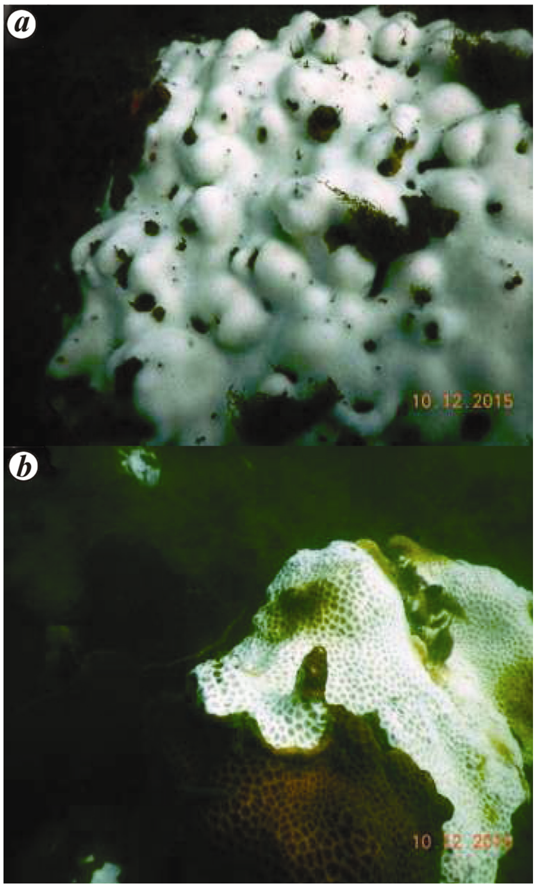

Figure 1. Coral bleaching in Malvan Marine Sanctuary during December 2015. ***a***, Bleached *Porites* sp.; ***b***, Bleached *Favites* sp.

of corals were found normal without bleaching. However, a significant mortality of 8.38% (SD = 0.91) was witnessed during May 2016 because of bleaching. Mortality was found in most of the bleached coral genera with highest percentage in *Porites* (27.78%) and *Coscinarea* (17.04%). *Pavona* and *Leptastrea* were found to have recovered completely as mortality was nil in these genera. Sea-surface temperature ranged between 29.4°C and 29.8°C in December 2015, while it ranged between 28.6°C and 29.3°C in May 2016.

Global average temperature has been rising alarmingly during the past few decades. The year 2015 was the hottest on record in 136 years by breaking the previous record in 2014 (ref. 10). Before 2015, the highest recorded monthly anomaly for the global oceans was 0.74°C above the 20th century average, in September 2014, but this monthly record was broken in August 2015 (+0.78°C), again in September 2015 (+0.83°C), and then broken again in October 2015 (0.86°C). Moreover, the last four months of 2015 were more than 0.80°C higher than their respective average[11]. During 2014, the NOAA Coral Reef Watch 5 km degree heating week values exceeded 8°C-weeks in the Pacific Islands, where the current bleaching started. With the beginning of austral summer, ocean temperatures started increasing and bleaching was reported in the southern hemisphere. By the end of 2015, coral reefs worldwide were found exposed to thermal stress of 4°C-weeks or more, and almost all reefs were found affected by elevated sea-surface temperature[12]. It has been estimated that 36% of the world's coral reefs have been affected by this third major coral bleaching and nearly all the reefs around the world have suffered from some thermal stress[2]. The current global bleaching started during June 2014 in Guam[13] and then spread to Hawaii, Florida, Marshall Islands, Papua New Guinea, Solomon Islands, Fiji, American Samoa, Chagos Archipelago, Maldives, Indonesia, Red Sea, Panama, Kiribati, Cuba, Bahamas, Turks and Caicos, Cayman Islands, Dominican Republic, Haiti, Bonaire, Tanzania, New Caledonia and the Great Barrier Reef. Recent aerial and underwater surveys on the Great Barrier Reef in Australia have revealed that 93% of the corals have been affected[13] with severe mortality[14]. Considering the intensity of thermal bleaching around the world, coral mortality (8%) in MMS is not very high. However, corals that survive major bleaching may have slower growth rate, decreased reproduction and be susceptible to disease outbreaks.

There is some evidence that corals can get acclimatized to small-scale changes in the environment. However, they are unable to cope with increasing temperatures[15]. So, more thermal stress and mortality are only to be expected in the future. In MMS, about 1°C fluctuation was found in the temperature level between December 2015 and May 2016, which had made a significant impact. In the Gulf of Mannar, a major reef region in mainland India, significant coral mortality was witnessed during 2010 and the corals recovered immediately after the event[16]. The ability of the reef to recover depends on many factors, including the species involved environmental cues, presence of predation, disease outbreaks and other stresses. In the Gulf of Mannar, coral recovery was possible with the fast-growing acroporans and favourable environmental parameters. However, in MMS, fast-growing acroporans are not part of the reef and all the coral species found are slow-growers.

Climate change and the consequent elevated sea-surface temperature are global phenomena and have been experienced in every part of the world. It is, therefore, impossible to reduce the sea-surface temperature with local management as the task requires international initiatives. However, it is important to reduce the human-induced threats to facilitate the coral recovery. In Malvan coast, tourism and fishing are the main source of the income for the local fishermen[17], but both these activities pose serious threat to the recovering corals; hence, they should be regulated. The accordance of Sanctuary status to this region has always been opposed by the local fishermen[8] because of their apprehension that they would be denied access to their traditional fishing ground. Since tourism and fishing are fundamental to the livelihood of local fishermen, it is inevitable to make them aware of the importance of corals and of the consequences of coral degradation. Disease outbreaks are possible during recovery, and hence regular and continuous monitoring of corals is mandatory. Wide-scale coral rehabilitation through fragment transplantation has been done successfully in the Gulf of Mannar, which can be replicated on a large scale inside the MMS for long-term benefits.

1. Hoegh-Guldberg, O., Reviving the ocean economy: the case for action – 2015, World Wide Fund for Nature Report, Geneva, Switzerland, 2015, p. 60.
2. Hughes, L., Steffen, W. and Rice, M., Australia's coral reefs under threat from climate change. Climate Council of Australia Ltd, Australia, 2016, p. 22.
3. National Oceanic and Atmospheric Administration, NOAA declares third ever global coral bleaching event: bleaching intensifies in Hawaii, high ocean temperatures threaten Caribbean corals, Washington, 8 October 2015; http://www.noaanews.noaa.gov/stories2015/100815-noaa-declares-third-ever-global-coral-bleaching-event.html
4. Hoegh-Guldberg, O. and Ridgway, T., Coral bleaching comes to the Great Barrier Reef as record-breaking global temperatures continue, *The Conversation*, 21 March 2016; http://theconversation.com/coral-bleaching-comes-to-the-great-barrier-reef-as-record-breaking-global-temperatures-continue-56570
5. Wake, B., Snapshot: snow white coral. *Nature Climate Change*, 2016, **6**, 439.
6. Qasim, S. Z. and Wafar, M. V. M., Occurrence of living corals at several places along the coast of India. *Mahasagar-Bull. Natl. Inst. Oceanogr*., 1979, **12**(1), 53–58.
7. Singh, H. S., Marine protected areas in India. *Indian J. Mar. Sci*., 2003, **32**(3), 226–233.
8. Barman, R. P., Mukherjee, P. and Das, A., On a collection of fishes from the Malvan Marine Sanctuary, Malvan, Maharashtra, India. *Rec. Zool. Surv. India*, 2007, **107**(Part 1), 71–87.

9. English, S., Wilkinson, C. and Baker, V., *Survey Manual for Tropical Marine Resources*, ASEAN Australian Marine Science Project: Living Coastal Resources, Townsville, Australia, 1997, p. 368.
10. National Oceanic and Atmospheric Administration, Global analysis – annual 2015; https://www.ncdc.noaa.gov/sotc/global/201513
11. National Oceanic and Atmospheric Administration, Global climate report – Annual 2015; https://www.ncdc.noaa.gov/sotc/global/201513#gtemp
12. Heron, S. F. *et al.*, Validation of reef-scale thermal stress satellite products for coral bleaching monitoring. *Remote Sensing*, 2016, **8(1)**, 59.
13. Eakin, C. M. *et al.*, Global coral bleaching 2014–17. *Reef Encounter*, 2016, **31**(1), 20–26.
14. Hughes, T., Coral crisis: Great Barrier Reef bleaching is 'the worst we've ever seen'. *Nature*, 2016; http://www.nature.com/news/coral-crisis-great-barrier-reef-bleaching-is-the-worst-we-ve-ever-seen-1.19747
15. Ainsworth, T. D. *et al.*, Climate change disables coral bleaching protection on the Great Barrier Reef, *Science*, 2016, **352**(6283), 338–342.
16. Edward, J. K. P., Mathews, G., Raj, K. D., Thinesh, T., Patterson, J., Tamelander, J. and Wilhelmsson, D., Coral reefs of Gulf of Mannar, India – signs of resilience. In Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 2012.
17. Kalyan De, Sautya, S., Mote, S., Tsering, L., Patil, V., Nagesh, R. and Ingole, B., Is climate change triggering coral bleaching in tropical reef? *Curr. Sci.*, 2015, **109**(8), 1379–1380.

ACKNOWLEDGEMENTS. We thank UNDP–GEF Sindhudurg project for funds, and the Principal Chief Conservator of Forests (Wildlife) and Chief Wildlife Warden, Maharashtra for research permissions.

Received 18 July 2016; revised accepted 28 August 2017

doi: 10.18520/cs/v114/i02/384-387

Dichogamy and style curvature avoid self-pollination in *Eremurus altaicus*

Wei Gu, Miao Ma* and Jun-Feng Fan*

College of Life Sciences, Key Laboratory of Xinjiang Phytomedicine Resource Utilization, Ministry of Education, Shihezi University, Shihezi, Xinjiang 832003, The People's Republic of China

This paper gives a systematic study of *Eremurus altaicus* in terms of flowering characteristics, pollinating features, style movement pattern, stigma receptivity and mating system. The result showed that it was protandrous and that the stigma had no receptivity until the end of pollen dispersal. Its style showed a regular movement pattern during the flowering phase. The style was upright, very close to anthers at first; then it quickly curved down 90° from the base just before the dehiscing of anthers, but went back to the former upright state after pollen dispersal of all 6 anthers. From the blossoming to the end of pollen dispersal, the stigma was smooth and dry, and had no receptivity to pollens until the style went back to the upright state with papillae, and mucus appeared. The curving down movement of the style significantly widened the relative distance between the stigma and the dehiscing anthers. Therefore, protandry and style movement are double safeguard mechanisms for avoiding selfing and promoting outcrossing in *Eremurus altaicus*, which has important significance in its reproduction and evolution potential.

Keywords: Foxtail lily, mating system, protandry, pollination, style movement.

*For correspondence. (e-mail: mamiaogg@126.com; 1229501410@qq.com)

NUMEROUS studies suggest that generally plants avoid self-pollination and promote outcrossing. Dioecism, herkogamy, dichogamy and self-incompatibility are considered important mechanisms for angiosperm to avoid self-fertilization[1–4]. However, self-compatibility and self-fruitfulness are viewed as adaptive strategies of reproduction assurance in habitats lacking effective pollinators[5–10]. In the past few decades, several studies were done on the mating system and reproductive strategy of plants, and fruitful results were achieved[11–16].

Eremurus altaicus, the common name which is foxtail lily, is a herbaceous perennial of genus *Eremurus* (Liliaceae), mainly distributed in Central Asia, Siberia and China[17]. It was found only on the adrets of Tianshan Mountain and Altai Mountain (from 1000 to 2200 m amsl) in China. It has a raceme opened in sequence from bottom to top, and the styles of each floret showed a regular automatic movement of 'erect → bend down → erect' during the flowering stage leading to change in the spatial position and distance between the stigma and anther. However, development stages of the anther and stigma at different phases of style movement and ecological significance of the style curvature are still unclear presently.

Therefore, flowering characteristics, pollen dispersal features, mating system, anther dehiscence and stigma receptivity at different style movement stages of *Eremurus altaicus* were studied in this paper to reveal the adaptive significance of its style curvature.

From May 15 to June 25, in 2015 and 2016, fixed point observations (48°11.053′N, 87°01.482′E) of a natural *Eremurus altaicus* population (100 individuals) were performed at a grassland on the adret of Altai Mountain (at an altitude of 1066 m) in Burqin County, Xinjiang, where the perennial *Eremurus altaicus* (Liliaceae) (12 ovules in each floret) is a dominant species.

During 15 May–25 June in 2015 and 2016, we observed the whole flowering season of 100 foxtail lily individuals and single flower pollinating features, and recorded the time of initial, full and final flowering stage and the dehiscence of the six anthers.