(Hemiptera: Aphididae) in varying prey densities from northeast India. *Curr. Sci.*, 2016, **110**, 434–438.
19. Yasuda, H. and Dixon, A. F. G., Sexual size dimorphism in the two spot ladybird beetle *Adalia bipunctata*: developmental mechanism and its consequences for mating. *Ecol. Entomol.*, 2002, **27**, 493–498.
20. Stewart, L. A., Hemptinne, J.-L. and Dixon, A. F. G., Reproductive tactics of ladybird beetles: relationships between egg size, ovariole number and developmental time. *Func. Ecol.*, 1991, **5**, 380–385.
21. Osawa, N., Sibling and non-sibling cannibalism by larvae of a ladybeetle *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) in the field. *Res. Pop. Ecol.*, 1989, **31**, 153–160.
22. Agarwala, B. K. and Dixon, A. F. G., Laboratory study of cannibalism and interspecific predation in ladybirds. *Ecol. Entomol.*, 1992, **17**, 303–309.
23. Agarwala, B. K. and Dixon, A. F. G., Why do ladybirds lay eggs in clusters? *Func. Ecol.*, 1993, **7**, 541–548.
24. Agarwala, B. K. and Bhowmik, P. J., Effect of chemical defence on the fitness of ladybird predator, *Cheilomenes sexmaculata* (Fabricius). *J. Biol. Control*, 2007, **21**, 89–96.

ACKNOWLEDGEMENTS. We thank Joydip Majumder and Dipankar Sinha for help with the collection of insect samples and laboratory studies. B.K.A. acknowledges support from a grant of the Ministry of Environment and Forests, Govt. of India, and A.F.G.D. acknowledges support from a grant (no. L01415) of the Ministry of Education, Youth, and Sports, Czech Republic.

Received 12 December 2016; revised accepted 19 May 2017

doi: 10.18520/cs/v113/i12/2350-2353

Application of indigenously developed remotely operated vehicle for the study of driving parameters of coral reef habitat of South Andaman Islands, India

S. Ramesh[1,*], G. A. Ramadass[1], V. Doss Prakash[1], C. S. Sandhya[1], R. Ramesh[1], D. Sathianarayanan[1] and N. V. Vinithkumar[2]

[1]National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, Government of India, Chennai 600 100, India
[2]Andaman and Nicobar Centre for Ocean Science and Technology, NIOT, Port Blair 744 103, India

Coral reef biodiversity in South Andaman Islands, India was studied using indigenously developed remotely operated underwater vehicle, PROVe. The vehicle was manoeuvred in coral reef habitats using underwater navigational aids to record faunal assemblages along with underwater spatio-temporal spectral irradiance characteristics coupled with surface radiance, water temperature, salinity and underwater visuals by high-definition camera devices. PROVe-based observations and the outcome from scientific payloads indicated that it will be a new additional tool for the Indian scientific community to map coral reef habitats, correlate and validate the satellite-derived parameters to understand coral reef health.

Keywords: Coral reef, driving parameters, remotely operated vehicle, spectral irradiance.

MARINE biodiversity of the Andaman and Nicobar (A&N) Islands, India is remarkable with its rich assemblages of coral reef distribution within 6°–14°N lat. and 92°–94°E long. (ref. 1). Islands of the Andaman have an estimated coral reef area of 934.26 sq. km and can be grouped into North Andaman, Middle Andaman and South Andaman regions[2]. Among these island groups, South Andaman is rich in biodiversity; all the reefs have small reef flat and gradual reef slope with good luminosity, and good coral live cover along with dead corals and rubbles[3].

Coral reef occurrences are governed by the symbiotic relationship of coral community with dinoflagellates (zooxanthelle). Sunlight irradiance intensity and spectral characteristics change with depth and play a critical role in the structuring of shallow-water coral reef community[4–6]. Solar irradiation (heat budget) and nutrients play a supportive role in the survival of algal cells which may break down due to thermal stress and lead to bleached appearance of corals at higher temperature[7,8]. Study of shallow-water coral habitats suggests that the production of suitable proteins as host strategy is important to protect the symbiotic algae from high irradiance by absorbing photons or by reemission[9,10]. Important environmental factors affecting the ecology of reef-forming, symbiont-bearing corals are the quantity and quality of light[11]. It is an established fact that zooxanthellae algae generate oxygen photosynthesis which supports 95% of respiratory demand of the coral community[12]. Hence the measure of light for such photosynthesis in terms of availability of photons is the critical parameter to understand the ecology of the shallow-water coral community. It is a measure of radiant power and is defined in terms of photon (quantum) flux, specifically the number of moles of photons in the radiant energy between 400 and 700 nm.

Several methodologies have been followed worldwide to map the coral reef habitats. Survey techniques include underwater observations by scuba and snorkel divers, visual quadrant methods[13], manta tow, random swims/timed swims, point intercept transects or line intercept transects with triangulation references[14,15], high-resolution mapping from airborne lidar[16], multispectral remote sensing imagery, underwater towed digital

*For correspondence. (e-mail: sramesh@niot.res.in)

photo/video mapping systems[17–20] and underwater vehicle-based observations[21,22].

In India, mapping of coral reef biodiversity was carried out by extensive diving operations to understand the species diversity and its associated faunal changes. In recent decades, studies using satellite-based imageries were undertaken to understand the wavelength spectra and their roles in biodiversity characteristics[23]. Advancement in underwater technologies such as remotely operated vehicles (ROV) and their use for monitoring shallow-water marine habitats such as coral reefs are becoming more popular worldwide due to their precise navigational capabilities with required sensors for fine resolution details of the habitat distribution with accurate positions for revisiting. With increasing popularity, ROVs are used in short-term and long-term ocean monitoring studies, deep ocean resources studies and engineering interventions[24–27]. This type of vehicle provides researchers with a variety of advantages of adding scientific payloads and high-definition imaging systems for studying marine habitats in open ocean environments without the risk of human intervention under water. In India, such ROVs are rarely available and utilized due to scarcity of expertise in handling such complex underwater systems. The National Institute of Ocean Technology (NIOT) under the aegis of the Ministry of Earth Sciences, Government of India has indigenously designed and developed a shallow-water ROV called PROVe and deployed the same for exploring shallow-water habitats and polar environment.

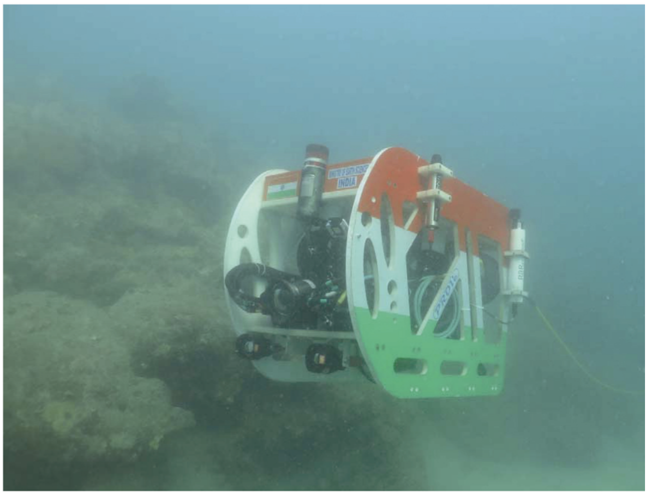

Figure 1. Underwater photograph of polar-cum-shallow water remotely operated underwater vehicle (PROVe).

Table 1. Specifications of Polar Remotely Operated Vehicle

Design depth	500 m
Weight	175 kg
Dimension	0.957 m × 0.604 m × 0.63 m
Speed	2.5 kn
Payload	10 kg
Buoyancy	Syntactic foam (Modular)
Power	300V DC, 5 kW
Thrusters	Four electric thrusters, 25 kgf each (two forward, one vertical and one lateral)
Data telemetry	Single-mode fibre optic communication
Hardware	NI Real Time Controller with FPGA
Software	LabVIEW Real Time with Xilinx
Cameras	Colour zoom camera (ROS Spectator)
	Underwater still camera (make: IMENCO, SDS1210)
	HD camera (1080 p, 50 fps)
Luminaries	LED and halogen lights (Kongsberg OE11-150)
Navigation	MEMS-based inertial navigation system
	DVL (Doppler velocity log)
	Compass (magnetic-based)
	Depth sensor
Scientific sensors	Spectral radiance and irradiance meter (RAMSES)
	Scanning sonar (Imagenex 881A)
	Water temperature and salinity (RBR CTD-DO)

PROVe is an unmanned, free-swimming, electric-powered inspection class ROV. It has the capability to operate at 500 m depth (Figure 1), integrated with underwater positioning with inertial navigation system, high-definition camera imaging with lights and scientific payloads (underwater spectral irradiance, water temperature, salinity, water sampler, ice corer, etc.). Table 1 shows the specifications of the vehicle. The ROV has four electrical thrusters for maneuvering at a speed of 2.5 kn in manual or semi-automatic mode. The thrusters are brushless direct current (BLDC) motor-driven and can develop a maximum thrust of 25 kgf (forward) and 25 kgf (reverse). The ROV frame is made up of polypropylene material, and the submerged weight of the vehicle is compensated by syntactic foam fitted to the upper part of the frame for positive buoyancy. The ROV is taken down to greater depths using the vertical thrusters. The vehicle is always connected to a Kevlar aramid electro-optic umbilical cable comprising fibre optic cable and power conductors. The umbilical cable supplies system control signal and the necessary power (5 kW) for vehicle operation.

Navigation system includes Doppler velocity log, three-axis tilt-compensated compass module, depth sensor and differential global positioning system (DGPS) for positioning and assisting in underwater navigation[28,29]. Underwater visuals from the cameras and sector scanning imaging sonar are also used for vision-based ROV operation. Position of the vehicle will be initiated using the DGPS in surface water and disconnected during the dive-down and manoeuvring period. Underwater position is estimated using navigational algorithm developed with attitude data from the compass module and linear velocities from Doppler velocity log for geo-referencing of the acquired underwater visuals and scientific sensor data[30]. The vehicle has semiautomatic path following capability (auto-heading and auto-depth), but in the present study of reconnaissance exploration, vision-based navigation is performed using the navigational pilot joystick with support of depth, altitude, position and underwater visuals, due to undulating nature of the coral reef terrain.

RAMSES-make spectral radiance and irradiance sensors were interfaced with PROVe (Figure 2) to understand the underwater spectral characteristic of light in coral reef habitats and measurements under ice in the polar region. Radiance sensor has spectral response in the 320–950 nm range using 256 channel silicon photodiode arrays with 190 useful channels. Irradiance sensor has typical saturation of 8 $Wm^{-2} nm^{-1}$ at 500 nm. Conductivity, temperature, depth, dissolved oxygen sensor (RBR CTD-DO) and scanning sonar (Imagenex 881A) were also integrated in the ROV for data-logging in real time. Apart from sensors, three cameras and four LED lights were mounted in the ROV at different locations for underwater imaging. An underwater colour zoom camera (ROS Spectator) and a high-definition camera (GoPro Hero 4) were mounted in the ROV front side, while an underwater still camera (make: IMENCO, SDS1210) was mounted at the bottom of the ROV.

Manoeuvring of vehicle was carried out based on depth, altitude and position along with underwater visuals; ROV was piloted in manual mode at less than

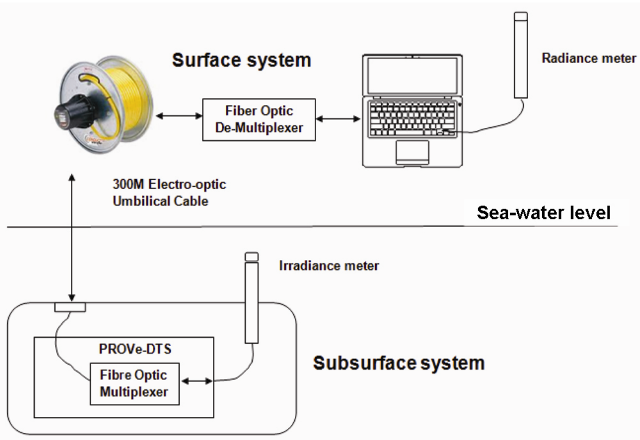

Figure 2. RAMSES sensor (radiance and irradiance meter) assembly interface details.

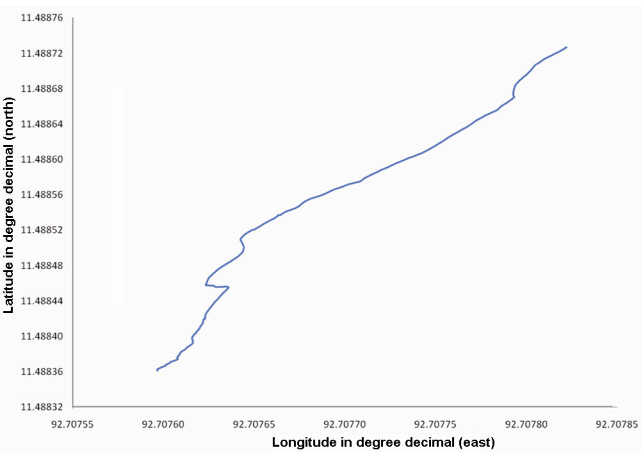

Figure 3. Manoeuvred ROV trajectory at Chidiyatapu Island.

1 m altitude to obtain high-quality coral reef images along with the associated fauna and flora. Figure 3 shows an example of manoeuvred trajectory of ROV at 10 m water depth in Chidiyatapu.

Coral reef distribution is a result of variations in the natural driving parameters such as space, light[31], irradiance with depth[32], nutrient supply[33], wave energy, water temperature[34], salinity, pH[35], turbidity[36], etc. The present study is focused on recording some of the driving parameters of coral reefs, such as water temperature, light penetration with depth (downwelling irradiance), water depth, salinity variations, turbidity, etc. along with geo-referenced coral community visual images using ROV. These parameters were collected in real time using PROVe-connected scientific sensors and video camera images with precise positional systems aided by navigational sensor to understand the characteristics of driving parameters, coral reef habitats distribution and associated fauna and flora.

Five different islands/sites in South Andaman were chosen for the present study to deploy PROVe. Figure 4 and Table 2 provide details of deployment sites. The observational period, i.e. March–April 2016 is peak summer in the A&N Islands, and the recorded surface water temperature varied from 31°C to 32°C. Corals observed by ROV cameras at a depth of 2 m were in healthy condition without bleaching since the recorded temperature had reduced to <31°C below 0.5 m depth, which is less than the bleaching temperature for corals; it corroborates with the temperature tolerance limit of coral reef regions in tropic oceans elsewhere[37]. Observed continuous measurements of water temperature profiles at the five different study sites show reduction of 0.5°C below 1 m depth at all

Figure 4. Location map of PROVe deployment site in South Andaman, India (courtesy Google Maps).

observed islands, except Jolly Buoy, indicating greater amount of heat transfer at the study region similar to the earlier observation of latent heat flux (140 W/m^2) and sensible heat flux (10 W/m^2)[38].

Even though variation in salinity was observed in decimal units between islands, regions in the Andaman Sea (North Bay and Chidiyatapu) showed low salinity profile in the 31.6–31.8 psu range when compared to islands in the Bay of Bengal (Grub Islands and Red Skin) with values in the 32.2–32.4 psu range due to high amount of freshwater input from Irrawaddy[39]. Jolly Buoy falls in the intermixing zone salinity since it connects the water bodies on both sides. Not much variation was recorded in the vertical profile, and the values were within the range for coral reef tolerance due to high metabolic tolerance of corals for salinity[40,41].

To get a better picture of the intensity correlation of sunlight radiance with PROVe deployment period for underwater irradiance measurement, Table 3 provides details of time, date and zenith angle. Maximum observed radiance intensity was 600 mW/m^{2}nm Sr during midday, in the wavelength 400–700 nm range due to maximum solar radiation at noon.

Figure 5 shows spectral irradiance intensity plots for the five different islands collected at a depth of 4 m. The maximum intensity of 780 mW/m^2 nm was recorded in Jolly Buoy Island; also maximum intensity was recorded in the 430–600 nm range. Irradiance data of Chidiyatapu region clearly showed the attenuation characteristics of different wavelengths with depth, and maximum recorded intensity at 500 nm wavelength as green light was ~200 mW/m^2 nm. Representative irradiance intensity profile of Red Skin island is presented in Figure 6 with reference to specific wavelengths, i.e. 443, 490 and 555 nm. The results can be used to derive and compare water quality parameters from satellite imagery. There was a gradual decrease in intensity with depth due to water body absorption which has a major influence on chlorophyll concentration[23].

The spectral quality of light as a function of depth is dependent on the concentration of dissolved organic materials, organic matter and sediment particulates in sea water[42]. To understand the same, utilizing the standard equations, photon availability ratio was calculated for two selected islands from Andaman Sea and the Bay of Bengal. Vertical profiles of the ratio showed reduction at 2 m depth at Chidiyatapu region in 600–700 nm range and increase in 400–600 nm range when compared to the reduction and increase at 11 m depth for the same wavelength range in Red Skin Island, indicating changes in dissolved matter and suspended particle characteristics of the studied islands. In the study region, calculated observed light intensity in photons was above 432 m^{-2} s^{-1} at Chidiyatapu, while at Red Skin Island it reduced to less than

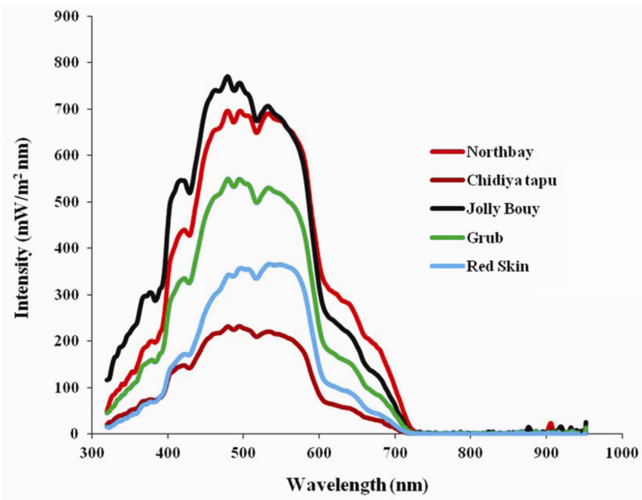

Figure 5. Spectral irradiance intensity plot collected at 4 m depth for different Islands.

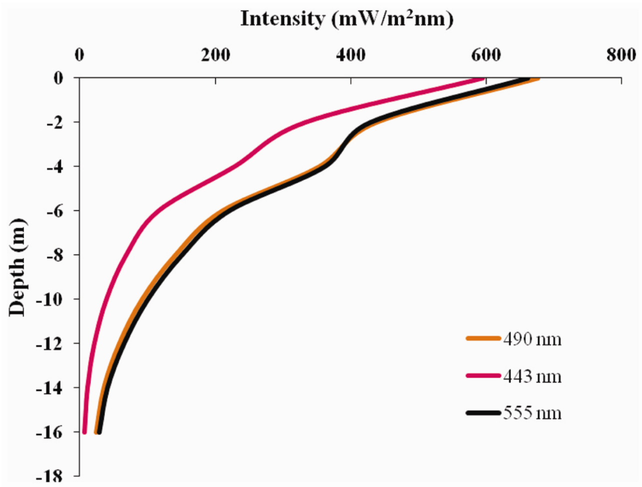

Figure 6. Irradiance intensity profile versus depth plot for Red Skin Island.

Table 2. Location details with depth of Remotely Operated Vehicle operation in South Andaman Islands, India

Island/site	Latitude	Longitude	Depth (m)
North Bay	11°42.1′N	92°44.2′E	20
Chidiyatapu	11°29.3′N	92°42.2′E	10
Jolly Buoy Island	11°30.4′N	92°36.9′E	16
Grub Island	11°35.4′N	92°35.7′E	5
Red Skin Island	11°35.5′N	92°35.6′E	18

Table 3. Date and time of PROVe operation with zenith angle

Island/Site	Date	Time	Zenith angle (°)
North Bay	31–03–2016	09:52:04	50.08
Chidiyatapu	03–04–2016	15:11:24	47.93
Jolly Buoy Island	05–04–2016	12:35:48	83.55
Grub Island	06–04–2016	10:52:36	54.63
Red Skin Island	06–04–2016	14:26:26	59.01

Figure 7. ROV-based image of Jolly Bouy Island. (lat. 11°30.75′N; long. 92°36.816′E; water depth: 8.6 m).

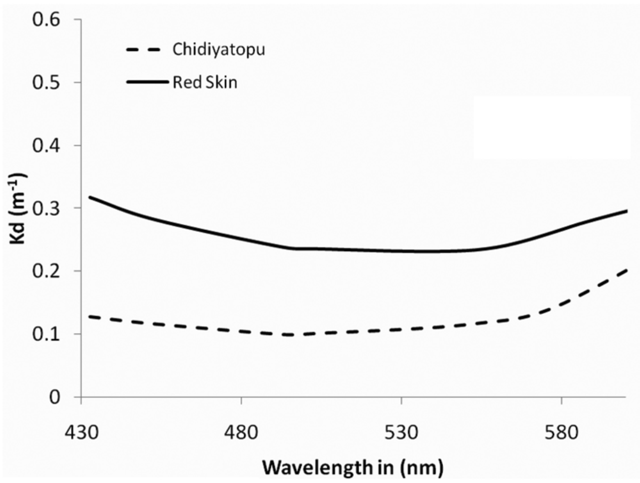

Figure 8. K_d value versus wavelength plot at 5 m depth for Chidiyatapu and Red Skin Island.

200 $m^{-2} s^{-1}$ at 8 m depth. Majority of the coral reef abundances observed were in shallower water depth of less than 10 m and were healthier with rich biodiversity since the calculated light intensity was more than 200 photons $m^{-2} s^{-1}$, as observed in earlier studies[37]. Underwater photographs of the coral and associated fauna recorded from the PROVe-based high-definition cameras (Figure 7) in the five different islands corroborate the richness in coral assemblages at the sites where the calculated photons were >200 $m^{-2} s^{-1}$ using spectral irradiance measurement[23].

Considering the properties of light, most commonly referenced phenomena are attenuation and scattering in an optically transparent window of the electromagnetic spectrum of 400–700 nm. To understand the characteristics of water column for the propagation of light underwater, diffuse attenuation coefficient $K_d(z, \lambda)$ was determined using eq. (1) below. It quantifies the presence of light in the euphotic zone using standard formulae[43]. This is also known as the 'apparent optical property of water'.

$$K_d (z, \lambda) = -\frac{1}{E_d \lambda} \frac{dE_d}{dz}, \tag{1}$$

where $K_d(z, \lambda)$ is the diffuse attenuation coefficient (m^{-1}); $E_d(\lambda)$ the downwelling irradiance (W m^{-2}) and dz is the thickness of the medium (m).

The K_d value was <0.2 in the <600 nm wavelength, indicating clear water for good coral diversity at Chidiyatapu when compared to the value above 0.2 up to <600 nm for Red Skin Island (Figure 8). This clearly shows that light attenuation increases from blue through red in both the islands, as observed in Roatan Island of Central America[44].

PROVe was deployed at five different coral reef islands of the South Andaman region. Driving parameters of coral reef diversity such as underwater light characteristics, water temperature and salinity were measured by integrating suitable sensors with PROVe, and data were recorded along with high-definition camera visual footings by manoeuvring the rugged coral reef terrain using the navigational system. Even though recorded water temperature was in the threshold for coral bleaching (~31°C), no coral bleaching was observed in the recorded visuals. However, coral bleaching was observed a few weeks after the survey period in some of the islands due to further increase in sea surface temperature, i.e. 33°C for a week. Irradiance intensity variation at different depths with reference to different wavelengths has clearly established that available wavelength beyond 10 m depth will be in the 490–550 nm range only. Calculated values of photons up to a depth of 8–10 m were greater than 200 $m^{-2} s^{-1}$, indicating clarity in water for the rich coral assemblages and associated fauna, as recorded in underwater visuals.

This study has shown the capability of PROVe developed in India and its use in the observation of coral reef habitat in spatio-temporal scale along with characteristics of light underwater in terms of spectral irradiance. This vehicle will be an additional tool to aid the scientific community in the exploration of shallow water habitats, environmental monitoring, light characteristics under ice and to support and calibrate the satellite-based technological advancement for oceanographic applications.

1. Savant, P. V., Biodiversity conservation through ecotourism: a new approach. In *125 Years of Forestry (1883–2008) Andaman and Nicobar Islands*, Department of Environment and Forests, A and N Admin, 2009, pp. 1–3.
2. MWRD, Coral reefs of the Andaman and Nicobar Group of islands. Report prepared for the Zoological Survey of India. Marine and Water Resources Division, Space Application Centre, 2000.
3. Raghuraman, R., Sreeraj, C. R., Raghunathan, C. and Venkataraman, K., Scleractinian coral diversity in Andaman–Nicobar Island in comparison with other Indian reefs. International day for Biodiversity. In *Marine Biodiversity*, *One Ocean – Many Words*, Uttar Pradesh State Biodiversity Board, 2012, pp. 75–92.

4. Dustan, P., Depth-dependent photoadaptation by zooxanthellae of the reef coral *Montastrea annularis*. *Mar. Biol.*, 1982, **68**, 253–264.
5. Schlichter, D., Fricke, H. W. and Weber, W., Light harvesting by wavelength transformation in a symbiotic coral of the Red Sea twilight zone. *Mar. Biol*., 1986, **91**, 403–407.
6. Mass, T., Kline, D.I., Roopin, M., Veal, C.J., Cohen, S., Iluz, D. and Levy, O., The spectral quality of light is a key driver of photosynthesis and photoadaptation in *Stylophora pistillata* colonies from different depths in the Red Sea. *J. Exp. Biol.*, 2010, **213**, 4084–4091.
7. Baker, A. C., Glynn, P. W. and Riegl, B., Climate change and coral reef bleaching: an ecological assessment of long-term impacts, recovery trends and future outlook. *Estuarine Coastal Shelf Sci.*, 2008, **80**(4), 435–471.
8. D'Angelo, C. and Wiedenmann, J., Impacts of nutrient enrichment on coral reefs: new perspectives and implications for coastal management and reef survival. *Curr. Opin. Environ. Sustain.*, 2014, **7**, 82–93.
9. Salih, A., Larkum, A., Cox, G., Kühl, M. and Hoegh-Guldberg, O., Fluorescent pigments in corals are photoprotective. *Nature*, 2000, **408**(6814), 850–853.
10. D'Angelo, C. D., Smith, E. G., Oswald, F., Burt, J., Tchernov, D. and Wiedenmann, J., Locally accelerated growth is part of the innate immune response and repair mechanisms in reef-building corals as detected by green fluorescent protein (GFP)-like pigments. *Coral Reefs*, 2012, **31**(4), 1045–1056.
11. Iglesias-Prieto, R., Beltran, V. H., LaJeunesse, T. C., Reyes-Bonilla, H. and Thome, P. E., Different algal symbionts explain the vertical distribution of dominant reef corals in the eastern Pacific. *Proc. R. Soc. London, Ser. B*, 2004, **271**(1549), 1757–1763.
12. Muscatine, L., McCloskey, L. R. and Marian, R. E., Estimating the daily contribution of carbon from zooxanthellae to coral animal respiration. *Limnol. Oceanogr.*, 1981, **26**(4), 601–611.
13. Maragos, J. E., A study of the ecology of Hawaiian reef corals. Ph D thesis, University of Hawaii, USA, 1972.
14. Hill, J. and Wilkinson, C., Method for ecological monitoring of coral reefs. Australian Institute Marine Sciences, 2004, vol. 1, p. 117.
15. Obura, D. O., *Coral Reef Monitoring*, Indian Ocean Commission, Mauritius, 2014, p. 67.
16. Goodman, J. A., Samuel, J. P. and Stuart, R. P., *A Guide for Mapping, Monitoring and Management*, Coral Reef Remote Sensing, 2013, p. 436.
17. Field, M. E., Chavez Jr, P. S., Evans, K. R. and Cochran, S. A., New mapping techniques help assess the health of Hawaii's coral reefs (No. 084-01), 2001, p. 4.
18. D'Antonio, N. L. and Gibbs, A. E., Still-image frame grabs and benthic habitat interpretation of underwater video footage, March 2014, Faga'alu Bay, Tutuila Island, American Samoa. US Geological Survey Data Release, 2016.
19. Gibbs, A. E. and D'Antonio, N. L., Underwater video footage, March 2014, Faga'alu Bay, Tutuila Island, American Samoa. US Geological Survey data release, 2016.
20. De Clippele, L. H. *et al*, Using novel acoustic and visual mapping tools to predict the small-scale spatial distribution of live biogenic reef framework in cold-water coral habitats. *Coral Reefs*, 2017, **36**, 255–268.
21. Lam, K., Shin, P. K., Bradbeer, R., Randall, D., Ku, K. K., Hodgson, P. and Cheung, S. G., A comparison of video and point intercept transect methods for monitoring subtropical coral communities. *J. Exp. Mar. Biol. Ecol.*, 2006, **333**(1), 115–128.
22. Leujak, W. and Ormond, R. F. G., Comparative accuracy and efficiency of six coral community survey methods. *J. Exp. Mar. Biol. Ecol*., 2007, **351**(1–2), 168–187.
23. Sridhar, P. N., Ali, M. M., Rao, M. V. and Nagamani, P. V., Photosynthetically active radiation, a critical parameter for mass coral bleaching in the North Indian Ocean. *Curr. Sci.*, 2012, **102**(1), 114–118.
24. Norcross, B. L. and Mueter, F. J., The use of an ROV in the study of juvenile flatfish. *Fish. Res.*, 1999, **39**(3), 241–251.
25. Raskoff, K. A., Hopcroft, R. R., Kosobokova, K. N., Purcell, J. E. and Youngbluth, M., Jellies under ice: ROV observations from the Arctic 2005 hidden ocean expedition. *Deep Sea-Res. II*, 2010, **57**(1), 111–126.
26. Ramadass, G. A. *et al.*, Deep-ocean exploration using remotely operated vehicle at gas hydrate site in Krishna–Godavari basin, Bay of Bengal. *Curr. Sci*., 2010, **99**(6), 809–815.
27. Jhunjhunwala, T., Upadhyay, V., Sirikonda, R., Balasubramaniam, K. and Rajagopal, P., MIKE: a remotely operated vehicle (ROV) for visual inspection of underwater structures. Non Destructive Evaluation 2015. Abs., 2015, 220C, 215.
28. Ramesh, S., Sathianarayanan, D., Ramesh, R., Harikrishnan, G., Vadivelan, A., Ramadass, G. A. and Atmanand, M. A., Qualification of polar remotely operated vehicle at East Antarctica. OCEANS 2016 MTS/IEEE Conference, 2016, pp. 1–5.
29. Vedachalam, N. *et al.*, Design and development of remotely operated vehicle for shallow waters and polar research. IEEE Underwater Technology (UT) Conference, 2015, pp. 1–5.
30. Ramesh, R., Bala Naga Jyothi, B., Vedachalam, N., Ramadass, G. A. and Atmanand, M. A., Development and performance validation of navigation system for underwater vehicles. *J. Navig.*, 2016, **69**, 1097–1113.
31. Hughes, T. P. and Connell, J. H., Multiple stressors on coral reefs: a long-term perspective. *Limnol. Oceanogra.*, 1999, **44**, 932–940.
32. Huston, M. A., Patterns of species diversity on coral reefs. *Annu. Rev. Ecol. Syst.*, 1985, **16**, 149–177.
33. Leichter, J. J. and Salvatore, J., Intermittent upwelling and subsidized growth of the scleractinian coral *Madracis mirabilis* on the deep fore-reef slope of Discovery Bay, Jamaica. *Mar. Ecol. Prog. Ser.*, 2006, **316**, 95–103.
34. Gareth, J. W., Jennifer, E. S., Eric, J. C., Jamison, M. G., Enric, S. and Stuart, A. S., Benthic communities at two remote Pacific coral reefs: effects of reef habitat, depth, and wave energy gradients on spatial patterns. *Peer, J.*, 2013, **1**, e81.
35. Tyler, C., Issac, R. S., Dirk, V. E., Damien, T. M. and Bradley, D. E., Drivers of pCO_2 variability in two contrasting coral reef lagoons: the influence of submarine ground water discharge. *Global Biogeochem. Cycles*, 2014, **28**, 398–414.
36. Joseph, F. P. *et al.*, Sediment and turbidity associated with offshore dredging increase coral disease prevalence in nearby reefs. *PLoS ONE*, 2014, **9**, e102498.
37. Gangadhara Rao, L. V. and Shree Ram, P., *Upper Ocean Physical Process in the Tropical Indian Ocean*, Monograph prepared under CSIR Emeritus Scientist Scheme, National Institute of Oceanography, Visakhapatnam, 2005, p. 68.
38. Guan, Y., Hohn, S. and Merico, A., Suitable environmental ranges for potential coral reef habitats in the tropical ocean. *PLoS ONE*, 2015, **10**(6), p.e0128831.
39. Dileep Kumar, M., Oceanography of marginal seas. In *The Indian Ocean – A Perspective* (eds Sen Gupta, R. and Ehrlich, D.), A.A. Balkama Publishers, India, 2001.
40. Ferrier-Pages, C., Gattuso, J. P. and Jaubert, J., Effect of small variations in salinity on the rates of photosynthesis and respiration of the zooxanthellate coral *Stylophora pistillata*. *Mar. Ecol. Prog. Ser.*, 1999, **181**, 309–314.
41. Muthiga, N. A. and Szmant, A. M., The effects of salinity stress on the rates of aerobic respiration and photosynthesis in the hermatypic coral *Siderastrea siderea*. *Biol. Bull.*, 1987, **173**(3), 539–551.
42. Kirk, J. T. O., *Light and Photosynthesis in Aquatic Ecosystems*, Cambridge University Press, UK, 1994, 2nd edn.
43. Mobley, C. D., *Light and Water: Radiative Transfer in Natural Waters*, Academic Press, USA, 1994, p. 592.

44. Mishra, D. R., Narumalani, S., Rundquist, D. and Lawson, M., Characterizing the vertical diffuse attenuation coefficient for downwelling irradiance in coastal waters: implications for water penetration by high resolution satellite data. *ISPRS J. Photogramm. Remote Sensing*, 2005, **60**(1), 48–64.

ACKNOWLEDGEMENTS. We thank the Ministry of Earth Sciences, Government of India for providing financial support for developing PROVe under 'Unmanned Underwater Vehicle' programme. We also thank Dr S. S. C. Shenoi (Director, NIOT, Chennai) and Dr M. A. Atmanand (NIOT) for constant support and encouragement. We thank the members of Deep Sea Technologies and Marine Bio-Technology group of NIOT at Chennai and Andaman for support during system development and exploration at Andaman respectively. We also thank the Indian Navy and Forest and Fisheries Department of Andaman for permission to conduct this work in Andaman Islands.

Received 9 December 2016; revised accepted 11 July 2017

doi: 10.18520/cs/v113/i12/2353-2359

Foraging rhythm of bees in relation to flowering of sweet basil, *Ocimum basilicum* L.

D. P. Abrol*, Uma Shankar and Debjyoti Chatterjee

Division of Entomology, Faculty of Agriculture, S.K. University of Agricultural Sciences and Technology of Jammu, Main Campus Chatha, Jammu 180 009, India

Sixteen species of insects belonging to four families of Hymenoptera visited flowers of *Ocimum basilicum*. Among them, non-*Apis* bees represented 85% of all flower visitors. Nectar was the main attractant for floral visitors. Besides *Ocimum*, agricultural crops such as cucumber, bitter gourd, brinjal, etc. in adjacent fields were visited by the same species of flower visitors. Hence, if planted near the agricultural fields, *Ocimum* sp. could attract pollinating insects for enhancing crop productivity.

Keywords: Agricultural crops, foraging rhythm, non-*Apis* bees, *Ocium basilicum*.

WILD basil, *Ocimum* sp. belonging to the family Lamiaceae, is a well-known medicinal herb commonly grown in India. Its aroma and exposed nectar attracts a large number of insects including pollinators. This plant because of its protandrous[1] property requires pollen vectors for its cross pollination. However, very little is known about the pollination mode of this important herb[2]. Therefore, the pollinator spectrum of *Ocimum* sp. was studied. In addition, the insect visitors of flowers of agricultural crops grown in nearby fields were also monitored. Assemblage of flower visitors was compared between wild Basil and agricultural crops to elucidate the importance of basil as a pollinator reservoir.

The study was conducted in the trial field of agricultural crops at SKUAST, Jammu Campus during late September 2012. Shrubs of wild *Ocimum* sp. growing naturally across the agricultural field were monitored regularly at peak flowering period during the daytime at an hourly interval. Representative samples of flower visitors were collected and identified up to RTUs[3] with the help of literature and then confirmed by experts. Collections were also made from nearby crops like cucumber, brinjal, bitter gourd and pea to examine the similarity of flower visitors between these crops and wild Basil.

Ocimum sp. (Wild Basil) started flowering in mid-September and continued up to the onset of mid-November. Flowers are bright purple/violet coloured with exposed nectar and a sweet aroma. Sixteen species of flower visitors belonging to four families in the order Hymenoptera were recorded (Table 1). The frequency of visits for Ocimum flowers was highest between 1100 and 1300 h (Figure 1). It was also evident that besides *Apis dorsata* and *A. mellifera*, non-*Apis* bees and solitary bees belonging to genera *Amegilla*, *Xylocopa*, *Thyreus*, *Nomia*, *Anthidium* and *Megachile*, were more frequent visitors (85% visits), collecting nectar and pollen from *Ocimum* flowers (Figures 2 and 3). Reports of visits by solitary bees, viz. *Megachile bicolor*, *Megachile disjuncta*, *Megachile lanata* and *Anthedium* sp., *Amegilla* spp., *Thyreus* and *Xylocopa* spp. are new records of efficient flower visitors and prospective pollinators of wild basil from this geographic area. The majority of flower visitors collected only nectar (81%) while a few collected both

Table 1. Flower visiting insects in *Ocimum* sp. in Jammu

Insect order	Insect morpho species	Family	Foraging preference
Hymenoptera	*Andrena* sp.	Andrenidae	N, P
	Amegilla zonata	Apidae	N
	Apis dorsata	Apidae	N, P
	Apis mellifera	Apidae	N, P
	Ceratina (*Pithitis*) *smaragdula*	Apidae	N
	Xylocopa latipes Drury	Apidae	N
	Xylocopa pubescense	Apidae	N
	Thyreus histryo	Apidae	N
	Halictus sp.	Halictidae	N
	Nomia sp.	Halictidae	N, P
	Megachile bicolour (Fabricius)	Megachilidae	N
	Megachile hera Bingham	Megachilidae	N
	Megachile lanata (Fabricius)	Megachilidae	N
	Megachile disjuncta	Megachilidae	N
	Megachile cephalotes	Megachilidae	N
	Anthedium orientale	Megachilidae	N

*For correspondence. (e-mail: dharam_abrol@rediffmail.com)