Project Title	Unravelling the mechanisms of thermal tolerance in coral symbionts
University (where student will register)	University of Warwick
Which institution will the student be based at?	As above
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☐ Organisms & Ecosystems ☒ Dynamic Earth ☐
Key words	Coral reefs, climate change, symbiosis, adaptation
Please explain how the project fits within the NERC remit	This project strongly aligns with NERC's remit by tackling the organismal responses to climate change.
Supervisory team (including institution & email address	**PI: Dr Ed Smith (University of Warwick, ed.g.smith@warwick.ac.uk)** **Co-I: Dr Richard Puxty (University of Warwick, R.Puxty@warwick.ac.uk)**

Project Highlights:

- Investigate coral symbiont communities from the world's warmest reefs.
- This study will use an integrative approach, combining molecular, genomic, and physiological methodologies. You will have the opportunity to learn new approaches and apply cutting-edge technologies in your research.
- You will gain mechanistic insights into symbiont thermal tolerance that can be used to improve human interventions into the coral reef crisis.

Overview (including 1 high quality image or figure):

Mass coral bleaching events associated with thermal stress have caused substantial declines in coral ecosystems. Coral bleaching results from the breakdown in the relationship between the coral and its symbiotic algae of the family Symbiodiniaceae and can occur at temperatures just 1-2°C above the average summer maxima (Goreau et al., 2000). Nevertheless, it has been shown that changing the dominant association to a thermally tolerant symbiont can increase the coral holobiont's bleaching threshold by up to 1.5°C (Berkelmans & Van Oppen, 2006). As such, there is substantial interest in identifying novel thermally tolerant symbionts and understanding the mechanisms that enhance thermal tolerance.

This project will focus on Symbiodiniaceae communities associated with the coral reefs of the Persian/Arabian Gulf (PAG). This young sea is home to the world's warmest coral reefs and the coral-algal associations have the highest known bleaching thresholds (Riegl et al., 2011). Interestingly, the reefs of the southern PAG are largely devoid of the most widely reported stress tolerant symbiont species *Durusdinium trenchii* (Hume et al., 2015). While widespread associations with *Cladocopium thermophilum* and *Symbiodinium spp.* symbionts have been documented in the PAG (Smith et al., 2017a; Smith et al., 2017b; Smith et al., 2017c; Howells et al., 2020), little is known about the underlying mechanisms that facilitate symbiont thermal tolerance in this region. In this project, you will combine next generation sequencing with photophysiological approaches to uncover a mechanistic understanding of symbiont thermal tolerance that can be used to help further efforts to maintain reefs in the face of climate change.

Figure 1: Mortality associated with coral bleaching. Within four months, this coral colony died as a result of a bleaching event where water temperatures exceeded 37°C. In this project, your research will help identify how some coral symbionts are able to maintain a successful symbiosis under high temperatures. Image from Smith et al. 2017c.

Alt text: Image of coral colony in June and September 2014. While visibly healthy in June, the colony had died by September.

Methodology:

In this project, you will likely combine fieldwork, laboratory experiments, and computational approaches. Long-read sequencing, genome assembly, and comparative genomics will be used to investigate coral symbiont adaptation to extreme reef temperatures. Alongside the genomics approaches, culturing, thermal stress experiments, and chlorophyll fluorescence measurements will be used to compare physiological responses between thermally tolerant and sensitive symbionts.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

Training will be provided in a range of different techniques, as required, including molecular biology (e.g., high molecular weight DNA extractions, PCR, sequencing library preparation), bioinformatics (e.g., genome assembly, comparative genomics), and experimental biology (e.g., experimental design, algal culturing, chlorophyll fluorometry).

Partners and collaboration (including CASE):
Further information on partners and collaboration (including CASE):

This project will involve collaboration with Dr. John Burt and members of Burt Lab at New York University Abu Dhabi.

Possible timeline:

Year 1: Survey the symbiont communities in the southern PAG and establish algal cultures.

Year 2: Compare the thermal physiology of your cultured strains to strains collected from other regions.

Year 3: Assemble the genome of a thermally tolerant symbiont from the PAG and compare to other Symbiodiniaceae genomes.

Further reading:

Aranda, M., Li, Y., Liew, Y.J., Baumgarten, S., Simakov, O., Wilson, M.C., Piel, J., Ashoor, H., Bougouffa, S., Bajic, V.B. and Ryu, T. (2016) Genomes of coral dinoflagellate symbionts highlight evolutionary adaptations conducive to a symbiotic lifestyle. *Scientific reports*, *6*(1), p.39734.

Berkelmans, R. and Van Oppen, M.J. (2006) The role of zooxanthellae in the thermal tolerance of corals: a 'nugget of hope' for coral reefs in an era of climate change. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1599), pp.2305-2312.

González-Pech, R.A., Stephens, T.G., Chen, Y., Mohamed, A.R., Cheng, Y., Shah, S., Dougan, K.E., Fortuin, M.D., Lagorce, R., Burt, D.W. and Bhattacharya, D. (2021) Comparison of 15 dinoflagellate genomes reveals extensive sequence and structural divergence in family Symbiodiniaceae and genus Symbiodinium. *BMC biology*, *19*, pp.1-22.

Goreau, T., McClanahan, T., Hayes, R. and Strong, A.L. (2000) Conservation of coral reefs after the 1998 global bleaching event. *Conservation biology*, *14*(1), pp.5-15.

Howells, E.J., Bauman, A.G., Vaughan, G.O., Hume, B.C., Voolstra, C.R. and Burt, J.A. (2020) Corals in the hottest reefs in the world exhibit symbiont fidelity not flexibility. *Molecular Ecology*, *29*(5), pp.899-911.

Hume, B.C., D'Angelo, C., Smith, E.G., Stevens, J.R., Burt, J. and Wiedenmann, J. (2015) Symbiodinium thermophilum sp. nov., a thermotolerant symbiotic alga prevalent in corals of the world's hottest sea, the Persian/Arabian Gulf. *Scientific reports*, *5*(1), p.8562.

Liu, H., Stephens, T.G., González-Pech, R.A., Beltran, V.H., Lapeyre, B., Bongaerts, P., Cooke, I., Aranda, M., Bourne, D.G., Forêt, S. and Miller, D.J. (2018) Symbiodinium genomes reveal adaptive evolution of functions related to coral-dinoflagellate symbiosis. *Communications biology*, *1*(1), p.95.

Riegl, B.M., Purkis, S.J., Al-Cibahy, A.S., Abdel-Moati, M.A. and Hoegh-Guldberg, O. (2011) Present limits to heat-adaptability in corals and population-level responses to climate extremes. *PloS one*, *6*(9), p.e24802.

Smith, E.G., Hume, B.C., Delaney, P., Wiedenmann, J. and Burt, J.A. (2017) Genetic structure of coral-Symbiodinium symbioses on the world's warmest reefs. *PloS one*, *12*(6), p.e0180169.

Smith, E.G., Ketchum, R.N. and Burt, J.A. (2017) Host specificity of Symbiodinium variants revealed by an ITS2 metahaplotype approach. *The ISME Journal*, *11*(6), pp.1500-1503.

Smith, E.G., Vaughan, G.O., Ketchum, R.N., McParland, D. and Burt, J.A. (2017) Symbiont community stability through severe coral bleaching in a thermally extreme lagoon. *Scientific Reports*, *7*(1), p.2428.

Further details:

Please see the lab page here.

To learn more about the project, contact Ed Smith (ed.g.smith@warwick.ac.uk). Please include a CV, details of past research, and outline your interest in the project.