

SCOR/IGBP Working Group 138
Modern Planktonic Foraminifera and Ocean Changes

Co-chairs: Gerald Ganssen (Amsterdam) and Michal Kucera (Bremen)

Promoting community building, knowledge synthesis and
knowledge transfer on modern planktonic foraminifera

Final report 2011 – 2018

SCOR/IGBP Working Group 138: Timeline

29 August – 1 September 2011, Amsterdam, The Netherlands

Kick-off meeting and Focus symposium for early career researchers organised by Gerald Ganssen and Michal Kucera



Ganssen, G.M., Kucera, M., 2012. SCOR/IGBP working group on modern planktonic foraminifera kicked off. PAGES news, 20(1): 6.

24 – 27 June 2013, Prague, Czech Republic

Workshops on Collection Methods and Taxonomy (in association with TMS spring meeting) organised by Michal Kucera

19 – 24 January 2014, Concepción, Chile

SCOR/IGBP WG138 @ FORAMS 2014, including keynote lectures by Howard Spero and Michal Kucera and a SCOR special session on Ecology of planktonic foraminifera: from present to past co-chaired by WG members Kate Darling and Michal Kucera

26 June 2014, NIOZ, Texel, The Netherlands

Workshop on Foraminifera Geochemistry, (in association with TMS spring meeting) organised by Lennart de Nooijer

30 August – 4 September 2015, Santa Catalina Island, California, USA

Final Workshop & Short Course on Culturing of Planktonic Foraminifera organised by Howard Spero and Michal Kucera



SCOR/IGBP Working Group 138: Membership

Full Members:

1. Co-chair: Gerald Ganssen (proxies), The Netherlands
2. Co-chair: Michal Kucera (ecology and diversity), Germany
3. Jelle Bijma (ecology), Germany
4. Jonathan Erez (calcification, symbiosis, proxies), Israel
5. Richard Zeebe (bio-physico-chemistry), USA
6. Howard Spero (calcification, symbiosis, proxies), USA
7. Margarita Marchant (ecology), Chile
8. Divakar Naidu (micropalaeontology), India
9. Daniela Schmidt (microstructure), UK
10. Elena Ivanova (paleo applications), Russia

Associate Members:

1. Frank Peeters (spatio-temporal distribution), The Netherlands
2. Stefan Mulitza (proxies), Germany
3. Michael Schulz (ecological modeling), Germany
4. Thorsten Kiefer (PAGES), Switzerland
5. Caroline Cleroux (deep dwelling species), USA/France
6. Jaroslaw Tyszka (eForams), Poland
7. Lennart de Nooijer (calcification), The Netherlands
8. Steve Eggins (microgeochemistry), Australia
9. Kate Darling (genotypes), UK
10. Baerbel Hoenisch (bio-chemico-physics), USA
11. Zhimin Jian (micropaleontology), China
12. Dirk Kroon (micropalaeontology and taxonomy), UK
13. Rashieda Toefy (ecology), South Africa (at SA SCOR expense)
14. Sangmin Hyun (paleoceanography, sedimentation), Korea (at Korea's SCOR expense)
15. Kazuyo Tachikawa (paleoceanography, proxies), France (at French SCOR expense)

SCOR/IGBP Working Group 138: Products

Documentaries

A Foram's Tale - Culturing process

<https://www.youtube.com/watch?v=6MakjP6MkdE>

A Foram's Tale - Documentary

https://www.youtube.com/watch?v=xfZ_9UWcAB8

A Foram's Tale (Short version) for 2012 Ocean Sciences Meeting

<https://www.youtube.com/watch?v=EldBtOjGBpw>

A Foram's Tale – Documentary of Focus symposium
(not available on youtube)



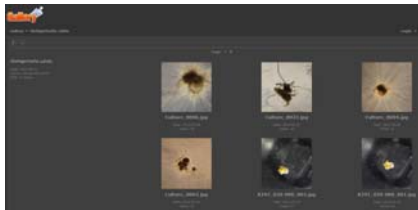
Website with resources

http://www.eforams.org/index.php/WG138_Startpage



Gallery of images:

<http://foraminiferaimagedatabase.marum.de/gallery2/main.php>



PFR2: DNA library with curated taxonomy:

<http://pfr2.sb-roscoff.fr/>



SCOR/IGBP Working Group 138: Publications

Publications acknowledging SCOR support

(WG members and associates in bold, WG-associated early career researchers in green)

- Gajardo, N., **Marchant, M.**, 2012. Variaciones estacionales de los foraminíferos planctónicos durante 2005-2006 frente a Iquique (20° S) y Concepción (36° S), Chile. *Lat. Am. J. Aquat. Res.*, 40(2): 376-388.
- Gajardo, N., González, H.E., **Marchant, M.**, 2013. Characterization of El Niño, La Niña, and normal conditions through planktonic foraminifera (2006 – 2007) in the southeastern Pacific. *Ciencias Marinas* (2013), 39(3): 253 – 264.
- Gajardo, N., **Marchant, M.**, Hebbeln, D., 2013. Variación temporal de los afloramientos costeros frente a Chile central (36° S; 74° W), mediante los isótopos estables de oxígeno de foraminíferos planctónicos, durante El Niño 2006. *Gayana* 77(1): 10-20.
- de Nooijer, L.J., Spero, H.J., Erez, J., Bijma, J.**, Reichart, G.J., 2014. Biomineralization in perforate foraminifera. *Earth Science Reviews*, 135, 48–58.
- Jonkers, L., Kucera, M.**, 2015. Global analysis of seasonality in the shell flux of extant planktonic foraminifera. *Biogeosciences*, 12, 2207-2226. doi: 10.5194/bg-12-2207-2015.
- Morard, R., Darling, K.**, Mahé, F., Audic, S., Ujiie, Y., **Weiner, A.**, André, A., Seears, H., Wade, C., Quillévéré, F., Douady, C., Escarguel, G., de Garidel-Thoron, T., **Siccha, M., Kucera, M.**, de Vargas, C., 2015. PFR²: a curated database of planktonic Foraminifera 18S ribosomal DNA as a resource for studies of plankton ecology, biogeography, and evolution. *Molecular Ecology Resources*, 15, 1472–1485. doi:10.1111/1755-0998.12410
- Siccha, M., Kucera, M.**, 2017. ForCenS, a curated database of planktonic foraminifera census counts in marine surface sediment samples. *Scientific Data* 4: 170109. doi:10.1038/sdata.2017.109.
- Schiebel, R., Michel, E., **Spero, H.**, Vonhof, H.B., de Garidel-Thoron, T., Ren, H., Martinez-Garcia, A., Smart, S.M., Quillevere, F., Hull, P., **Aze, T., Jonkers, L., Bijma, J.**, Sigman, D., Jentzen, A., Coxall, H., **Morard, R., Meilland, J.**, Haug, G.H., **Kucera, M.** (submitted). Advances in planktonic foraminifer research: New perspectives for paleoceanography. *Revue de Micropaleontologie*, REVMIC_2018_24.
- Spezzaferri, S., **Kucera, M.**, Pearson, P.N., Wade, B., Rappo, S., Poole, C., **Morard, R.**, Stalder, C., 2015. Fossil and genetic evidence for the polyphyletic nature of the planktonic foraminifera "*Globigerinoides*", and description of the new genus *Trilobatus*. *PLoS ONE*, 10(5): e0128108. doi:10.1371/journal.pone.0128108.
- Caromel, A.G.M., **Schmidt, D.N.**, Fletcher, I., Rayfield, E.J., 2015. Morphological change during the ontogeny of the planktic foraminifera. *Journal of Micropalaeontology*, 35: 2-19. doi:10.1144/jmpaleo2014-017.
- Morard, R.**, Escarguel, G., **Weiner, A.**, André, A., Douady, C. J., Wade, C. M., **Darling, K. F.**, Ujiie, Y., Seears, H. A., Quillévéré, F., de Garidel-Thoron, T., de Vargas, C., **Kucera, M.**, 2016. Nomenclature for the nameless: a proposal for an integrative molecular taxonomy of cryptic diversity exemplified by planktonic foraminifera. *Systematic Biology*, 65(5):925-940. doi: 10.1093/sysbio/syw031.
- Weiner, A.K.M., Morard, R., Weinkauff, M.F.G., Darling, K.F.**, André, A., Quillévéré, F., Ujiie, Y., Douady, C.J, de Vargas, C., **Kucera, M.**, 2016. Methodology for single-cell genetic analysis of planktonic foraminifera for studies of protist diversity and evolution. *Frontiers in Marine Science*, 3:255. doi: 10.3389/fmars.2016.00255.

Selection of further publications by WG members and associates (2011-2018)

- Allen, K, **Hoenisch, B, Eggins, S**, Haynes, Laura L.; Rosenthal, Yair; Yu, Jimin, 2016, 'Trace element proxies for surface ocean conditions: A synthesis of culture calibrations with planktic foraminifera', *Geochimica et Cosmochimica Acta*, vol. 193, pp. 197-221.
- Allen, KA, **B Hönlisch, SM Eggins**, J Yu, **HJ Spero**, H Elderfield, 2011. Controls on boron incorporation in cultured tests of the planktic foraminifer *Orbulina universa*. *Earth and Planetary Science Letters* 309 (3), 291-301.
- Bird, C, **Darling, K F**, Russell, A D, Davis, C V, Fehrenbacher, J, Free, A, Wyman, M & Ngwenya, B T 2017. Cyanobacterial endobionts within a major marine planktonic calcifier (*Globigerina bulloides*, Foraminifera) revealed by 16S rRNA metabarcoding. *Biogeosciences*, 14, 4, 901-920. DOI: 10.5194/bg-14-901-2017
- Bird, C, **KF Darling**, AD Russell, JS Fehrenbacher, CV Davis, A Free, BT Ngwenya, 2018. 16S rRNA gene metabarcoding and TEM reveals different ecological strategies within the genus *Neogloboquadrina* (planktonic foraminifer). *PloS one* 13 (1), e0191653
- Birch, H., Coxall, H. K., Pearson, P. N., **Kroon, D.** & O'Regan, M. May, 2013, Planktonic foraminifera stable isotopes and water column structure: Disentangling ecological signals. *Marine Micropaleontology*. 101, p. 127-145.
- Caromel, AGM, **DN Schmidt**, EJ Rayfield, 2017. Ontogenetic constraints on foraminiferal test construction. *Evolution & development* 19 (3), 157-168
- Davis, CV, JS Fehrenbacher, TM Hill, AD Russell, **HJ Spero**, 2017. Relationships Between Temperature, pH, and Crusting on Mg/Ca Ratios in laboratory - grown *Neogloboquadrina* Foraminifera. *Paleoceanography* 32 (11), 1137-1152
- Dueñas-Bohórquez, A., da Rocha, R. E., Kuroyanagi, A., **de Nooijer, L. J., Bijma, J.** and Reichart, G. J., 2011. Interindividual variability and ontogenetic effects on Mg and Sr incorporation in the planktonic foraminifer *Globigerinoides sacculifer*, *Geochimica et Cosmochimica Acta*, 75 (2), pp. 520-532.
- Fehrenbacher, JS, AD Russell, CV Davis, AC Gagnon, **HJ Spero**, JB Cliff, Zihua Zhu, Pamela Martin, 2017. Link between light-triggered Mg-banding and chamber formation in the planktic foraminifera *Neogloboquadrina dutertrei*. *Nature Communications* 8, 15441.
- Fehrenbacher, JS, AD Russell, CV Davis, **HJ Spero**, E Chu, **B Hönlisch**, 2018. Ba/Ca ratios in the non-spinose planktic foraminifer *Neogloboquadrina dutertrei*: Evidence for an organic aggregate microhabitat. *Geochimica et Cosmochimica Acta*, 236, 361-372.
- Feldmeijer, W., Metcalfe, B., Brummer, G.J.A. & **Ganssen, G.M.**, 2015. Reconstructing the depth of the permanent thermocline through the morphology and geochemistry of the deep dwelling planktonic foraminifer *Globorotalia truncatulinoides*. *Paleoceanography*, 30 (1), 1-22. doi: 10.1002/2014PA002687
- Ganssen, G.M., Peeters, F.J.C.**, Metcalfe, B., Anand, P., Jung, S.J.A., **Kroon, D.** & Brummer, G.J.A., 2011. Quantifying sea surface temperature ranges of the Arabian Sea for the past 20 000 years. *Climate of the Past*, 7, 1337-1349. doi: 10.5194/cp-7-1337-2011
- Gibson, KA, RC Thunell, ML Machain-Castillo, J Fehrenbacher, **HJ Spero**, Kate Wejnert, Xinantecatl Nava-Fernández, Eric J Tappa, 2015. Evaluating controls on planktonic foraminiferal geochemistry in the Eastern Tropical North Pacific, *Earth and Planetary Science Letters* 452, 90-103.
- Henehan, MJ, JWB Rae, GL Foster, **J Erez**, KC Prentice, **M Kucera**, Helen C Bostock, Miguel A Martínez-Botí, J Andy Milton, Paul A Wilson, Brittney J Marshall, Tim Elliott, 2015. Calibration of the boron isotope proxy in the planktonic foraminifera *Globigerinoides ruber* for use in palaeo-CO₂ reconstruction. *Earth and Planetary Science Letters* 364, 111-122.
- Henehan, MJ, GL Foster, JWB Rae, KC Prentice, **J Erez**, HC Bostock, Brittney J Marshall, Paul A Wilson. Evaluating the utility of B/Ca ratios in planktic foraminifera as a proxy for the carbonate system: A case study of *Globigerinoides ruber*. *Geochemistry, Geophysics, Geosystems* 16 (4), 1052-1069, 2015.
- Holland, K, **SM Eggins, B Hönlisch**, LL Haynes, O Branson, 2017. Calcification rate and shell chemistry response of the planktic foraminifer *Orbulina universa* to changes in microenvironment seawater carbonate chemistry. *Earth and Planetary Science Letters* 464, 124-134
- Howes, E., Kaczmarek, K., Raitzsch, M., Mewes, A., Bijma, N., Horn, I., Misra, S., Gattuso, J. P. and **Bijma,**

- J., 2017. Decoupled carbonate chemistry controls on the incorporation of boron into *Orbulina universa* , *Biogeosciences*, 14 , pp. 415-430 .
- Hönisch, B. , Allen, K. A. , Russell, A. D. , **Eggins, S. M.** , **Bijma, J.** , **Spero, H. J.** , Lea, D. W. and Yu, J. 2011. Planktic foraminifers as recorders of seawater Ba/Ca, *Marine Micropaleontology*, 79 (1), pp. 52-57.
- Hönisch, B., Katherine A Allen, David W Lea, **Howard J Spero**, **Stephen M Eggins**, Jennifer Arbuszewski, Yair Rosenthal, Ann D Russell, Henry Elderfield, 2013. The influence of salinity on Mg/Ca in planktic foraminifers—Evidence from cultures, core-top sediments and complementary $\delta^{18}\text{O}$. *Geochimica et Cosmochimica Acta* 121, 196-213.
- Hyun, S.**, Kimoto, K., Cho, S-H., 2013. Occurrence of modern planktonic foraminiferal species and their seasonal variations around the Jeju Island, Korea. *Ocean and Polar Research*, 35, 181-191 (Korean with English abstract).
- Jacob, DE, R Wirth, OBA Agbaje, O Branson, **SM Eggins**, 2017. Planktic foraminifera form their shells via metastable carbonate phases. *Nature Communications* 8 (1), 1265
- Johnstone, H.J.H., Lee W., and **Schulz, M.**, 2016. Effect of preservation state of planktonic foraminifera tests on the decrease in Mg/Ca due to reductive cleaning and on sample loss during cleaning. *Chemical Geology*, 420, 23-36. doi:10.1016/j.chemgeo.2015.10.045
- Jonkers, L., **Kučera, M.**, 2017. Quantifying the effect of seasonal and vertical habitat tracking on planktonic foraminifera proxies. *Climate of the Past*, 13: 573-586. doi:10.5194/cp-13-573-2017
- Keul, N. , Langer, G. , Thoms, S. , **de Nooijer, L.** , Reichart, G. J. and **Bijma, J.**, 2016. Exploring foraminiferal Sr/Ca as a new carbonate system proxy , *Geochimica et Cosmochimica Acta*. doi:10.1016/j.gca.2016.11.022
- Kretschmer, K., Jonkers, L., **Kucera, M.**, **Schulz, M.**, 2018. Modeling seasonal and vertical habitats of planktonic foraminifera on a global scale. *Biogeosciences*, 15: 4405-4429. doi:10.5194/bg-15-4405-2018
- Kuroyanagi, A , RE da Rocha, **J Bijma**, **HJ Spero**, AD Russell, **SM Eggins**, H Kawahata, 2013. Effect of dissolved oxygen concentration on planktonic foraminifera through laboratory culture experiments and implications for oceanic anoxic events. *Marine Micropaleontology* 101, 28-32.
- LeKieffre, C, **HJ Spero**, AD Russell, JS Fehrenbacher, E Geslin, A Meibom, 2018. Assimilation, translocation, and utilization of carbon between photosynthetic symbiotic dinoflagellates and their planktic foraminifera host. *Marine Biology* 165 (6), 104.
- Marshall, BJ , RC Thunell, **HJ Spero**, MJ Henehan, L Lorenzoni, Y Astor, 2015. Morphometric and stable isotopic differentiation of *Orbulina universa* morphotypes from the Cariaco Basin, Venezuela, *Marine Micropaleontology* 120, 46-64.
- Martinez-Botí, M., Mortyn, P. G., **Schmidt, D. N.**, Vance, D. & Field, D. B. Jul 2011. Mg/Ca in foraminifera from plankton tows: evaluation of proxy controls and comparison with core-tops. *Earth and Planetary Science Letters*. 307, p.113 – 125
- Morard, R., Garet-Delmas, M.-J., Mahé, F., Romac, S., Audic, S., **Kucera, M.**, de Vargas, C., 2018. Surface ocean metabarcoding confirms limited diversity in planktonic foraminifera but reveals unknown hyper-abundant lineages. *Scientific Reports*, 8: 2539. doi:10.1038/s41598-018-20833-z
- Naik, SS , SP Godad, **PD Naidu**, V Ramaswamy, 2013. A comparison of *Globigerinoides ruber* calcification between upwelling and non-upwelling regions in the Arabian Sea. *Journal of Earth System Science* 122 (4), 1153-1159.
- Raitzsch, M., **Bijma, J.**, Benthien, A., Richter, K.-U., Steinhöfel, G., **Kucera, M.**, 2018. Boron isotope-based seasonal paleo-pH reconstruction for the Southeast Atlantic – A multispecies approach using habitat preference of planktonic foraminifera. *Earth and Planetary Science Letters*, 487 (1): 138–150. doi:10.1016/j.epsl.2018.02.002
- Rebotim, A., Voelker, A. H. L., Jonkers, L., Waniek, J. J., Meggers, H., Schiebel, R., Fraile, I., **Schulz, M.**, and **Kucera, M.**, 2017. Factors controlling the depth habitat of planktonic foraminifera in the subtropical eastern North Atlantic, *Biogeosciences*, 14, 827-859, doi:10.5194/bg-14-827-2017, 2017.
- Rippert, N., Nürnberg, D., Raddatz, J. , Maier, E. , Hathorne, E. C. , **Bijma, J.** and Tiedemann, R., 2016. Constraining foraminiferal calcification depths in the western Pacific warm pool , *Marine Micropaleontology*, 128 , pp. 14-27.

- Sadekov, AY, **Darling, KF**, Ishimura, T, Wade, CM, Kimoto, K, Singh, AD, Anand, P, **Kroon, D**, Jung, S, **Ganssen, G**, Ganeshram, R, Tsunogai, U & Elderfield, H, 2016. Geochemical imprints of genotypic variants of *Globigerina bulloides* in the Arabian Sea. *Paleoceanography*, 31, 1440-1452.
- Spero, HJ**, **SM Eggins**, AD Russell, L Vetter, MR Kilburn, **B Hoenisch**, 2015. Timing and mechanism for intratest Mg/Ca variability in a living planktic foraminifer. *Earth and Planetary Sci. Letters* 409, 32-42.
- Steinhardt, J., Cléroux, C., **de Nooijer, J.L.**, Brummer, G.J.A., Zahn, R., **Ganssen, G.M.** & Reichart, G.-J., 2015. Reconciling single-chamber Mg/Ca with whole-shell $\delta^{18}\text{O}$ in surface to deep-dwelling planktonic foraminifera from the Mozambique Channel. *Biogeosciences*, 2411-2429.
- Toyofuku, T.; Matsuo, M.Y.; **de Nooijer, L.J.**; Nagai, Y.; Kawada, S.; Fujita, K.; Reichart, G.-J.; Nomaki, H.; Tsuchiya, M.; Sakaguchi, H.; Kitazato, H., 2017. Proton pumping accompanies calcification in foraminifera. *Nature Comm.* 8(14145): 11 pp. [dx.doi.org/10.1038/ncomms14145](https://doi.org/10.1038/ncomms14145)
- van Dijk, I.; **de Nooijer, L.J.**; Boer, W.; Reichart, G.-J., 2017. Sulfur in foraminiferal calcite as a potential proxy for seawater carbonate ion concentration. *Earth Planet. Sci. Lett.* 470: 64-72.
- van Dijk, I.; **de Nooijer, L.J.**; Wolthers, M.; Reichart, G.-J., 2017. Impacts of pH and $[\text{CO}_3^{2-}]$ on the incorporation of Zn in foraminiferal calcite. *Geochim. Cosmochim. Acta* 197: 263-277. [dx.doi.org/10.1016/j.gca.2016.10.031](https://doi.org/10.1016/j.gca.2016.10.031)
- Venancio, I., Franco, D.R., Belem, A.L., **Mulitza, S.**, Siccha, M., Albuquerque, A.L.S., **Schulz, M.**, **Kucera, M.**, 2016. Planktonic foraminifera shell fluxes from a weekly resolved sediment trap record in the southwestern Atlantic: Evidence for synchronized reproduction. *Marine Micropaleontology*, 125: 25–35.
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- Vetter, L, R Kozdon, CI Mora, **SM Eggins**, JW Valley, **B Hönisch**, **HJ Spero**, 2013. Micron-scale intrashell oxygen isotope variation in cultured planktic foraminifers. *Geochimica et Cosmochimica Acta* 107, 267-278
- Vetter, L, R Kozdon, JW Valley, CI Mora, **HJ Spero**, 2014. SIMS measurements of intrashell $\delta^{13}\text{C}$ in the cultured planktic foraminifer *Orbulina universa*, *Geochimica et Cosmochimica Acta* 139, 527-539
- Waterson, AM, KM Edgar, **DN Schmidt**, PJ Valdes, 2017. Quantifying the stability of planktic foraminiferal physical niches between the Holocene and Last Glacial Maximum. *Paleoceanography and Paleoclimatology* 32 (1), 74-89

SCOR/IGBP Working Group 138: Initiated new network projects

1) An expedition lead by Michal Kucera on the German vessel METEOR dedicated to solving remaining “mysteries” of the ecology of planktonic foraminifera has taken place in the central Atlantic between 11.8. and 5.9.2017, with 10 early-career researcher participants from six countries, that represent the broader WG138 community. The cruise has been organized by the WG138 community and motivated by WG138 efforts. The results will provide the basis for substantial advancement in the understanding of planktonic foraminifera ecology.

<https://www.ldf.uni-hamburg.de/meteor/wochenberichte/wochenberichte-meteor/m139-m141/m140-scr.pdf>

<https://www.marum.de/en/about-us/AG-Micropaleontology-Paleoceanography/FORAMFLUX-M140.html>

The principal aim of the cruise was to provide data and samples to characterise the biology and ecology of planktonic foraminifera, and their coupling with biogenic and mineral particle flux. To this end, we used three approaches. Sampling of the water column by filtration and by plankton tows, combined with physical water properties profiles and water sampling was used to determine horizontal and vertical species distribution, diversity and physiology of planktonic foraminifera. The sampling was carried out using a vertically resolving plankton sampler (modified multiple closing plankton net) along transects between the mooring stations and two hyperreplicated full day continuous sampling schemes. Plankton samples will be processed for genetic analysis, for TEM study of digestive content and symbiont content and the photosynthetic activity of the symbionts has been measured on board. Short-term particle flux and particle composition in the water column were studied by deployment of drifting particle traps, marine snow catchers and in situ cameras. Long-term particle flux will be studied by analysis of samples from sediment traps. To resolve the short-term (reproduction related) component of shell flux, the sediment traps operate at 3-4 days resolution. To achieve this, we are using a serial design of 3 traps on one mooring, providing 120 cups per deployment.

2) The international network FORCIS lead by WG138 associate Thibault de Garidel Thoron (CEREGE, France) has been established, aiming to synthesize data on species distribution and densities in the plankton over the last 50 years in an attempt to identify trends of population change due to anthropogenic stress. Its first meeting took place in November 2017 in Aix en Provence.

SCOR/IGBP Working Group 138: Reflection on deliverables

The main goal of the proposed WG was to synthesize the existing knowledge of modern planktic foraminifera, to build on this knowledge for identifying priority research and to transfer expertise to the generation of young researchers.

We believe we met all of these objectives: the efforts of the WG facilitated several key synthesis products, including a benchmark synthesis and analysis of planktonic foraminifera seasonality (Jonkers and Kucera, 2015), their distribution in the sediments (Siccha and Kucera, accepted) and their genetic diversity (Morard et al., 2015, 2016; Weiner et al., 2016). It helped to identify key open questions in their biomineralisation (de Nooijer et al., 2014) and stimulated the development of revised taxonomy and of standardized identification key (work in progress). The identified gaps in knowledge have been used to formulate and realise new projects and networks (see previous section) and the first meeting in Amsterdam and final meeting on Catalina Island brought together much of the international community of students and young postdocs. The legacy of WG138 will live in the form of several documentaries, explaining the importance of planktonic foraminifera and showing how the research on these organisms is carried out.

In addition to the progress on individual research and syntheses of individual types of data, the WG138 community envisaged to deliver a comprehensive eBook as an open resource containing authoritative reviews of all aspects of modern planktonic foraminifera taxonomy, ecology and biomineralisation. An updated review is in progress as a journal article (Schiebel et al., submitted). The envisaged eBook project does not appear viable within the time horizon of the WG138 duration, due to our ambition to be comprehensive, (we have not been successful in populating every aspect of the synthesis with potential authors) and so whilst we are not abandoning the project, this particular deliverable has not yet been met.