RheFFO

Rheology, nano/micro-Fluidics and bioFouling in the Oceans.

Working Group Proposal submitted to SCOR June 2015

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Summary (247/250)

Ocean water is a biofluid, thickened by exopolymeric substances (EPS) produced mainly by algae and bacteria. Locally, particularly at scales <~1 cm, this EPS has been shown to increase viscosity many-fold, and gives elasticity to the water. Some of this EPS occurs as sheaths and glycocalyxes around algae and bacteria, and are thought to be part of their ecological engineering strategy.

In the last ~15 years, superhydrophobicity (SH) has been discovered at hydrophobic, sculptured surfaces. SH is manifest by superhydrophic drag reduction (SDR) in surface layers up to several, µm thick. It also can promote strong repulsion of materials such as dirt and fouling organisms. Commercially available SH self-cleaning materials are now widely available, and are being developed for non-toxic ("green") antifouling coatings for ships, etc.

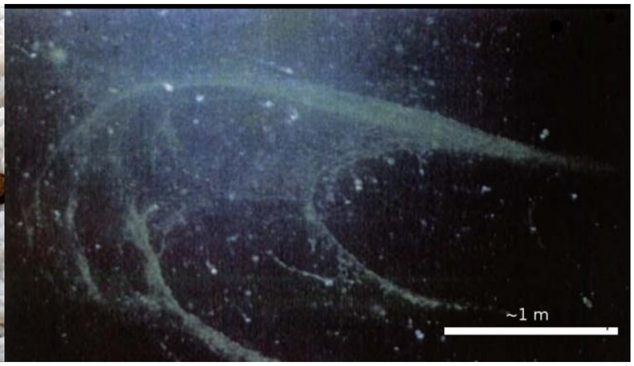
There is little awareness of these developments amongst the ocean-environment research community, and little understanding of the sciences underlying their development: namely rheology; nano/microfluidics (NMF), and the electrochemical bases of non-toxic antifouling mechanisms.

Swarming of protists and bacteria occurs, where concentration is much increased and synchronised swimming occurs, in which viscosity can be changed many-fold. *RheFFO* WG shall investigate such effects occurring locally in the oceans.

A principal object of this WG is to form a nucleus of scientists all literate in: (i) ocean sciences of pelagic ecology and biogeochemistry; (ii) rheology; (iii) surface science, including NMF and biofouling/antifouling mechanisms. The WG will thus have strong activities in capacity development (CD), from an interdisciplinary team of experts mainly to young scientists.

2. Scientific Background and Rationale (1237/1250)

2.1. Rheology



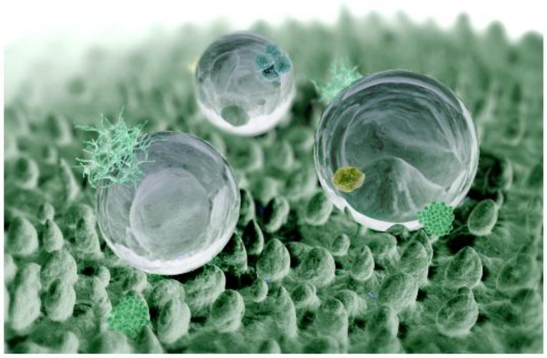
Left: Foam on the beach at Yamba, north of Sydney, Australia, produced from EPS, believed to be primarily secreted by Phaeocystis *sp. (c) Icon Images.*

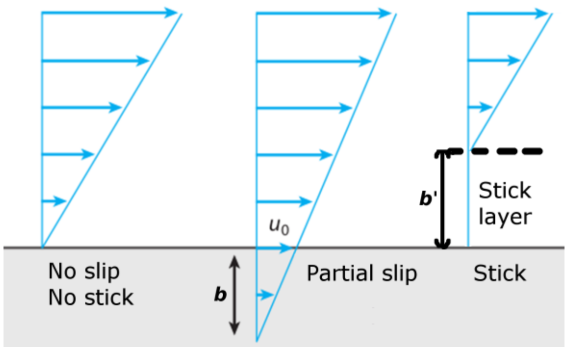
Right: Marine organic mega-aggregate during a mucus event in the northern Adriatic. Its form reflects deformation by a large turbulent eddy. From Stachowitsch et al. (1984, P.S.Z.N.I., Mar. Ecol., 5: 243-264).

The sea is a non-Newtonian biofluid, and its rheological properties have been made in relation to its biological content. Yet most oceanographers are still unaware of this, or if they are aware, they do not have the training to apply these findings to their own research and models.

2.2. Superhydrobicity (SH), antifouling and self-cleaning

Have you ever wondered how many algae keep so clean? Lotus leaves do it by having SH self-cleaning surfaces. Encounter and fouling of surfaces by plankton, including their larvae, take place largely in near-surface layers. Recent developments in “green” (i.e. non-toxic) methods of antifouling on ships (Wang et al., 2014), other marine structures and desalination membranes (Balzano et al., 2014) can be applied to investigate adhesion, recognition, and repulsion by plankton.





Left: Computer-enhanced image of SH leaf surface in air ((c) Julia Lauren Vasic on March 30 2008).
Right: A fluid flowing over a surface. Left - standard model; middle SH tends to produce slipping; right - adsorption of ions or mucus tends to produce a “sticky” layer. b *is slip length;* b*’ is sticking length;* u_0 *is slip velocity.* b *can range from nanometres to micrometres, or occasionally millimetres.*

2.3. Nano/microfluidics

Recent developments in nano- and microfluidics, including “lab-on-a-chip”, have shown that surfaces in fluids exert influence from nanometre to millimetre scale into the fluid. This concerns pico- to micro- plankton, including the sculptured surfaces of diatoms, the microfibrils around pro- and eukaryotes and the micrometre-scale feeding appendages of copepods and other zooplankton (Rothstein, 2010; Wong et al., 2011; Jenkinson, 2014). Most oceanographers are unaware of this.

2.4. Incorporation rheological measurements into models of ocean fluidics

GEOHAB (2011) posed the question, “How can we quantify modifications in turbulence by phytoplankton through changes in the viscosity of its physical environment?” At that time, the state-of-the-art (Jenkinson & Sun, 2010) was that viscosity η of seawater and freshwaters was composed of an aquatic component η_W due to water (and salts) plus an excess organic component η_E due mainly to EPS.

Total viscosity,

$\eta = \eta_W + \eta_E$ [Pa s] (1)

Broadly, η_E shows a negative relationship power-law relationship with shear rate $\dot{\gamma}$, so that

$\eta_E = k.\dot{\gamma}^P$ [Pa s] (2)

where *k* is a coefficient and *P* is an exponent, both related to phytoplankton-produced EPS concentration and type. *P* can vary from 0 to ~-1.4 (shear thinning), and has exceptionally been found positive (shear thickening). Using chlorophyll *a* concentration *chl* as a proxy for phytoplankton, then

$$\eta_E = k.chl^Q.\dot{\gamma}^P \qquad \text{[Pa s]} \qquad (3)$$

where *Q* is the phytoplankton concentration exponent, found to be about 1.3 generally. Further research, however, has shown that *Q* can vary locally with the growth phase of the bloom (Seuront & Vincent, 2008).

EPS thickening, moreover, is generally lumpy, probably associated with polymer spontaneous assembly (Chin et al., 1998; Ding et al., 2008, 2009). This produces length-scale dependent viscosity, which can be modelled using a lumpiness exponent.

Eq. 3 can now be "corrected" for length scale by a third exponent:

$$\eta_E = k.chl^Q.\dot{\gamma}^P.(L/M)^d \qquad \text{[Pa s]} \qquad (4)$$

where *L* is the length-scale of interest, *M* is the length scale of measurement, and *d* is the length-scale exponent. A model of whether lumpy EPS could thicken the water enough to stabilize a pycnocline (Jenkinson & Sun, 2011a) found that the value of *d* in Eq. 4 was very critical. To investigate *d*, *η* of phytoplankton and bacteria (PB) cultures was measured in capillaries of different radii. While *η* was increased in some combinations of shear rate, capillary radius, 0.35 to 1.5 mm, and PB species, presumably by EPS, *η* was surprisingly decreased in other combinations (Jenkinson & Sun, 2014). This may be associated by superhydrophobic conditions, sometimes called the *Lotus Leaf Effect*, at the surfaces of PB and EPS (scales nm to possibly 100s µm).

2.4.1. Some effects of increased viscosity (with suggested primary length scales) include:

1. Damping of turbulence and of sub-Kolmogorov-scale water movement: 1 nm – 1 m (Jenkinson, 1986);
2. Due to elasticity and lumpiness, complex changes to patterns of water movement, and de-coupling of shear rate from dispersion: 1 nm – 1 m (Jenkinson, 1986);
3. Partial and/or total clogging of the gills of fish (Jenkinson, 1989; Jenkinson et al., 2007), molluscs, tunicates, sponges, polychaetes, etc.: 1 nm – 1 mm;
4. Due to rising organic matter and adsorption to the air-sea surface, reduction of air-sea gas exchange (Calleja et al., 2009), wave and ripple damping (Carlson, 1987): 10 µm – 10 m;
5. Complex situations, illustrated by *Phaeocystis*, which produces closely associated stiff mucus holding cells together in colonies (~50-2000 µm), while also producing looser diffuse mucus that increases viscosity at larger scales (Seuront et al., 2006), as studied in sludge organic aggregates (Liu et al., 2010): 50 µm – 1 m;
6. Flocculation into mucous aggregates, thus increasing sinking or rising speed and hence vertical organic flux (Mari et al., 2012): 100 µm – 1 mm.
7. Possible reinforcing of pycnoclines by PB EPS (Jenkinson & Sun, 2011, 2014): 10 cm – 10 m;
8. Trapping of toxins close to metabolically active surfaces, such as cell membranes and gills (Jenkinson, 1989): 10 nm – 1 mm.

2.5. Investigation techniques of seawater and lakewater thickening include:

2.5.1. Rheology

1. Rheometry: a) concentric cylinder; b) sliding piston; c) capillary flow; d) ichthyoviscometry;
2. Studies of fluid movement at small scale: a) 3D particle image velocimetry (PIV); b) 3D particle tracking velocimetry (PTV);
3. Studies of small forces at small scale: Atomic Force Microscopy (AFM)
4. Combination of electrochemical techniques with rheometry, microscopy and PIV/PTV, ***in situ*** **if and when possible**;

2.5.2. Nano- and microfluidics of biosurfaces (particularly sticking layers and slip layers at surfaces)

1. High-speed video with PIV and PTV of flow through capillaries coated with organic sculptured layers of hydrophobic (Rothstein, 2010), hydrophilic (Bauer & Federle, 2009) and omniphobic (Wong et al., 2011) surfaces. To be combined with transmission electron microscopy (TEM), scanning electron microscopy (SEM), pressure/flow curves, and possibly standard rheometry of the test materials.
2. Scanning electrochemistry of organic matter film dynamics: Hanging mercury drop.
3. Use of electrochemical techniques developed to study the effects of biological coatings on corrosion dynamics;
4. Studies of attraction-repulsion fields, electrical double layers (EDLs).
5. Immunological type radicle-radicle recognition and adhesion.

2.5.3. Biofouling, with adhesion, recognition and repulsion

1. Fouling organisms need to encounter suitable surfaces, recognise them as suitable, then initiate a series of actions to adhere to the surface, and possibly to use means to penetrate it. Organisms subject to fouling are likely to have evolved antifouling mechanisms to avoid being fouled. Related to fouling and antifouling actions can be considered:
    a. Predation and avoidance of predation;
    b. encounter and avoidance of "unwanted" sexual encounter;
    c. Parasitism/symbiosis and avoidance of unwanted parasitism/symbiosis;
    d. Pathogenic infection (by bacteria, viruses) and its avoidance;
    e. Colonisation of different substrates (macrophytes, corals, rocks) by benthic dinoflagellates (*Gambierdiscus*, *Ostreopsis*) involved in harmful and toxic algal blooms (especially in tropical and subtropical regions, but apparently expanding their range associated with global warming);
    f. By diffusion reduction and binding of toxins to mucus, protection of cells against nutrient competition and "stealing" by other microbial organisms.

2. The aim will be to use techniques developed largely for "green" biomolecule-modulated industrial antifouling techniques (for ships, cooling intakes, fish-farm cages and nets, etc.) to investigate fouling by organisms of other organisms and of non-living substrates in the sea (plankton, fish and benthic organisms, organic aggregates, sediment, rocks, etc., possibly already covered by biofilms).

3. The techniques to be used require further discussion by the WG members.

3. Terms of Reference (210/275)

3.1. Vision

The ocean science community lacks expertise in (1) Rheology (the study of deformation in non-Newtonian materials); (2) nano- and microfluidics; (3) fouling and antifouling; (4) surface-surface recognition and adhesion. These domains affect trophic, sexual, parasitic, pathogenic and other types of encounter, that take place close to electrically controlled surfaces including glycocalyxes. Only when this knowledge is shared among ocean researchers, modellers and engineers, can there be more fundamental understanding of the processes occurring at the cell-size small scale. Without such knowledge sharing, which requires strong CD, future models of how the oceans will react ecologically and biogeochemically to future global changes will be unnecessarily flawed.

3.2. Objectives

A Through capacity development (CD) of younger scientists, particularly in emerging countries, the multidisciplinary team of experts create a corps of ocean researchers, modellers and engineers literate in: (1) Rheology; (2) Nano- and microfluidics; (3) Fouling and antifouling at surfaces; (4) Electrochemical investigation tools, that they will teach to their students and graduate students in the decades to come.

B. During the lifetime of the WG, carry out research to carry this expertise to other oceanographic problems, to involve the members' students in theoretical and empirical research, published in scholarly papers, books, multimedia, and incorporated in outreach material across the globe.

4. Work plan (619/1000)

Year	Actions

1	• Before the Workshop, produce the kick-off draft SCOR Core Research Project (CRP) for RheFFO.
	• **Workshop 1.** Objective: "Define the implementation plan for the Core Research Project"
	    • Interdisciplinary CD by multidisciplinary team of experts of key younger scientists.
	    • All experts and younger scientists participate. Each expert gives one or two 1.5-h lecture(s) on his/her expertise.
	    • Each younger scientist outlines his/her expertise, and how (s)he believes the WG is needed to help solve bottlenecks in ocean research.
	    • Experts give practical demonstrations of their techniques, and give the others hands-on experience.
	    • The experts work together to write a keynote paper for a high impact open access scholarly journal, led by designated chair. Younger scientists may be invited to participate.
	    • A terminal task of the Workshop will be to go through and refine the Core Research Project, and produce the final version.

	• Back in their home institutes, the experts lecture on these topics, incorporating *RheFFO* expertise. Between meetings, using electronic media, they help younger scientists to seek funding and write ocean-science proposals, incorporating *RheFFO* expertise. • They finalise the keynote paper for publication. • They shall incorporate *RheFFO* material in other ocean work. • The Rheology and micro- and nanofluidics experts raise funds and recruit PGs and PDs in their home labs to work on ocean-related problems using their expertise, as well as helping the trained younger scientists around the world. • Progress report 1. • Keynote paper 1.

2	• **Workshop 2**
	  ◦ All WG members participate, with their PGs and PDs as suitable.
	  ◦ Continued CD –. One lecture course per expert, with major contribution by younger scientists, and contribution by the PGs and PDs.
	  ◦ Appropriate reports by Experts' and PDs and PGs report on research done back home.
	  ◦ One or two multi-editor books should be initiated with chapters written by members of the WG and others. The authors should take advantage of the meeting to work together on their books and chapters, as well as on the second keynote annual paper.
	  ◦ Experts' reports on progress in achieving WG deliverables.
	  ◦ The experts work together to write a paper on a topic different from that in Year 1.
	• Social activities will be strongly encouraged liaison between PDs and PGs from different institutes and disciplines, as long-term friendship will be crucially important for maintaining the developed corps of expertise after the end of the WG.
	• Back home, each expert shall recruit more PDs and PGs. Experts should invite their colleagues and their PDs and PGs to work together in their home institutes and if possible on sea cruises.
	• Progress report 2.
	• Keynote paper 2.

3	• **Workshop 3**
	  ◦ As above
	  ◦ The books should be nearing completion or in press. Finalising should be done.
	  ◦ The workshop also needs to focus on preparing the winding up of the WG at next year's workshop.

	• Progress report 3. • Keynote paper 3.

4	• Before the workshop, the final report should be drafted, for finalisation at the workshop.
	• **Workshop 4**
	    • As above. The last annual paper will be prepared.
	    • All the books and monographs will be already completed or in press.
	• The WG has to be wound up with a final paper for online publication by SCOR, that will be a scientific review of new discoveries made during the WG in relation to other progress made in ocean science, rheology and nano- and microfluidics, pointing out new questions and gaps in knowledge.
	• Annual progress report 4.
	• Final report for whole period of WG.
	• Final report, incorporating progress report for Year 4.
	• Keynote paper 4.

5. Deliverables

- One Kick-off Core research project
- One finalised Core Research Project
- Four keynote papers in top learned journals.
- Two multi-editor books (or a book and a monograph).
- 4 annual progress reports
- 1 Final Report, for publication by SCOR.

6. Capacity development (172/500)

6.1. Production of a corps and a network of interdisciplinary expertise worldwide.

An important aim of this WG is to produce a world-wide nucleus of scientists with expertise in rheology, nano- and microfluidics, and biofouling and antifouling, along with the electrochemistry tools to do some of this research, all in relation to plankton ecology, biogeochemistry and other aspects of oceanography. EECB will continue throughout the WG to progressively deepen interdisciplinary understanding. A principal aim will be to develop a corps and a network of young scientists and engineers trained in all aspects of *RheFFO* knowledge. We will aim so that these young scientists become friends and remain friends for the rest of their careers, publishing together, co-mentoring each other's students, and thus continuing CD into the future.

6.2. Cross-disciplinary knowledge transfer

The experts in different fields, physical oceanography, plankton biology and harmful algal blooms, biogeochemistry, rheology, nano/microfluidics, biofouling, electrochemistry and atomic force microscopy, shall develop interdisciplinary capacity in exceptionally talented young scientists from different backgrounds, specially invited to joint the WG workshops.

7. Working Group composition

7.1. Full Members

Name	Gender	Place of work	Expertise relevant to proposal
Ian R. JENKINSON Chair	M	Institute of Oceanology Chinese Academy of Sciences, Key Laboratory of Marine Ecology and Environmental Sciences, Qingdao, P.R. China	Physical-Chemical-Biological coupling, particularly related to p harmful algal blooms. Rheology and ocean turbulence. Superhydrophobic surfaces. Ecological engineering;
Elisa BERDALET Chair	F	Institut de Ciències del Mar (CSIC). Barcelona, Spain	Physical-biological interactions. - Harmful Algal Blooms. - Biochemical methods. - Microplankton physiology. Vice-chair of the Scientific Steering Committee of the SCOR/IOC-UNESCO program GEOHAB, Global Ecology and Oceanography of Harmful Algal Blooms
Laurent SEURONT Chair	M	Centre National de la Recherche Scientifique and Université de Sciences et de Technologies de Lille, Wimereux, France.	Phytoplankton, zooplankton, coastal oceanography, multiscaling and (multi) fractals in physical, biological and economic systems, and particularly in marine ecology, seawater viscosity in relation to phyto- and bacterioplankton.
Jinju (Vicky) CHEN	F	Lecturer in Nano-Biomechanics, Newcastle University, UK	Modelling and experimental characterisation of rheology of biofilms, biofilm formation, and biofilm attachment. Microfluidics for biofilm characterisation
Mariachiara CHIANTORE	F	Associate Professor in Ecology at DiSTAV, Università di Genova, Italy	Modeling and mitigation of benthic harmful algal blooms. Ecology of *Ostreopsis* spp., especially environmental triggers, toxic effects.
Wei-Chun CHIN	M	School of Engineering, University of California, Merced, USA	Experience with marine gels and EPS aggregation mechanism. Applying various techniques from nanotechnology and engineering. Impact of environmental factors (pH, temperature and pollutants) on marine microgels and EPS.

Stephen HERMINGHAUS	M	Max Planck Institute of Dynamics and Self-Organization, Head of Dept. Dynamics of Complex Fluids, Göttingen, Germany	Rheology, nano/microfluidics, rheological effects of swarming cells, rheological effects of marine plankton, rheological effects at surfaces. Experience in organization
Sophie LETERME	F	Plankton Ecology Laboratory, Flinders University, Adelaide, Australia.	Senior Lecturer,
Zhuo LI	F	Tongji University, College of Environmental Science & Engineering, Shanghai, P.R. China	Associate professor, rheology, developing micro/nano- fluidic biosensors, and computational fluid dynamics (CFD).
James G. MITCHELL	M	School of Biological Sciences, University of Flinders, Adelaide, Australia	Heads a group focusing on nanometer to micrometer scale processes and marine ecosystems. Lessons learned have been applied to nanotechnology, including microfluidics and nanofabrication.

7.2. Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
Myriam BORMANS	F	National Centre for Scientific Research and Université de Rennes I, Rennes, France	Research director. Role of turbulence in phytoplankton dynamics, colony formation and EPS production, morphological traits based ecology. Provides experimental grid stirred tank, and NanoSIMS (Secondary Ion Mass Spectrometry) expertise
Valentina GIUSSANI	F	Department of Earth and Environmental Science, University of Genoa, Italy	Doctorante, Ecotoxicology and management of benthic harmful algal blooms, especially in relation to their mucilaginous matrix.
Moshe HAREL	M	CEO, Sha'ked Microbial Solutions Ltd., Tel Aviv, Israel	Mutual relationship of a green-alga and the freshwater cyanobacterium *Microcystis* sp., and dynamics of EPS.
Xavier MARI	M	Researcher, Institute of Research for Development, Marseille, France	Characterisation of TEP, measuring sinking and rising, cohesive properties, aggregation dynamics in estuaries
Javeed Shaikh MOHAMMED	M	Head, Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin,	Biological microelectromechanical systems (BioMEMS), Nanotechnology, Microfluidics, Hydrogels

		Kuala Terengganu, Malaysia	
Michael ORCHARD	M	Physical Ecology Laboratory, University of Lincoln, UK	Research Assistant. High-speed video-microscopy of predation in marine protists. Adhesion, rheology and surface science
RI QIU	M	State Key Laboratory for Marine Corrosion and Protection, Luoyang Ship Material Research Institute, Qingdao, P.R. China	Assistant professor. Prevention of marine biofouling and corrosion, using "green" organic techniques and surface properties. Superhydrophobic surfaces. Electrochemistry as a tool to measure ion migration and for changing behaviour of fouling organisms.
Massimo VASSALLI	M	CNR – The Biophycs Institute, Genoa, Italy	Using physical tools such as atomic force microscopy and optical tweezers to measure physical properties of biological systems (mainly mechanics and rheology of cells, gels and proteins).
Peng WANG	M	Institute of Oceanology Chinese Academy of Science, Key Laboratory for Marine Corrosion and Biofouling, Qingdao, P.R. China	Associate professor. Prevention of marine corrosion and biofouling, using "green" organic techniques and surface properties. Electrochemistry. Superhydrophobic surfaces.
Tim WYATT	M	CSIC, Institut de Investigaciones marinas, Vigo, Galicia, Spain	Senior Research Fellow, HABs, fisheries, organic matter and ecological engineering, eclecticism and excellent writing skills.

8. Working Group contributions (500/500)

BERDALET, E.

1. Berdalet shall provide CD in (i) Physical-biological interactions; (ii) Harmful Algal Blooms; (iii) Biochemical methods; (iv) Microplankton physiology. She is Vice-chair of the Scientific Steering Committee of GEOHAB.

2. Berdalet will provide world level expertise on ocean pelagic ecology and biogeochemistry, as well as project leadership and co-ordination.

CHEN, J.

1. Chen's research team shall contribute to Multiscale modelling and characterisation of biofilms, nanobiomechanics of bacteria (DTA award).

2. Chen's group shall also provide infrastructure for research on and characterisation of microfluidic devices.

HERMINGHAUS, S.

1. Herminghaus heads the department 'Dynamics of Complex Fluids' at the Max-Planck-Institut for Dynamics and Self-Organization, Göttingen, that investigates collective behavior and pattern formation in soft matter systems, important for understanding the dynamics of self-propelled entities, such as some plankton.
2. Herminghaus shall provide CD in microfluidics, rheology and structure formation in complex matter, shall provide infrastructure for the study of the interaction of active swimmers with surrounding flow fields.

JENKINSON, I.R.

1. Jenkinson pioneered and give CD in: (i) measurement of viscosity and elasticity in algal cultures and in seawater; (ii) measurement of reduced viscosity in algal cultures in capillary flow, e.g. Lotus leaf effect); (iii) incorporate of such findings into models of ocean fluidics.
2. Jenkinson will provide CD in seawater rheology, and an interface between (i) ocean scientists and (ii) rheologists and fluidicists, and will direct CD in both directions.

LETERME, Sophie

1. Leterme’s group of two research associates and a PhD shall provide infrastructure and expertise on transparent exopolymeric polymer (TEP) production by microbes in desalination systems.
2. Biofouling potential of microbes in desalination systems, and expertise in plankton ecology in relation to surface nano/microstructure.

LI, Zhuo

1. ZL’s research group consists of ten members focusing on rheology in polymer solutions and activated sludge
2. The group shall provide micro/nano- fluidics infrastructure and CD for fluid dynamics investigation and nano-biosensors for monitoring chemical components, as well as running computational fluid dynamics (CFD) software.

MITCHELL, J.G.

1. Mitchell’s research 27-member group focuses on the influences of nanometer to micrometer scale processes on marine ecosystems.
2. Mitchell will provide expertise and CB on nanometre to micrometre surface structure in relation to NMF in plankton and other pelagic particles.

SEURONT, L.

1. Seuront is internationally recognized for his expertise in micro-scale patterns and processes in the ocean.

Seuront’s shall provide CD on: (i) biologically-driven viscosity and its temporal dynamics and (ii) inferring the potential impact of this excess viscosity on structure and function in pelagic ecosystems, as well as bioproduction of excess viscosity, and its effects on structure and function in pelagic ecosystems.

ZHANG, D.

1. Zhang is head of the Key State Lab of Marine Corrosion and Biofouling. Her laboratory shall provide electrochemical tools to work on marine antifouling based on superhydrophobicity

and slippery liquid-infused porous surfaces (SLIPS), related to marine biofouling and corrosion control.

2. Zhang's team shall provide CD, particularly in relation to surface-based and electrochemically-based control by organisms of surface fouling, and defeat of antifouling activity.

9. Relationship to other international programs and SCOR Working groups (224/500)

9.1 GEOHAB – Global Ecology and Oceanography of Harmful Algal Blooms

There are close links between some *RheFFO* members and GEOHAB. Berdalet is Vice-Chair of GEOHAB. Wyatt and Jenkinson have participated in GEOHAB meetings and scientific activities for many years. GEOHAB (2013) has recommended that measurements of viscosity and rheology be carried out in relation to harmful algal blooms. It is foreseen that strong relations between *RheFFO* WG and GEOHAB (or its successor organization) will continue.

9.2 SCOR WG 141 – Surface Microlayer (SML) Working Group

There are strong cross-cutting subjects between *RheFFO* and SCOR WG 141. These particularly concern the accumulation of dissolved, colloidal and particulate organic matter in the SML, and its modulation of processes including air-sea gas exchange (Calleja et al, 2009), ripple damping (Carlson, 1987), upward flux of salt, water vapour (evaporation and spray) and plankton spores during storms, and downward entrainment of gas as bubbles. In October 2014, Jenkinson accepted a very kind offer by YANG Gui-Peng, to participate in a SCOR WG 141 Workshop at Qingdao, PR. China. This experience will provide input to *RheFFO* in organising SCOR workshops, while the subject matter is also relevant to RheFFO.

9.3 Other organisations

- Other organisations with which *RheFFO* will make contact are
- SOLAS, WOCE,
- Turbulence programmes, GOTM, GETM, FABM
- IMBER
- Programmes in Rheology, Nano/microfluidics, Corrosion, Biofouling and antifouling.

10. References (500/500)

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Appendix

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