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Environmental genomics applications for environmental management activities in the oil and gas industry: state-of-the-art review and future research needs

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ABSTRACT

Environmental genomics is a rapidly advancing field that promises to revolutionise the way in which industry conducts biodiversity monitoring. The International Association of Oil and Gas Producers Environmental Genomics Joint Industry Program (JIP) was formed in June 2019 with the aim of facilitating the development and uptake of environmental genomics within the oil and gas industry. Towards this goal, a white paper was produced that summarises the state-of-the-art in environmental genomics research, and the opportunities and limitations of applying environmental genomics within industry. The white paper included a comprehensive literature review, and importantly, involved consultation with professionals from academic, regulatory and industry backgrounds from across the globe that had expertise in environmental genomics applications. While this consultation revealed a consensus that the application of environmental genomics has advanced greatly in a brief period, with demonstrable benefits, there was an acknowledgement that key aspects are still lacking that would allow confident application of genomics approaches within industry. Through the review and consultation process, a range of knowledge gaps and areas requiring further development were identified. To elucidate which of these areas were most critical to the successful application of environmental genomics within industry, the JIP is drafting guidance that describes sampling design considerations, minimum standards for laboratory analyses and approaches to genomics data interpretation. Through the drafting of guidance, the JIP hopes to determine which gaps are most critical, enabling these to be prioritised for targeted research. The guidance will then be updated regularly to capture the latest research outcomes.

Keywords: academics, biodiversity, consultation, eDNA, environmental DNA, Environmental Genomics Joint Industry Program, IOGP, knowledge gaps, monitoring, oil and gas industry, regulators.

Introduction

Biodiversity monitoring is undertaken throughout the oil and gas industry, often as a regulatory requirement, to understand and manage environmental risks. Conventional biodiversity monitoring, which usually includes observing or collecting species, is labour-intensive, expensive and often needs to be carried out by experts with taxonomic training. Evaluating environmental DNA (eDNA) provides a genomic approach to identify species through the presence of their DNA in an environmental sample, such as water, sediment or soil. DNA fragments in the sample are amplified, sequenced and matched to known species sequences in online libraries to confirm detections.

A major advancement in eDNA methods was the step change in sequence throughput rate facilitated by Next-Generation Sequencing (NGS) technology. Previous sequencing

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methods were only capable of reading a few thousand base pairs and focused on only one or two species, whereas modern NGS machines are capable of reading over a billion base pairs in a single sequencing run, which allows detection of thousands of species in a sample (Shendure *et al.* 2017). Samples required for eDNA analysis are small, rapidly collected and do not require field-based taxonomic expertise. With simple training, oil and gas industry personnel can be readily tasked with collecting eDNA samples which can be sent to an eDNA laboratory for analysis.

The International Association of Oil and Gas Producers (IOGP) Environmental Genomics Joint Industry Program (JIP) was formed in June 2019 with the objective of facilitating the development and uptake of eDNA within industry. A white paper was commissioned by the JIP and included a comprehensive review of the published literature and consultation with a range of academic, regulatory and industry professionals from across the globe that had experience in eDNA. The objective of the white paper was to summarise the state-of-the-art in eDNA science, the opportunities and limitations of applying eDNA within industry and key areas that needed to be addressed to achieve greater acceptance and uptake of eDNA by industry, regulators and other stakeholders.

Methods

JIP members developed an agreed list of priority applications to help focus the white paper review and consultation on aspects of eDNA that were currently considered most critical to industry. These priority applications included

- Baseline assessments
- Detection of key species
- Rapid assessment of invasive species
- Species population status and dynamics
- Monitoring of environmental effects of oil and gas activities
- Remediation and restoration.

Focusing on the above applications, a review of primary literature and other professional publications was undertaken to identify the opportunities, knowledge gaps and limitations of using eDNA technology in the oil and gas industry. To provide additional information and viewpoints to those revealed in the literature, consultation was undertaken with professionals from academic and industry backgrounds, with an interest in eDNA. Consultation with regulators from various jurisdictions was also conducted to provide an indication of the current level of regulatory awareness of eDNA and the potential hurdles in achieving acceptance of the use of eDNA within regulatory frameworks.

Consultation involved a two-phased approach: During Phase 1, a digital questionnaire was developed and distributed to approximately 100 individuals and organisations. Respondents were predominantly representatives of government organisations, with the remainder being equally distributed amongst academia, industry and service providers, as well as a single not-for-profit respondent. The goal of the questionnaire was to identify a respondent's current state of knowledge of eDNA, as well as their view of information gaps that hindered successful deployment and uptake of the technology. Based upon the survey responses in Phase 1, telephone interviews were conducted in Phase 2 to obtain more detailed information from respondents, particularly for the prioritised industry applications.

A facilitated discussion and feedback session was also held with participants attending the International Workshop on Environmental Genomics (IWEG), which was virtually hosted from St John's, Newfoundland, Canada in June, 2020. This interactive session included distributing a truncated version of the original questionnaire to participants. IWEG participants who answered the questionnaire were mainly academic or research-focused, followed by industry representatives, which reflected the target audience of the meeting. Response results were compiled and collated for questions common to both the original consultation and IWEG questionnaire.

Results and discussion

The literature review and consultation revealed a consensus that the application of eDNA has advanced greatly in a brief period, with demonstrable benefits. The majority of regulatory agencies that were consulted were aware of eDNA and its potential application within industry environmental monitoring and decision-making processes. Furthermore, multiple regulators were either leading, or active participants in, initiatives to standardise eDNA approaches in survey designs, sampling, reporting requirements or varying combinations of each. The review and consultation highlighted that eDNA performance was comparable, complementary to, or outperformed conventional monitoring approaches in a range of applications. However, there was an acknowledgement in both the literature and consultation responses that knowledge on several key aspects was lacking, and that if addressed, would allow for more confident reliance on eDNA data within industry. The key aspects most frequently cited are outlined below.

Understanding DNA persistence and dispersal

DNA degrades at variable rates in the environment, affected by ultraviolet (UV) radiation, temperature and microbial activity (Barnes *et al.* 2014). eDNA is also assumed to disperse to various degrees from its point of origin, particularly in the marine environment where it can be transported on currents (Salter *et al.* 2019). The review and consultation highlighted a strong recognition of the need to understand

how DNA persistence and dispersal affect the representativeness of eDNA in detecting species presence, with such an understanding likely to be required at a habitat or species level.

Integrating eDNA data with different data types

Within industry, eDNA data will likely be required to be integrated with other data types (e.g. historical data, baseline data, biotic indices or explanatory physico-chemical data). However, eDNA data are inconsistently reported, making it difficult to develop a standardised approach for integrating eDNA data with other data types. Additionally, eDNA assessments often detect a slightly different suite of species than conventional approaches (e.g. Stat *et al.* 2018), making comparisons among data types difficult. It was recognised that standardisation of eDNA data reporting and development of novel data integration methods would assist in better utilisation of eDNA data and uptake by industry, regulators and other stakeholders.

Improvement of sequence reference libraries

Many published studies and respondents indicated that sequence libraries have significant gaps and require input from studies in a variety of habitats and geographical locations to improve the accuracy of biodiversity studies (Taberlet *et al.* 2012; Cowart *et al.* 2015; Porter and Hajibabaei 2018; McGee *et al.* 2019). The completeness of sequence libraries varies widely among taxa, which may bias biodiversity assessments towards certain groups. While reference databases will continue to be populated over the long-term, it was recognised that a coordinated effort, both nationally and internationally, for library development, and a greater openness in sharing of curated sequence libraries would speed up this process.

Incorporation of eDNA into biotic indices

Programs that monitor changes in ecosystem health often use biotic indices, such as physico-chemical parameters and data on a range of indicator species (Monaghan 2016). In the short-term, researchers suggest that eDNA data could supplement or be incorporated into existing biotic indices (Pawloski *et al.* 2018). In the longer-term, however, it has been suggested that, due to its holistic assemblage representation, eDNA data could become a new type of biotic index that reflects change at an ecosystem level. Even where sequence library information is lacking, taxonomy-free approaches, combined with machine learning predictive models could be used to identify ecologically relevant changes in detected sequences (e.g. in Molecular Operational Taxonomic Units: MOTUs) within eDNA data (Cordier *et al.* 2019). eDNA data also lends itself to a variety of new applications of assessing ecosystem health, such as co-occurrence network analysis (Bush *et al.* 2019).

Standardisation of methods

In order to generate reliable, comparable and ecologically meaningful data that meet industry requirements, a broad standardisation of eDNA workflows is needed (Porter and Hajibabaei 2018; Harper *et al.* 2019; McGee *et al.* 2019). This standardisation would include sampling, storage, laboratory protocols, DNA barcode references, sequencing platforms and processes, data analyses and interpretation and biotic indices (Leese *et al.* 2016). The desire for standardisation of methods was also echoed by the majority of regulators interviewed, with some indicating that, ideally, international guidance should be developed that could be used across multiple jurisdictions.

Conclusion

This review highlights a persistent and growing optimism for using eDNA to advance the quality of biodiversity monitoring within industry, as well as to aid in our understanding potential changes in ecosystem structure, function and health. The science of eDNA is rapidly advancing and substantial progress has been made by the oil and gas sector in the past 5 years through the initial and continued academic–industry–regulator networking at IWEG and through the efforts of the IOGP Environmental Genomics JIP. However, the literature review and consultation identified five key areas that need to be addressed to more confidently rely on eDNA data within industry. As a first step to address these key areas, in 2022, the JIP is developing standardised industry guidance that describes sampling design considerations, minimum standards for laboratory analyses, and standard approaches to bioinformatics and data interpretation. Through the development of this guidance, the JIP will also identify remaining critical gaps, enabling these to be prioritised for targeted research, with the guidance being updated regularly to reflect the latest research findings. It is hoped that this standardised guidance will build confidence in the application of eDNA within industry and raise awareness and acceptance of eDNA approaches with regulators and stakeholders.

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Dr Marc Skinner is a senior marine scientist and biostatistician with over two decades of technical and project management experience in temperate North American marine and freshwater ecosystems as well as Caribbean marine environments. He has previously served as Stantec's Technical Leader for Marine Ecosystems in Canada and Practice Leader for the Environmental Services Group in Atlantic Canada. Marc's professional and research interests focus on environmental monitoring of industrial development in natural resource sectors, particularly oil and gas, forestry, aquaculture and commercial fisheries. His expertise lies in environmental effects monitoring, benthic ecology, sediment geochemistry, water quality, seagrass ecology and physiology, and remote sensing. In addition, he provides senior advice on study design and data analysis for marine, freshwater and wildlife projects. Marc has been invited on multiple occasions to provide scientific advice to Canadian federal regulatory agencies. He maintains R&D collaborations with industrial partners, US and Canadian regulatory agencies, NGOs and academia, particularly regarding environmental genomics, to provide innovative approaches to regulatory challenges. Dr Skinner is also an Adjunct Professor with the Faculty of Graduate Studies at Dalhousie University as well as the Faculty of Forestry and Environmental Management at the University of New Brunswick.

Catie Young is currently employed at Fisheries and Oceans Canada (DFO) in the Aquatic Resources Branch, St John's, NL. At DFO she assists with multispecies surveys at sea, laboratory work, and managing and editing a large multispecies database. She is also currently enrolled in part time studies completing her Master of Environmental Science at Memorial University of Newfoundland (MUN). Her research is titled, 'Distributions of deep-sea corals and sponges near Hatton Basin, Northwest Atlantic', and includes an environmental DNA (eDNA) component which will compare analysis of eDNA samples to video analysis results to evaluate the utility of this technique for characterising corals and sponges in sensitive and relatively inaccessible environments. When at Stantec, Catie worked with the Environmental Service Team in St John's, Newfoundland and Labrador. She has supported projects across a variety of sectors, including environmental assessments and marine and freshwater environmental effects monitoring for offshore oil and gas and mining projects, habitat compensation site reconnaissance for hydroelectric development, ecological risk assessment sampling and military base decommissioning.

Mary Murdoch is a Senior Principal at Stantec and Technical Leader for Ecosystems Services in Canada. She leads our Environmental DNA service offering and is actively engaged in environmental genomics projects in US, Canada and Australia, and in developing opportunities elsewhere in the world. Environmental genomics applications span marine, freshwater and terrestrial environments, and include development of new tools and approaches to improve biomonitoring. Mary has long-term involvement in marine offshore oil and gas projects involving environmental assessment and effects monitoring and near-shore dredging projects. She led our environmental baseline and assessment services for a large-scale proposed onshore shale gas exploration and development project. She is also a senior consultant for aquatic environmental assessment and monitoring services for mining and industrial sector clients in Canada. She is an author of several peer-reviewed publications in the fields of environmental genomics and toxicology, and regularly presents technical papers at industry-based conferences. As an innovation coach within Stantec, she supports, promotes and participates in Stantec's internal research and development program to advance technical delivery.

Dr Jordan Angle is currently the Environmental Genomics Lead within ExxonMobil Upstream Integrated Solutions. Jordan oversees the business-unit application of genomic technologies and also drives the technical R&D to further improve implementation. He also serves ExxonMobil as subject matter expert in nature-based and natural climate solutions. He holds a PhD in Microbiology from The Ohio State University where he studied methane-producing microorganisms and their contributions to greenhouse gas emissions from freshwater wetlands. Prior to that, he obtained BS and MS degrees in Biology from Eastern Illinois University.

Dr Jeff Pollock is currently the Environment and Biodiversity Advisor for Chevron's Gulf of Mexico Business Unit, based in Houston, Texas. Jeff provides subject matter expertise in the areas of biodiversity and protected species, environmental risk, environmental impact assessment and emergency response. Jeff holds a PhD in ecology from the University of Alabama and has over 15 years of subsequent professional experience in both the energy industry and environmental consulting.

Thomas Merzi is currently R&D Biodiversity Project Manager within TotalEnergies. Thomas is a trained ecologist with a master's degree in Biodiversity, Ecology and Environment; he studied Macroevolution in the University of Virginia and finalised its research at the University of Grenoble, studying Population Genomics. This was followed by an international volunteer experience as an environmental engineer in the Mahakam Delta in Indonesia from 2008 to 2010. Thomas was then appointed Environmental Engineer in TotalEnergies' affiliate in Angola, where he was first in charge of environmental impacts' studies and regulatory reporting; and later operations, managing chemicals, wastes and oil spill activities. Back in France at the end of 2013, Thomas was assigned Ecotoxicology Expert for the Group's E&P affiliates, in charge of risk assessment modelling studies and all E&P sites monitoring surveys. Since summer 2019, Thomas has joined the R&D team where he coordinates R&D actions on environmental genomics, eDNA topics and all biodiversity topics. R&D Biodiversity Team focuses on providing innovative tools and solution for project's planification and field monitoring techniques' improvement in which eDNA and molecular biology play a major role.

Dr Nicolas Tsesmetzis is the Project Leader for BioElectochemical Systems and Metagenomics in Shell's BioTechnology group. Nicolas is an expert in the field of Petroleum Microbiology and has 14+ years of experience in Biofuels and Renewables with focus on microbial processes. He holds a PhD in Cell and Developmental Biology from the University of East Anglia, UK, and a MSc degree in Plant Biotechnology from the University of Reading, UK. Nicolas has co-authored several peer-reviewed research articles and book chapters. He was appointed as Visiting Professor of Practice in the School of Natural & Environmental Sciences from the Newcastle University, UK (2017–2020), and is a member of the Technical Scientific Committee of the ISMOS Conference. His research incorporates a broad spectrum of lab-based next-generation DNA/RNA technologies as well as advanced computational methods for in-depth analysis of genomic, metagenomic and metatranscriptomic data from environmental and industrially relevant processes.

Dr Paola Maria Pedroni is Principal Advisor for Environmental Impact Assessments and Biodiversity with the HSEQ Department of Eni Natural Resources, based at headquarters in Milan, Italy. Her current responsibilities include integration of environmental sustainability and management of biodiversity and ecosystem services into company-wide operating practices and global asset portfolio. As part of her work in international oil and gas trade associations, Paola is Eni representative on the Environment Committee of IOGP, which she served as Co-chair, and on the joint IPIECA-IOGP Biodiversity & Ecosystem Services Working Group, which she served as Chair. Paola has also a broad range of R&D experience having worked for over 20 years in the biotechnology and environmental fields on projects for the development of recombinant vaccines and biocatalysts, the biological production of H_2 from solid waste with genetically designed photosynthetic bacteria and the biofixation of CO_2 with microalgae combined to waste water treatment.

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Anita Skarstad is a Principal Researcher at the Equinor Research Centre, based in Trondheim in the middle of Norway, working within Environmental Risk and Oil Spill Response. Anita's background is from Biotechnology, Cell Biology and Molecular Biology and she is task manager for different eDNA-based methodology development projects, for instance, JIPs funded by the Research Council of Norway, Equinor and other oil and gas companies within marine sediment environmental monitoring using eDNA technology. She is Equinor representative in the IOGP JIP-34 Environmental Genomics.

Cyril Mickiewicz serves in the Environmental Department of Eni US Operating Co. Inc., based in Houston, Texas. Mr Mickiewicz's responsibilities include oversight of the waste management program and supporting compliance with the Gulf of Mexico (GOM) discharge permit for offshore facilities and drilling operations. He also performs greenhouse gas (GHG) data collection, trend analysis, and assists with the development of energy efficiency projects for GOM and Alaska operations. Mr. Mickiewicz has over 25 years of experience in various aspects of the environmental industry. Prior to working for Eni US, Cyril managed environmental due diligence, site investigation and remediation projects in Texas, Louisiana, Florida and Oklahoma. His particular emphasis was the remediation of groundwater impacted by chlorinated solvents using *in situ* bioremediation techniques and water extraction systems at commercial real estate and industrial sites.

Felicite Robertson assumed the role of Environment Manager in 2018. Felicite spent 4 years as a Commercial Analyst in the gas industry with focus on International Commercial Arbitration (price re-openers) and analysis of financial, operational and legal risks. Felicite holds a Maritime Law degree. Today she works with the Environment Director towards the development and promotion of good environmental practices to support Members' efforts to manage environmental risk and improve environmental and GHG performance. She works closely with the Environment Committee to proactively develop and advocate the industry's position to inform regulatory changes with environmental implications and enhance industry's licence to operate, and she actively engages with regulators and relevant stakeholders to identify/address concerns, raise awareness and encourage fact-based discussion. Projects involve Recommended Practices for Methane Detection, Carbon Capture and Storage Guideline (joint Environment/Geomatics Committees): Advocacy and Outreach, via Regional Seas: (OSPAR, Barcelona, Abidjan and Cartagena Regional Seas conventions). Felicite manages the Sound and Marine Life JIP to increase awareness and advocacy of the industry's position on E&P sound and marine life-related issues and the JIP34 (Environmental DNA).

Harvey Johnstone assumed the role of Environment Director in 2021, bringing 34 years of experience in both government and private sector roles. Harvey spent 14 years with the Western Australian Government's Department of Environmental Protection (DEP). His roles with the DEP spanned air quality monitoring, and Management of Industry Licensing, Pollution Management and Contaminated Sites. He was instrumental in the advent of many regulatory changes including, load-based licencing, small industry regulation and the drafting of WA's Contaminated Sites legislation. Harvey left the DEP to join BP's Remediation Management Function in Perth, overseeing soil and groundwater liabilities in the western and southern parts of Australia, extending into Southeast Asia and the Middle East where he oversaw large remediation projects. He also acted as Environment Advisor to BP Upstream NOJVs in Australia. Harvey has extensive experience in decommissioning planning and operations, particularly onshore decommissioning and asset retirement obligations and was a part of the Decommissioning Due Diligence team for BP's Onshore assets. Harvey has managed projects and issues in many countries including Australia, Canada, China, Iraq, Oman, Vietnam, Singapore, UK and USA. Harvey has a Bachelor of Science degree from the University of Western Australia and a Certificate in Governance Practice from the Governance Institute of Australia.