

WORKING GROUP ON INTRODUCTIONS AND TRANSFERS OF MARINE ORGANISMS (WGITMO)

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WORKING GROUP ON INTRODUCTIONS AND TRANSFERS OF MARINE ORGANISMS (WGITMO)

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i Executive summary

The Working Group on the Introductions and Transfers of Marine Organisms (WGITMO) has contributed several major achievements to the ICES vision, including the first ICES Viewpoint on Biofouling and its source document, two Cooperative Research Reports, and numerous publications related to ToRs, and the continued population of the AquaNIS database. During the three-year cycle (2017–2019), the scientific experts of this working group, representing 21 countries, met and worked collaboratively with PICES, CIESM and other ICES working groups and international organizations. They have focused their scientific understanding of marine ecosystems to provide information (e.g. national reports, contributing to the AquaNIS database, ToR a), knowledge and advice on the introduction and transfer of marine organisms. This work has primarily concentrated on the following areas: climate change as a factor in invasion success (particularly in the Arctic ToR b); biofouling as a vector for introduction and spread (ToR c), and impact (ToR d); evaluating molecular tools for detection and monitoring (ToR e); and providing ecosystem overviews on non-indigenous species as requested (ToR f). The Group also addressed a request for information on ship-mediated introductions of harmful algal bloom species in the Arctic from the Working Group on Harmful Algal Bloom Dynamics (WGHABD) and presented this work at the WGHABD annual meeting (2018).

The first ICES Viewpoint and the source document on biofouling (Galil *et al.* 2019) were developed as a result of the theme session for the 2017 ICES ASC on bioinvasion trajectories and impacts in contrasting marine environments, organized by WGITMO as a collaboration between ICES-PICES-CIESM. One of the recommendations from that session was to “prioritize investigation on one of the most important non-native species transfer pathways – hull fouling and niche areas, both on commercial ships and recreational vessels, and through this contribute to IMO request for scientific information on use and effectiveness of IMO Biofouling guidelines globally”. Next steps for the WGITMO, jointly with the ICES/IOC/IMO Working Group on Ballast and Other Ship Vectors (WGBOSV), is submitting the ICES Viewpoint and source document to the IMO as a “substantive document” (an action paper, as well as an information paper) to the February 2020 meeting of the Pollution Prevention and Response Sub-Committee (PPR 7).

Recommendations from 2017 ICES ASC session also included development of applications of molecular methods (e.g. e-DNA), including the study of genetic structure of non-indigenous species populations (e.g. early warning). Members prioritized the use of molecular tools as a potential technology for early detection and monitoring of non-native species at a half day joint session (WGBOSV) in 2018. This ToR (e) was added following that meeting in recognition of the immediate importance of this issue. The Terms of Reference for a working group and workshop on molecular method tools for detection and monitoring to provide recommended guidelines for this rapidly emerging multifaceted tool will be finalized at the next shared day meeting of the groups (WGITMO, WGBOSV), with WGHABD in Poland in March 2020.

The WGITMO will seek a continuation of the existing group and modifies the previous ToR for utilization of DNA- and RNA-based molecular approaches to provide science-based tools for strategic planning, policy development, and operational processes regarding non-native species and biological invasions. Two new ToRs are drafted based on member priorities and concerns regarding introduction and transfer issues. One new ToR will address the ecological impact of marine litter as a vector for introduction and spread of marine non-indigenous species. A second new ToR addresses interactions of aquaculture and the environment as it relates to the introduction and spread of non-indigenous species and the risk posed by NIS including pathogens.

ii Expert group information

Expert group name	Working Group on Introductions and Transfers of Marine Organisms (WGITMO)
Expert group cycle	Multiannual fixed term
Year cycle started	2017
Reporting year in cycle	3/3
Chair(s)	Cynthia McKenzie, Canada
Meeting venue(s) and dates	13-15 March 2017, Woods Hole, USA (31 participants)
	7-9 March 2018, Madeira, Portugal (47 participants)
	4-6 March 2019, Weymouth, United Kingdom (50 participants)

1 Introduction

The Working Group on Introduction and Transfers of Marine Organisms (WGITMO) deals with aquatic non-indigenous organisms that have an influence on and occur in the marine environment. WGITMO addresses multiple research and applied issues related to bioinvasions, such as early detection and alerts to potential spread, population dynamics and distribution, ecological impacts including biofouling and the role of climate change, and the development and use of risk assessment tools. The group keeps annual records on new invasions in ICES areas and provides management advice upon request. The expert group has global vision, and links have been established with scientists representing other research organisations such as [the Mediterranean Science Commission \(CIESM\)](#) and [the North Pacific Marine Science Organisation \(PICES\)](#). The group held its first meeting in 1970 under the name of the Working Group on the Introduction of Non-Indigenous Marine Organisms, changing to its current one in 1980. WGITMO recently held its 45th meeting in Weymouth, UK at the Centre for Environment, Fisheries and Aquaculture Science (Cefas) as the final meeting of the three-year cycle.

WGITMO has contributed several major achievements to the ICES vision including the first ICES Viewpoint on Biofouling and a source document, two Cooperative Research Reports, and numerous publications related to ToRs and the continued population of the AquaNIS database. During the three year cycle (2017–2019), the scientific experts of this working group, representing 21 countries, met and worked collaboratively with PICES, CIESM and other ICES working groups and international organizations. They have focused their scientific understanding of marine ecosystems to provide information (e.g. national reports, contributing to the AquaNIS database, ToR a), knowledge and advice on the introduction and transfer of marine organisms. This work has primarily concentrated on the following areas: climate change as a factor in invasion success (particularly in the Arctic ToR b); biofouling as a vector for introduction and spread (ToR c), and impact (ToR d); evaluating molecular tools for detection and monitoring (ToR e); and providing ecosystem overviews on non-indigenous species as requested (ToR f). The Group also addressed a request for information on ship-mediated introductions of harmful algal bloom species in the Arctic from the Working Group on Harmful Algal Bloom Dynamics (WGHABD) and presented this work at the WGHABD annual meeting (2018).

This ICES Scientific Report summarized the three-year reporting cycle from 2017 to 2019. Traditionally WGITMO shares one joint day of the three day meetings with ICES/IOC/IMO Working Group on Ballast and Other Ship Vectors (WGBOSV) discussing two shared Terms of Reference, 1. Biofouling and 2. Climate change (2017, 2018); and 1. Biofouling and 2. Molecular tools (2019). Two additional countries have added members to this working group, Latvia and Iceland. The chair will reach out to the Netherlands and Spain for new members as the previous representatives have changed positions. Discussions continue on activities and collaborations between ICES, PICES and CIESM with active participation of PICES and CIESM representatives at the WGITMO meetings. Updates have been provided regarding the Suez Canal enlargement and bioinvasion crisis in the Mediterranean Sea. Participation of scientists continues to be strong from meeting host country institutions and has led to additional collaborations and membership. There has been increased number of participants at annual meetings resulting from renewed collaboration and better communication with the Intergovernmental Oceanographic Commission of UNESCO and the International Maritime Organization, particularly on joint days with WGBOSV for vessel biofouling and molecular method discussions.

Information on NIS and marine litter in Portugal was presented and discussed among the participants as a possible new ToR on marine debris as a vector for the introduction and transfer of marine organisms. This resulted in a proposed resolution of a new ToR that will address the

ecological impact of human-produced marine debris as a vector for introduction and spread of marine non-indigenous species. A second new ToR addresses interactions between aquaculture and the environment as it relates to the introduction and spread of non-indigenous species and the risk posed by NIS including pathogens.

The ICES acknowledgement wording was reviewed and provided to members (2019) as not all publications which had been reviewed and/or discussed at WGITMO meetings had been acknowledged.

Cynthia McKenzie, Canada, was re-elected for another three-year term as chair of WGITMO.

2 ToR A: Advance research, develop collaborations and address surveillance and knowledge gaps in issues related to the introduction and transfer of marine organisms, through annual reviews of national/international activities and responding to advice requests

National reports were presented and discussed from 19 countries during each of the three years in this cycle. Common themes included, besides new species introductions and monitoring, recent activities on traditional and innovative methods for detection and surveillance, particularly for biofouling. Several opportunities for collaboration were advanced. A table will be developed to indicate each country's activities, potential for collaboration and reports/publications and will be available to members on the shared WGITMO drive. In a project led by WGBOSV in collaboration with WGITMO, data for >1000 introduction events in aquatic systems were collected and analysed for 12 geographic regions globally to assess temporal trends in the introduction of nonindigenous species; a scientific paper is expected to be submitted before end of 2019. Results from a recently completed Normandy coast inventory of non-native species were presented to the working group at the 2019 meeting. The status of marine non-indigenous (NIS) species in Iceland and ongoing research projects on NIS in Latvia were presented by the new members of the working group representing these countries.

In Europe, several countries reported new sightings including the invasive tunicate *Didemnum vexillum* in Germany and a new location on an oyster farm in the United Kingdom (Scotland). An ICES Cooperative Research Report on the status of introductions of non-indigenous marine species in the North Atlantic and adjacent waters 2003–2007 led by several members of the working group was released (Pederson *et al.* 2017 CRR#334). An ICES Alien species alert on *Didemnum vexillum* was published (McKenzie *et al.* 2017 CRR#335) as information on this invasive species was considered a critical knowledge gap. *Didemnum vexillum* Kott (2002) is a high-impact, globally-invasive, colonial tunicate species that is native to Japan. It is generally a temperate cold-water organism, and its introduced range currently includes New Zealand, The Netherlands, France, Ireland, United Kingdom, Spain, Italy, Germany and both the west and east coasts of the United States and Canada. Like other invasive tunicates, *D. vexillum* has the capacity to reproduce rapidly, outcompete native species, deteriorate environmental integrity, and cause significant economic harm. For these reasons, the report aimed to increase awareness of *D. vexillum*, with a focus on identification, natural history, current global distribution, potential impacts, and prospects for management and control where introductions occur. Information and case studies from member countries were used in the report and has been used in advice requests and publications in preparation:

Pederson, J.A., Gollasch, S., Laing, I., McCollin, T., Miossec, L., Occhipinti-Ambrogi, A., Wallentinus I., Werner, M. 2017. Status of introductions of non-indigenous marine species in the North Atlantic and adjacent waters 2003-2007. Eds. ICES Cooperative Research Report #334.

McKenzie, C. H., Reid, V., Lambert, G., Matheson, K., Minchin, D., Pederson, J., Brown, L., Gollasch, S., Simard, N., Therriault, T. 2017. Alien species alert: *Didemnum vexillum* Kott, 2002: Invasion, impact, and control. ICES Cooperative Research Report No. 335. 33 pp. <http://doi.org/10.17895/ices.pub.2138>

A report from the European Commission assessing Member States' monitoring programs under the Marine Strategy Framework Directive (MSFD) pointed out in 2017 a lack of monitoring data and knowledge for some descriptors, notably D2, and the need for a clear acceleration. A recent paper (Konstantinos *et al.* 2019) addresses these concerns regarding the initial baseline reporting of EU member states for the D2 descriptor. This paper is co-authored by many WGITMO members and has been discussed at length during WGITMO meetings.

Tsiamis Konstantinos, Andreas Palialexis, Kremena Stefanova, Živana Ničević Gladan, Sanda Skejić, Marija Despalatović, Ivan Cvitković, Branko Dragičević, Jakov Dulčić, Olja Vidjak, Natalia Bojanić, Ante Žuljević, Marilena Aplikioti, Marina Argyrou, Marios Josephides, Nikolas Michailidis, Hans H. Jakobsen, Peter A. Staehr, Henn Ojaveer, Maiju Lehtiniemi, Cécile Massé, Argyro Zenetos, Luca Castriota, Silvia Livi, Cristina Mazziotti, Patrick J. Schembri, Julian Evans, Angela G. Bartolo, Saa Henry Kabuta, Sander Smolders, Edo Knegtering, Arjan Gittenberg, Piotr Gruszka, Wojciech Kraśniewski, Cátia Bartilotti, Miriam Tuaty-Guerra, João Canning-Clode, Ana C. Costa, Manuela I. Parente, Andrea Z. Botelho, Joana Micael, Joana V. Miodonski, Gilberto P. Carreira, Vera Lopes, Paula Chainho, Carmen Barberá, Rahmat Naddafi, Ann-Britt Florin, Peter Barry, Paul D. Stebbing, Ana Cristina Cardoso 2019. Non-indigenous species refined national baseline inventories: A synthesis in the context of the European Union's Marine Strategy Framework Directive. *Mar Pol Bul* 145: 429-435

However, addressing the MSFD requirements is a challenging task with traditional methods (e.g. decline in taxonomic expertise, numerous cryptic species, issues with habitat accessibility etc.). Molecular tools, notably using barcoding and metabarcoding are in this context promising tools. A closed or targeted list of species (10) showed the metabarcoding method to be sensitive and the results obtained similar to traditional methods in a study in the Western English Channel. In the Canadian Arctic, environmental DNA (eDNA) methods were used to enhance detection of more difficult to sample organisms including benthic and fouling taxa, and provide robust baseline genetic information as a reference point for current native biodiversity prior to significant change. The study found that eDNA was spatially and temporally heterogeneous within ports and that the efficiency of the eDNA recovery was improved when sampling under-ice cover. DNA metabarcoding was also studied in a Spanish project as a cost-effective tool to provide data for port baseline surveys. They found that metabarcoding enhanced detection sensitivity, provided a time saving and cost-efficient alternative to visual identification and was easily standardized and reproducible. There are thus potentially several benefits for molecular approaches in support of surveillance programs. Following these discussion in 2017 and 2018, ToR e on molecular tools was developed to explore these methods further.

A review of the tools used for marine monitoring in the UK (Bean *et al.* 2017) and a paper on the importance of historical baselines in marine bioinvasions and their implications for policy and management (Ojaveer *et al.* 2018) were published by members of the WGITMO.

Bean, T.P., Greenwood, N., Beckett, R., Bignell, J.P., Brant, J., Copp, G.H, Devlin, M., Dye, S., Feist, S.W., Fernand, L., Foden, D., Hyder, K., Jenkins, C., Van der Kooij, J., Kröger, S., Kupschus, S., Leech, C., Leonard, K.S., Lynam, C.P., Lyons, B.P., Maes, T., Nicolaus, E.E.M., Malcolm, S., McIlwaine, P., Merchant, N., Paltriguera, L., Pearce, D.J., Pitois, S.G., Stebbing, P.D., Townhill, B., Ware, S., Righton, D. 2017. A review of the tools used for marine monitoring in the UK: Combining historic and contemporary methods with modelling and socioeconomics to fulfil legislative needs and scientific ambitions. *Frontiers in Marine Science* 4, 263. (doi: 10.3389/fmars.2017.00263)

Ojaveer H, Galil BS, Carlton JT, Alleway H, Gouletquer P, Lehtiniemi M, Marchini A., Miller W., Anna Occhipinti-Ambrogi, Melita Peharda, Gregory M. Ruiz G.M., Williams S.L., Zaiko A. 2018. Historical baselines in marine bioinvasions: Implications for policy and management. *PLoS ONE* 13, e0202383. <https://doi.org/10.1371/journal.pone.0202383>

The AquaNIS database/dataset continues as the main repository of new NIS data with each country updating the database annually. Geo-referenced data can now be stored, which will address the needs of HELCOM, OSPAR and other potential users. Interactive tools for data inquiry have been added. (www.corpi.ku.lt/databases/index.php/aquanis) AquaNIS has been used in advice requests and several publications, including one on transport vectors in preparation. The French data collected by Gouletquer *et al.* (2016) has been entered into AquaNIS, with ~600 records having been edited/ updated in 2018.

3 ToR B: Evaluate the impact climate change may have on the introduction and spread of non-indigenous marine organisms, including in Arctic environments

Evaluating the impact climate may have on non-indigenous species in Arctic environments and their detection was a focus of this ToR during this cycle. Significant progress was achieved on the compilation of a comprehensive list of introduced species in the Arctic, with the aim to evaluate the risk associated with current and future vectors of introduction, to identify knowledge/data gaps, and to serve as guidance for future research and management efforts related to NIS in the Arctic. Two scientific review papers were published in 2018, Chan *et al.* 2018 on trends and future invasion risk in the Arctic associated with climate change and Lacoursière-Roussel *et al.* 2018 on the use of eDNA metabarcoding as a surveillance approach for Arctic Biodiversity. Information from both papers had been presented and discussed at WGITMO and WGBOSV joint meetings (2017, 2018).

Chan, F.T., Stanislavczyk, K., Sneekes, A.C., Dvoretzky, A., Gollasch, S., Minchin, D., David, M., Jelmert, A., Albrechtsen, J., and Bailey, S.A. 2018. Climate change opens new frontiers for marine species in the Arctic: Current trends and future invasion risks. *Global Change Biology* 25(1): 25-38. <https://doi.org/10.1111/gcb.14469>

Lacoursière-Roussel, A., Howland, K., Normandeau, E., Grey, E.K., Archambault, P., Deiner, K., Lodge, D.M., Hernandez, C., Leduc, N., Bernatchez, L., 2018. eDNA metabarcoding as a new surveillance approach for coastal Arctic biodiversity. *Ecology and evolution*. 8, 7763-7777.

In response to the request from WGHABD concerning the role of shipping as a vector for the introduction of harmful algae bloom (HAB) organisms in the Arctic, a preliminary study was conducted during the intersession period, jointly with WGBOSV and external experts, on the current status and knowledge of HABs in the Arctic. The preliminary review revealed most available data had been collected from waters near Greenland or in the Canadian Arctic. Approximately 25% of the species reviewed to date (2018) are potentially harmful, but many are considered rare or occur only occasionally in the Arctic. Given these initial findings, WGITMO recommend WGHABD investigate this issue further and suggest a special session on HABs in the Arctic at a future meeting, which was delivered by WGHABD in 2019.

The Group discussed the need to continue to identify and monitor activities of the Arctic Council under the ARIAS strategy, with a view to providing advice or scientific information in the near future. Due to the rapidly changing climate and exponential growth of human activities in the Arctic, both Groups identified the need to continue to assess risks of species introductions and mitigation strategies.

PICES and ICES co hosted (in collaboration with other international groups) a theme session entitled “*Management and Conservation of Species on the Move*” at the Effects of Climate Change on the World’s Oceans International Symposium in Washington, DC in June 2018.

A paper on climate change and salinity is in preparation. Several members of the working group are authors and WGITMO will be acknowledged as contributing to the planning and discussions for this paper.

4 ToR C: Investigate biofouling as a vector for the introduction and transfer of marine organisms on vessels and artificial structures, their pressure and impact on the ecosystem with a comparison of prevention or selective mitigation methodologies

The first ICES Viewpoint and the source document on biofouling (Galil *et al.* 2019) were developed as a result of the theme session for the 2017 ICES ASC on bioinvasion trajectories and impacts in contrasting marine environments, organized by WGITMO as a collaboration between ICES-PICES-CIESM. One of the recommendations from that session was to “*prioritize investigation on one of the most important non-native species transfer pathways – hull fouling and niche areas, both on commercial ships and recreational vessels, and through this contribute to IMO request for scientific information on use and effectiveness of IMO Biofouling guidelines globally*”. A source document was created and led by B. Galil (Galil *et al.* 2019) and the WGITMO Chair in collaboration with the WGBOSV chair, members of these working groups and international experts. The document summarizes the current state of knowledge about the risk of biofouling as a pathway for introduction of non-native marine species, and recommends that active management be undertaken to reduce biofouling of commercial and recreational vessels as an urgent priority. The document was discussed, reviewed and submitted on behalf of both these working groups to ICES in 2018 and the ICES Viewpoint was developed from that source material and released in 2019.

ICES VIEWPOINT on Evaluating and Mitigating Introduction of Marine Non-native Species via Vessel Fouling, was reviewed and produced jointly with WGBOSV.
vp. 2019.01 <https://doi.org/10.17895/ices.advice.4687>

Galil, B.S., McKenzie, C., Bailey, S., Campbell M., Davidson, I., Drake, L., Hewitt, C., Occhipinti-Ambrogi, A., and Piola, P. 2019. ICES Viewpoint background document: Evaluating and mitigating introduction of marine non-native species via vessel biofouling. ICES Ad Hoc Report 2019. 17 pp. <https://doi.org/10.17895/ices.pub.4680>

A review of the Biofouling Viewpoint, the GloFouling Project implementation plan, research the importance of salinity on biofouling and copper-leakage from antifouling paint and evaluations of biofouling in-water cleaning and capture systems were presented at the meeting in 2019 under this ToR. Next steps for the WGITMO, jointly with WGBOSV, include preparing to submit the ICES Viewpoint and source document to the IMO as a “substantive document” (action paper) to the February 2020 meeting of the Pollution Prevention and Response Sub-Committee (PPR 7).

Information on the HELCOM Monitoring Guidelines and the EU Interreg Baltic Sea Region Project COMPLETE (Completing management options in the Baltic Sea Region to reduce risk of invasive species introduction by shipping) were presented and discussed (2017, 2018, 2019), particularly in respect to monitoring NIS, impacts and how to develop a regional roadmap for harmonized biofouling management. The overall goals relevant to WGITMO are a) Proposal (roadmap) for a regional biofouling management strategy; and b) Consistent regional monitoring of non-indigenous species, c) Development of an early warning system for NIS. There are 12 full partners in the project, including nine research institutes and universities (Finland, Estonia, Latvia, Lithuania, Poland and Sweden), a Federal agency (Germany), an NGO (Finland) and an intergovernmental environmental organization (HELCOM). The Lead Partner is the Kotka Maritime Research Association, Finland. Eight researchers representing full project partners are

members of the ICES/IOC/IMO WGBOSV and/or ICES WGITMO. Results from this project are expected to provide information for the expert group to provide advice to the IMO on the effectiveness of the biofouling guidelines and additional aspects to be considered in that context, e.g. rules for in-water cleaning.

Linkages continue with WGBOSV, IMO GloFouling Partnership, a multi-agency research project, project COMPLETE and other biofouling focused groups to develop and improve biofouling management guidelines and practices, and to support the evaluation of the international guidelines at the IMO. The combined ICES Working Groups recalled the open request for information related to biofouling management by the IMO, suggesting that outputs of the biofouling meetings held in the United States and research conducted within countries participating in ICES (e.g. Canada, Sweden, UK-Scotland), PICES (Canada) and CIESM (Italy) on biofouling on marinas and recreational vessels. This information could serve as a basis for a future contribution considering that the IMO Biofouling Guidance for leisure vessels might be evaluated as well.

The working group members addressed vessel and artificial structure biofouling in marinas and harbours (2017, 2018, 2019). A study on non-indigenous species (NIS) richness in Mediterranean marinas (50) found the highest NIS richness were Heraklion, Crete, Greece (27), Villa Igiea, Sicily, Italy (20) and Port Camargue, France (18). The following factors were significant in shaping NIS richness in marinas: sea surface temperature, number of berths, proximity to Suez Canal, proximity to aquaculture sites, proximity to commercial harbours, absence of pontoons, biogeographic sector and climate type. Knowledge of these factors can help set priorities for monitoring and management efforts to control the introduction of biofouling organisms in marinas.

Ulman, A., Ferrario, J., Forcada, A., Arvanitidis C., Occhipinti-Ambrogi A., Marchini A. 2019. A Hitchhiker's guide to Mediterranean marina travel for alien species. *Journal of Environmental Management* 241: 328–339. <https://doi.org/10.1016/j.jenvman.2019.04.011>

Another more targeted harbour study in Canada demonstrated the mitigation and management efforts under the new Canadian Aquatic Invasive Species Regulations, emphasizing the importance of communication and stakeholder planning for successful rapid response and control of an invasive tunicate.

A recent publication assessing recreational boating as a vector for spread for NIS has been published and had been presented and discussed at WGITMO meetings (2017, 2018).

Pelletier-Rousseau, M., Bernier, R., Clarke Murray, C., Drolet, D., Lacoursière-Roussel, A., Locke, A., Martin, J.L., McKenzie, C.H., McKindsey, C.W., Therriault, T.W., and Simard N. 2019. Assessment of recreational boating as a vector for marine non-indigenous species on the Atlantic Coast of Canada. *Biological Invasions* <https://doi.org/10.1007/s10530-019-01991-1>

Following an update on a workshop held in the United States (Maritime Environmental Resource Center (MERC) Biofouling Workshop Smithsonian Environmental Research Center, Edgewater, Maryland, August, 2016) with international experts to identify and discuss approaches used to quantify and manage biofouling on vessels, the Groups discussed the importance of replicate sampling and analysis of data using rarefaction curves to distinguish if new reports of introduced species are confounded by sampling effort. The Groups discussed the need to learn from years of experience in setting regulations and inspections procedures for ballast water when embarking on similar activities related to biofouling, with a view towards putting more practical procedures in place.

5 ToR D: Advance knowledge base to further develop indicators to evaluate the status and impacts of non-indigenous species in marine environments

The Special Session at ICES ASC 2017 ICES PICES CIESM “Bioinvasion trajectories and impacts in contrasting marine environments”, was specifically directed at exploring indicators to evaluate the status and impacts of non-indigenous species in different marine environments. The ASC session hosted ten oral and seven poster presentations, with presenters provided the opportunity to give a short introduction of their posters during the session. A general discussion on bioinvasion trajectories, impacts and other topics relevant to the subject was held at the end of the session. The contributed presentations covered the Atlantic and Pacific Oceans, the Arctic and the Mediterranean Sea. Presentations included introduction vectors, population structure and dynamics, environmental impact, application of genetic methods, and several applied aspects (incl. risk assessment and marine conservation) of marine bioinvasions. The discussion session was focussed on identifying broad future research needs in the field of marine bioinvasions, of potential interest of ICES, PICES and CIESM, including the Arctic. The outcome of the discussion, which emphasized collaboration and strength of joint ICES-PICES-CIESM activities, included eight research needs and areas for collaboration including:

- Invasion trajectories and vectors are a common theme between regions and collaborative studies to investigate specific routes and vector risk would benefit from multi-region studies, particularly with regard to the Arctic. *(See publications on the Arctic in ToR b)*
- A joint effort to obtain critical data on shipping (vessels/routes/hot spots) from relevant authorities and make them available to bioinvasion scientists, particularly for risk assessment studies.
- Sharing of data and making at least key information on recent introduction events freely available. ICES is using an online platform for reporting (AquaNIS), which already accommodates data from non-ICES areas. Sharing information on the success and failure of mitigation activities would be very productive between regions and would provide information for response options.
- Prioritize investigation on one of the most important non-native species transfer pathways – hull fouling and niche areas, both on commercial ships and recreational vessels, and through this contribute to the IMO request for scientific information on the use and effectiveness of IMO Biofouling guidelines globally. *(Now within ToR c, see the ICES Viewpoint and IMO submission regarding Biofouling)*
- Coordinate and facilitate the study of the impact of non-native species on environments and particularly on vulnerable habitats (Arctic and Marine Protected Areas). Update ICES Code of Practice and potentially develop new ones for affected industries (Aquaculture, live fish trade). Some concern was expressed on the ethics of introducing non-native species which may still be occurring in some regions. *(Resulting in new TOR on Aquaculture for 2020- 2022)*
- Investigations of the adaptive capability and differences between non-native populations should also be a priority as it has been shown to be relevant to impact and climate change. Explore NIS adaptability between different invaded locations in the ICES-PICES-CIESM domain to detect ecosystem level changes for specific invaders which would help to characterize impact.
- Develop applications of molecular methods (incl. e-DNA), including the study of genetic structure of non-indigenous species populations (e.g. early warning). Further, we need

to determine how these results should/will be used by management agencies. This is especially true for 'shared waters' where integration is critical for success (and the optimal use of limited funding). (*Resulting in new ToR e and developing workshop on guidelines for molecular tool use.*)

- Investing more effort in stakeholder communication and try 'standardising' messages to them. Communicate with/educate managers and influence them to ask the right questions. A good example is Clean, Drain, Dry that now has relatively standard messaging/signage in North America.

ICES, PICES and CIESM were invited to consider the list above and first identify their priorities, later identify research issues of joint interest between the three organisations. Several of these recommendations have been made a priority as ToRs or publications as indicated.

Working group members reviewed three risk assessment tools, the Aquatic Invasiveness Screening Kit (AS-ISK developed by Cefas UK) (2017, 2018), the Canadian Marine Invasive Screening Tool (CMIST developed by Fisheries and Oceans Canada) (2018) and the EU risk Assessment scheme, with additional case studies provided for each risk assessment tool. The implications for use for non-indigenous species risk for regulatory purposes were discussed. Risk-based identification and assessment of non-native species is an essential process for the implementation of legislation and regulatory controls to manage invasive species and avoid or mitigate their adverse impacts. A comparison of CMIST and AS-ISK provided similar results for each tool (G. H. Copp). Following the global applications of the Fish Invasiveness Screening Kit (FISK), Cefas, WGITMO and the University of Łódź led in the development of FISK's transformation into a decision-support tool, 'AS-ISK' (www.cefas.co.uk/nns/tools/), which is of general use for screening aquatic species regardless of their taxonomic status and the climate type of the risk assessment area. AS-ISK was developed to be compliant with the 'minimum standards' for use with the new EU Regulation on invasive alien species of EU concern, including questions on socio-economic and ecosystem services impacts as well as six additional questions through which the assessor evaluates the potential impact of predicted future climate conditions on the AS-ISK assessment. During 2017, in the framework of an EC-funded study, ten species were evaluated, including three fishes, the Lessepsian fish *Plotosus lineatus* and the freshwater mosquitofishes *Gambusia affinis* and *G. holbrooki*. This study demonstrated how the application of the adapted EU Risk Assessment scheme can help Member States in implementing the EU IAS regulation (1143/2014).

The Canadian Marine Invasive Screening Tool (CMIST), a tool for assessing risk of invasion by nonindigenous species in the marine environment, aims to simplify and improve the assessment process. CMIST has 17 questions based on the sequence of events in the invasion process: arrival, survival, establishment and spread as well as the species' potential impacts in the assessment area. To evaluate CMIST, 60 species/ecoregion combinations of nonindigenous marine invertebrates known to have been introduced to three Canadian marine ecoregions were scored and compared the results to scores from MI-ISK (Marine Invertebrate Invasiveness Scoring Kit). Assessment scores from both tools were then compared to the results of an expert opinion survey about the level of ecological risk posed by these species. The scores returned by the two tools were generally similar, had comparable levels of inter-assessor variability, and correlated well with the results of the expert opinion survey for two of the three ecoregions. For all ecoregions, CMIST scores were more strongly correlated with expert opinion scores than were MI-ISK scores. Further, CMIST easily distinguishes both elements of invasion risk (likelihood and impact), has fewer questions to score (17 compared to 49 for MI-ISK) and could easily be adapted for other taxa. The tool is now available publicly at www.bio.gc.ca/science/monitoring-monitorage/cmist/index-en.php. A Canadian Arctic study identified a suite of AIS (benthos, zooplankton, macroalgae) with the greatest likelihood of introduction using the Canadian Marine Invasive Screening Tool (CMIST). The top twenty three riskiest species were then modelled to

predict their potential spatial distributions at Arctic and global scales using the Maximum Entropy (MaxENT) habitat model. When separated by taxa, benthic invertebrates and macro algae showed a higher percentage of habitat gain than planktonic species under future climate scenarios. When the same analysis was done at a global scale, the projections showed that by 2050 and 2100, there will be an overall habitat loss (- 4% and - 4.2%, respectively). These results suggest that most of the modelled species will find better environmental conditions in colder regions, with a trend towards a positive pole-ward shift in future distributions. This approach will aid in the identification of present and future high-risk areas for AIS in response to global warming.

Version 2 of the Aquatic Species Invasiveness Screening Kit (AS-ISK) was released in November 2018 (www.cefas.co.uk/nns/tools/). This multi-lingual toolkit is currently undergoing a global trial as a contribution to this WGITMO ToR.

Linkages continue between WGITMO delegates and EU projects involving the risk analysis of non-native aquatic organisms (marine, brackish, freshwater), with particular regard to the 2014 EU Regulation on the management of invasive alien species. The EU Member States, represented by the Scientific Forum, accepted the inclusion of *Plotosus lineatus* in the list of species of Union concern, under its second update (Commission Implementing Regulation (EU) 2019/1262 of 25 July 2019 amending Implementing Regulation (EU) 2016/1141) while under evaluation by the Scientific Forum are two more fully risk assessed marine species namely the puffer fish *Lagocephalus sceleratus* and the green mussel *Perna viridis*.

Publications and presentations relating to the application of these tools reviewed, tested and discussed at WGITMO meetings and during the intersession period include:

Vilizzi, L., Copp, G.H., Adamovich, B., Almeida, D., Chan, J., Davison, P.I., Dembski, S., Ekmekçi, F.G., Ferincz, Á., Forneck, S., Hill, J.E., Kim, J-E., Koutsikos, N., Leuven, R.S.E.W., Luna, S., Magalhães, F., Marr, S., Mendoza, R., Mourão, C.F., Neal, J.W., Onikura, N., Perdikaris, C., Piria, M., Poulet, N., Puntilla, R., Range, I.L., Simonović, P., Ribeiro, F., Tarkan, A.S., Troca, D.F.A., Vardakas, L., Verreycken, H., Vintsek, L., Weyl, O.L.F., Yeo, D.C.J. & Zeng, Y. 2019. A global review and meta-analysis of applications of the Fish Invasiveness Screening Kit. *Reviews in Fish Biology and Fisheries* (early view) (doi: 10.1007/s11160-019-09562-2)

Roy, H.E., Bacher, S., Essl, F., Adriaens, T., Aldridge, D.C., Bishop, J.D.D., Blackburn, T.M., Branquart, E., Brodie, J., Carboneras, C., Cook, E.J., Copp, G.H., Dean, H.J., Eilenberg, J., Gallardo, B., Garcia, M., García-Berthou, E., Genovesi, P., Hulme, P.E., Kenis, M., Kerckhof, F., Kettunen, M., Minchin, D., Nentwig, W., Nieto, A., Pergl, J., Pescott, O.L., Peyton, J., Preda, C., Rabitsch, W., Roques, A., Rorke, S.L., Scalera, R., Schindler, S., Schönrogge, K., Sewell, J., Solarz, W., Stewart, A.J.A., Tricarico, E., Vanderhoeven, S., Van der Velde, G., Vilà, M., Wood, C.A. & Zenetos, A. 2019. Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union. *Global Change Biology* 25, 1032–1048. (doi: 10.1111/gcb.14527)

Peyton J, Martinou AF, Pescott OL, Demetriou M, Adriaens T, Arianoutsou M, Bazos I, Bean C, Botham M, Britton R, Lobon Cervia J, Charilaou P, Chartosia N, Dean HJ, Delipetrou P, Dimitriou A, Dörflinger G, Fawcett J, Fyttis G, Galanidis A, Galil B, Hadjikyriakou T, Hadjistylli M, Ieronymidou C, Jimenez C, Karachle P, Kassinis N, Kerametsidis G, Kirschel A, Kleitou P, Kleitou D, Manolaki P, Michaelides N, Mountford JO, Nikolaou H, Papatheodoulou A, Payiatis G, Ribeiro F, Rorke SL, Samuel Y, Savvidis P, Schafer S, Silva-Rocha I, Tarkan AS, Top N, Tricarico E, Turvey K, Tziortzis I, Tzirkalli E, Verrycken H, Winfield IJ, Zenetos A. and E. Roy HE., Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island. *Biological Invasions* 21,2107–2125, <https://doi.org/10.1007/s10530-019-01961-7>

Galanidi M., Turan C., Öztürk B., Zenetos A., 2019. European Union (EU) Risk Assessment of *Plotosus lineatus* (Thunberg, 1787); a summary and information update. *J. Black Sea/Mediterranean Environment*. 25, 2, 210-230.

Presentations on the ITMO-initiated global trials of the Aquatic Species Invasiveness Screening Kit (AS-ISK) were given at the following symposia: 20th *International Conference on Aquatic Invasive Species* (Fort

Lauderdale, USA, 22–26 October 2017), *Marine & Freshwater Invasive Species: Solutions for Water Security* (Beijing, China, 27–29 August 2018), and 2nd *National Scientific and Technical Conference on Operation and Protection of Flowing Waters (PotamON 2019) – Biocenosis of flowing waters in the context of hydrological changes* (Łukęcin, Poland, 25–27 September 2019).

6 ToR E: Evaluate the development and utilization of DNA- and RNA- based molecular tools for early detection and monitoring of non-native species

Following the ICES ASC 2017 ICES PICES CIESM Special Session on “*Bioinvasion trajectories and impacts in contrasting marine environments*”, one of the recommendations included the development of molecular methods (e.g. environmental-DNA, genomic tools), including the study of the population genetic structure of non-indigenous species populations and early warning detection systems. Further, the need was highlighted to determine how these results should/will be used by management agencies, particularly for ‘shared waters’ where integration is critical for success.

Members prioritized the use of molecular tools as a potential technology for early detection and monitoring of non-native species at a half day joint session (WGBOSV) in 2018. A new ToR was added following that meeting in recognition of the immediate importance of this issue. At the 2019 joint day, the groups agreed that the topic should be explored in greater detail and with other experts. Research projects on using parasites and genetics to inform invasion histories, detecting rapid differentiation in marine invaders, population genomics studies in marinas, ballast water risk and metabarcoding, and the challenges and possibilities of genome-editing technologies to manage marine invasive species were presented under the molecular tools ToR at the 2019 meeting. Following extensive discussion on this ToR, it was agreed that a one-year workshop group will be proposed. A workshop to discuss environmental DNA (eDNA) metabarcoding for detecting and monitoring invasive species (i.e. review and provide guidance on the use of these tools) will be developed, expanding on Darling *et al.* (2017). This publication (Darling, J.A., Galil, B.S., Carvalho, G.R., Rius, M., Viard, F. Piraino, S. 2017. *Recommendations for developing and applying genetic tools to assess and manage biological invasions in marine ecosystems*. Marine Policy 85: 54-64) provides recommendations for the future development of genetic tools for the assessment and management of NIS in marine systems within the context of the explicit requirements of the MSFD and acknowledges the benefits of discussions at WGITMO meetings for the paper. A recent paper that specifically focuses on the use of eDNA metabarcoding to study marine invasive species was recently published in Nature (Holman *et al.* 2019 *Detection of introduced and resident marine species using environmental DNA metabarcoding of sediment and water* <https://www.nature.com/articles/s41598-019-47899-7>). Since the goal of the planned workshop would be to provide guidance to end user groups, input will be sought to determine the workshop terms of reference at the joint meeting in 2020, where WGBOSV, and WGHABD will be meeting on the joint day with WGITMO and share similar ToR for use of these tools. During the next three year cycle (2020–2022), WGITMO will modify this ToR for utilization of DNA- and RNA-based molecular approaches to provide science-based tools for strategic planning, policy development, decision making, and operational processes regarding non-native species and biological invasions

Information regarding the use of eDNA metabarcoding for detection and surveillance of non-indigenous species in the Arctic was presented and discussed at the 2017 and 2018 WGITMO annual meetings (joint session on climate change and the Arctic) and resulted in the publication Lacoursière-Roussel, A., Howland, K., Normandeau, E., Grey, E.K., Archambault, P., Deiner, K., Lodge, D.M., Hernandez, C., Leduc, N., Bernatchez, L., 2018. eDNA metabarcoding as a new surveillance approach for coastal Arctic biodiversity. *Ecology and Evolution*. 8, 7763-7777. (doi:10.1002/ece3.4213)

7 ToR F: Contribute regional text to new ecosystem overviews for (i) Iceland, (ii) Norwegian Seas, (iii) Azorean ecoregion and (iv) the Oceanic north-east Atlantic ecoregion in relation to the rate of discovery of invasive species where information is available

An intersessional request was made by the ICES Secretariat for WGITMO to provide new ecosystem overviews for (i) Iceland, (ii) Norwegian Seas, (iii) Azorean ecoregions and (iv) the Oceanic north-east Atlantic ecoregion in relation to the rate of discovery of invasive species where information is available. Ecosystem overviews were developed for Iceland, the Norwegian Seas and the Azorean Ecoregions (2017) and the Baltic Sea (2018). Following a group discussion it was determined that the Oceanic north-east Atlantic ecoregion was not within the scope of this working group. This request also resulted in the addition of a working group member from Iceland. The ecosystem overviews for Iceland and the Norwegian Seas were presented to the group. The recently completed Azorean ecoregion overview were also presented to the group and discussed. It was noted that in these overviews the information contained in the AquaNIS data system was particularly important in developing these summaries. The request to provide an overview for the Oceanic north-east Atlantic ecoregion was discussed and determined that this ecosystem is not relevant to our working group. Our group is coastal based and does not have information on this oceanic region. The use of invasive species in this request was problematic as was the terminology on rate of discovery. The group decided that determining the rate of introduction or discovery is not a viable way to report on new introductions. However, this approach may be suitable to determine the European target of Good Environmental Status in coastal waters in the reporting period. There appears to be no easy way to standardize rate, which is uneven and episodic. Limits include non-reporting of new species, prevention of new species introductions and consideration of the stability of vector pressure. The group suggested that rather than use the number of species, the focus should be on vectors and how to prevent their facilitation of in species spread.

8 Other Activities and Future Plans

PICES and ICES have a long history of collaborating on many important marine issues, including non-indigenous marine species. PICES now has a longer-term expert group (an Advisory Panel in PICES terminology) related to non-indigenous marine species. This group met for the first time at PICES-2017 in Vladivostok and has a Term of Reference specifically dedicated to working with ICES and other international organizations to better understand and share information related to marine invasions.

In 2017, PICES, ICES, and CIESM hosted the joint theme session at the 2017 ICES Annual Science Conference in Fort Lauderdale, FL. PICES and ICES cohosted (in collaboration with other international groups) a theme session entitled “*Management and Conservation of Species on the Move*” at the Effects of Climate Change on the World’s Oceans International Symposium in Washington, DC in June 2018.

Understanding marine invasions is complex but PICES, ICES and CIESM have worked well together (and with other organizations) in the past and there are many avenues for continued collaboration on this topic. Many joint theme sessions have been organized/are planned and there is ongoing dialogue and participation in each other’s meetings. One specific action item following discussions at the ICES WG meetings in Portugal is using AquaNIS as a global marine invasive species database and information exchange portal. PICES is working to get existing data into a format that could be uploaded to AquaNIS to enhance information exchange. Discussions continue on activities and collaborations between ICES, PICES and CIESM with active participation of PICES and CIESM representatives at the WGITMO meetings.

A request from ICES WGHABD concerning the role of shipping as a vector for the introduction of harmful algal bloom organisms in the Arctic was addressed, jointly with WGBOSV, by conducting a review and presenting the information to the ICES WGHABD annual meeting. To build on this mutual concern regarding the movement of harmful algae, a presentation was given at the 18th International Conference on Harmful Algae, October 12–16, 2018 Nantes, France, highlighting the linkages between ICES WGITMO and WGBOSV and harmful algae by the Chair of WGITMO at the invitation of the conference convenors.

Two new ToRs are drafted based on member priorities and concerns regarding introduction and transfer issues. One new ToR will address the ecological impact of marine litter as a vector for the introduction and spread of marine non-indigenous species. A second new ToR addresses the interactions of aquaculture and the environment as it relates to the introduction and spread of non-indigenous species and the risk posed by NIS including pathogens.

Annex 1: List of participants

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Annex 2: WGITMO resolution 2017–2019

The **Working Group on Introduction and Transfer of Marine Organisms (WGITMO)**, chaired by Cynthia McKenzie, Canada, will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2017	13-15 March	Woods Hole, MA, USA	Interim report by 15 April	
Year 2018	7–9 March	Madeira, Portugal	Interim report by 15 April	
Year 2019	4–6 March	Weymouth, UK	Final report by 1 May to SCICOM	

ToR descriptors

ToR	DESCRIPTION	BACKGROUND	SCIENCE PLAN CODES	DURATION	EXPECTED DELIVERABLES
a	Advance research, develop collaborations and address surveillance and knowledge gaps in issue related to the introduction and transfer of marine organisms, through annual reviews of national/ international activities and responding to advice requests.	Data, information and knowledge collated and synthesised ensures timely update of AquaNIS. This information will be used as an underlying information source for other ToR's, responding to incoming advice requests as well as organising collaboration with other international science organisations (e.g. PICES and CIESM).	2.1; 2.4; 3.3	3 years	Annual reports to ICES. Further develop and advance AquaNIS database, and populate it with new data. Respond to incoming advice requests as requested.
b	Evaluate the impact climate change may have on the introduction and spread of non-indigenous marine organisms, incl. in Arctic environments.	This work will be carried out jointly with WGBOSV. Contributes to SICCOME and ICES high-priority action areas 'Arctic research'.	2.5; 2.2; 3.6	3 years	Primary publication on the Arctic environment and the spread of non-indigenous species.
c	Investigate biofouling as a vector for the introduction and transfer of aquatic organisms on vessels and artificial hard structures, their pressure and impact on the ecosystem with a comparison of prevention or selective mitigation methodologies.	Biofouling has been increasing recognized as an important vector in the introduction and transfer of aquatic organisms. Elements of this work will be carried out jointly with WGBOSV as a comparison vector in invasion pathways. Biofouling is an increasing concern for aquaculture (WGAQUA), energy installations, and coastal development as stressors on	2.7; 2.1; 6.4	3 years	Input on the general applicability of preventive measures and selective mitigation technologies through technical paper or manuscript submitted to peer-reviewed scientific journal.

coastal environments.					
d	Advance knowledge base to further develop indicators to evaluate the status and impacts of non-indigenous species in marine environments.	The aim is to develop wider knowledge-base to more effectively address several legislative acts related to introductions of non-native species, such as EU IAS Regulation and EU MSFD (D2). Specifically, WGITMO aims to improve/develop metrics and critically evaluate the underlying uncertainties.	2.2; 2.7; 6.1	3 years	At least one manuscript to be submitted to a peer-reviewed scientific journal.
e	Evaluate the development and utilization of DNA- and RNA-based molecular tools for early detection and monitoring of non-native species.	There are potentially several benefits for molecular approaches in support of surveillance programmes for non native species, however, this does not mean that such approaches are free from limitations and biases. Although further improvements are needed, these DNA-based approaches are promising, and already effective for active surveillance of specific/targeted species for which the above mentioned limitations had been overcome. Effective use of these new tools will be evaluated for detection of non-native species.	2.5; 1.6; 4.4	year 3	Input on the effective utilization of these methods for international and national regulators through meeting participation, correspondence group and/or technical paper.
f	Completed - Contribute regional text (~ 150 words and 1-2 graphs in each case) to new ecosystem overviews for (i) Iceland, (ii) Norwegian Seas, (iii) Azorean ecoregion and (iv) the Oceanic north-east Atlantic ecoregion in relation to the rate of discovery of invasive species where information is available.	Advisory request	2.1; 6.5	year 1	WGITMO will work intersessionally to deliver the first two ecosystem overviews (i and ii) by the end of 2016 and during 2017 for the ecosystem overviews (iii and iv) for the attention of ACOM.

Summary of the Work Plan

Year 1	Working on all ToRs, but with special focus on b, c, and d
Year 2	Working on all ToRs, but with special focus on a, c, and e
Year 3	Report on all ToRs

Supporting information

Priority	The work of the Group forms the scientific basis for essential advice related to the introduction and transfer of marine organisms, particularly non-indigenous species. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 25–35 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	The group will serve as primary respondents to incoming advice requests on various issues relating to introduction and transfer of marine organisms.
Linkages to other committees or groups	There is a very close working relationship with the Working Group on Ballast Water and Other Ship Vectors (WGBOSV). In addition to relevance to 'sectorial' expert groups, such as Biodiversity Science (WGBIODIV), Aquaculture (WGAQUA), Harmful Algae Bloom Dynamics (WGHABD), WGITMO also contributes to Integrated Ecosystem Assessments EG's.
Linkages to other organizations	PICES and CIESM