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Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

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SCOPING ACTIVITIES

CG3: Causes and impacts of massive accumulations of the brown macro-algae *Sargassum* in the nearshore environment of the Caribbean and West Africa

Progress Report

Submitted by Peter Kershaw (Chair of GESAMP), Ahmad Abu Hilal (GESAMP Member) and Christopher Cox (UN Environment)

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Corresponding author: Peter J. Kershaw peter@pjkershaw.com

Table of Contents

Background

1 Massive accumulations of the floating seaweed *Sargassum* occurred in 2011 on the coasts of several countries in West Africa and in the Wider Caribbean. The phenomenon appeared to be unprecedented in terms of the geographical scale and quantities on biomass involved, although it is consistent with a global increase in green and golden seaweed 'tides' in recent years (Smetacek and Zingone 2013). *Sargassum* inundation events were experienced in subsequent years, leading to significant ecological, social and economic impacts. This has stimulated a response from the local, regional and international organisations as well as the international research community.

2 The matter has been raised at a number of fora, including as a side event during the 2nd United Nations Environment Assembly (UNEA-2, Nairobi) in May 2016. It was discussed during the 43rd Annual Session of GESAMP, which took place in November 2016, hosted by UN Environment in Nairobi. GESAMP agreed to set up a Correspondence Group to investigate the topic further, in particular whether GESAMP might provide a useful mechanism for allowing the various groups to coordinate their efforts and discuss their findings.

2. Objectives of the GESAMP Correspondence Group

.1 To provide a brief summary of the current state of knowledge regarding the underlying causes and impacts of the massive accumulations of the brown algae *Sargassum*, observed in the Caribbean and West Africa since 2011;

.2 To provide a record of the many organisations and individual researchers who have published or are undertaking initiatives related to this phenomenon;

.3 To assess the potential role of GESAMP in helping to take this work forward, by bringing together the relevant multi-disciplinary expertise and the regional and international bodies with responsibility in this area; and

.4 To provide a scoping report with recommendations for consideration by the GESAMP Executive Committee in advance of the 44th Session (4-8 September 2017, Geneva).

3. Occurrence and transport of pelagic *Sargassum* in the Atlantic

3.1 The ecological importance of pelagic Sargassum

3 There are two species of *Sargassum* in the Atlantic which are free floating, not requiring a hard substrate for attachment, and reproduce by fragmentation (i.e. holopelagic). Typically *S. fluitans* (Broad-toothed Gulfweed) has large lanceolate leaves (shaped like the tip of a lance) and *S. natans* (Common Gulfweed) has finer fronds (Figure 3.1), although both species can express different morphological forms, that can be geographically distinctive (Parr 1939, Schell et al. 2015).

Figure 3.1. Examples of *S. natans* (left) and *S. fluitans* (right) (images taken from website of Univ. Southern Mississippi Gulf Coast Research Laboratory, www.gcrl.usm.edu)

4 Both species are characteristic of the Sargasso Sea, occupying the western Atlantic sub-tropical gyre. They tend to form large floating mats, wind-induced extended linear features (windrows) due to Langmuir circulation, and along frontal regions. This provides a unique habitat of great ecological significance, for foraging and spawning of pelagic fish (Franks et al 2007), including for migratory species, such as the endangered European eel (*Anguilla anguilla*), as well as several species of cetaceans, turtles and migratory birds. It has been described as the golden floating rainforest of the Atlantic Ocean (Laffoley et al. 2011). This special status was

recognised by the formation of the Sargasso Sea Commission[1] and the creation of the Sargasso Sea Geographical Area of Collaboration (Figure 3.2).

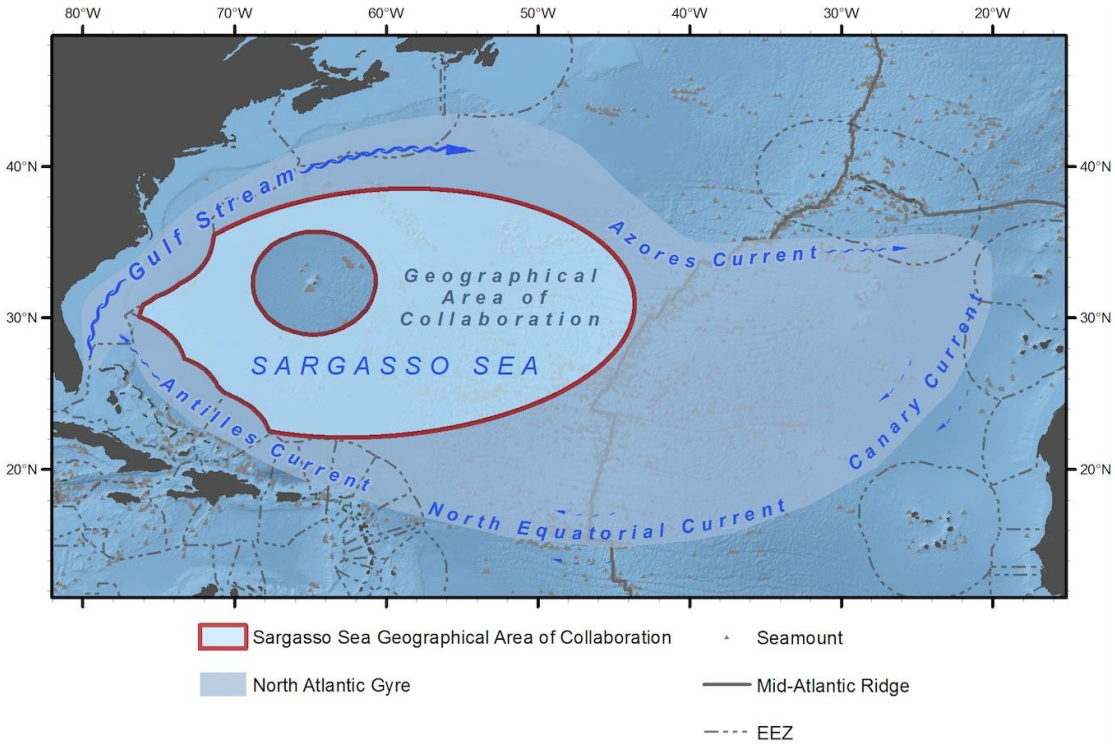

Figure 3.2. Location of the Sargasso Sea Geographical Area of Collaboration (taken from http://www.sargassoseacommission.org)

5 *Sargassum* has been reported by seafarers since Christopher Columbus traversed the region. Ship observations have proved to be very useful in extending our knowledge of the distribution and characteristics of *Sargassum*, and for providing verification of model predictions (Schell et al. 2015). More recently, satellite imagery has provided an additional technique. Observations by satellite of *Sargassum* as floating 'slicks' in the western Gulf of Mexico, in the summer of 2005, were first reported by Gower et al. (2006). The observations were made with the MERIS (Medium Resolution Imaging Spectrometer) and MODIS (Moderate Resolution Imaging Spectrometer) instruments. Subsequently, Gower and King (2011) published a time-series of MERIS observations for the western Gulf of Mexico and the western Atlantic, covering the period 2002-2008. The authors described a seasonal pattern of *Sargassum* appearing in the northwest Gulf of Mexico in the Spring of each year, being transport as a 'jet' past Cape Hatteras in July and arriving northeast of the Bahamas the following year.

3.2 Sargassum inundations

6 The occasional deposition of relatively minor amounts of pelagic *Sargassum*, on the beaches of the islands and continental coast of the Wider Caribbean, is not uncommon. But, the inundation of *Sargassum*, in massive quantities, on the shorelines of countries in both Central West Africa and the Wider Caribbean in 2011 (Figure 3.3) appears to have been unprecedented in terms of geographical extent and quantities involved (Franks et al. 2011, Johnson et al 2011, 2012, 2013). Similar events have recurred since, apart from 2013, leading to significant social and economic upheaval

[1] http://www.sargassoseacommission.org

as well as ecological concerns. The coverage of *Sargassum* in the 2015 event was about four times that of 2011, on the basis of MODIS satellite observations (Wang and Hu 2016).

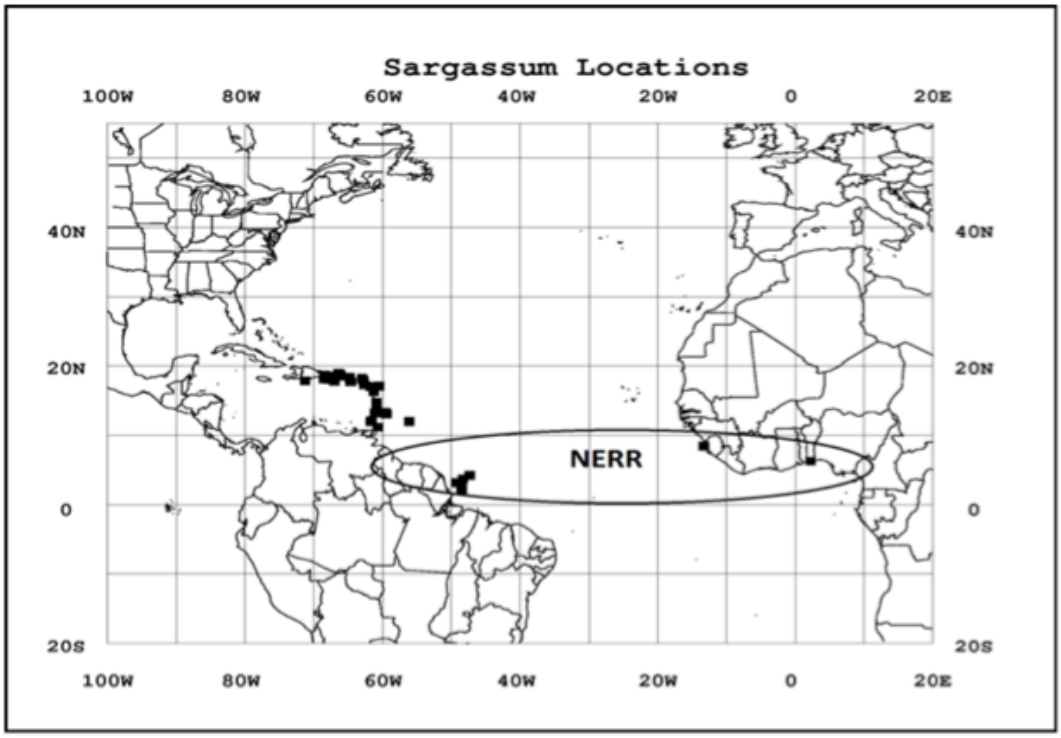

Figure 3.3. Locations of *Sargassum* inundations on the shoreline of at sea (black squares). The oval marks the location of the seasonal North Equatorial Recirculation Region (NERR). Image taken from Johnson et al 2011, and reproduced in UNEP 2016.

7 Franks et al. (2011) proposed that the *Sargassum* involved in the 2011 event had not originated from the Sargasso Sea. Rather, they considered that it has been advected from the tropical Atlantic east of Brazil, via the North Brazil, Guyana and Antilles Currents. This was on the basis of ocean circulation model simulations. This conclusion was supported by a study using satellite imagery, which revealed an origin north of the mouth of the Amazon, with a significant concentration observed in April 2011, spreading to the coasts of West Africa and the Lesser Antilles by July 2011 (Gower et al. 2013).

8 Shipboard observations in 2014, from aboard the SSV Corwith Cramer, revealled that the redominant form of *Sargassum* associated with the inundations was *S. natans VIII* Parr (Schell et al. 2015). This was quite distinct from the *S. Natans I* Parr form and *S. fluitans* associated with samples from the Sargasso Sea in both 2014 and from a 20-year time series. In addition to morphological differences, the two forms of *S. natans* show small but consistent differences in their genomic sequences (Amaral Zettler et al. 2016).

4. Impact of *Sargassum* inundations

4.1 Social and economic impacts

9 The inundations have had significant social and economic impacts, both in restricting activities and in the costs of removal.

10 The decomposition of piles of seaweed can produce very unpleasant odours, and invasions of flies, which may require local populations to be re-located (e.g. Grenada - Christopher Cox, UN Environment, personnel communication). Decomposition can lead to the production of highly toxic hydrogen sulphide, which can be fatal if inhaled even at low concentrations. As well as being a health hazard and nuisance, large piles of seaweed are unsightly and will reduce access to the sea and the use of the shoreline for other activities. This will have a very obvious impact on the tourism industry unless the material is removed, with the associated costs.

11 Fisheries can be affected in several ways. The accumulations can limit access to the beach for launching and recovering fishing boats. Floating seaweed will clog nets and has the potential to be a navigational a hazard. At least one fatality has been documented in which Sargassum was implicated in the incident (St Kitts and Nevis – Christopher Cox UN Environment, personnel communication).

4.2 Environmental impacts

12 Decomposition of piles of seaweed on the shoreline can result in the formation of hydrogen sulphide (toxic), oxygen depletion and eutrophication, leading to fish and invertebrate mortalities (Pfaff 2015). It is thought that sargassum accumulations may have a significant negative impact on marine turtles, by restricting access to nesting sites, causing anoxia as a result of decomposing vegetation and forming a barrier to the sea for hatchlings (Maurer et al. 2015).

13 Beaches may be compacted by heavy machinery used for removal, and sand may be inadvertently removed with the seaweed, leading to depletion and possible shoreline instability.

5. Response to *Sargassum* inundations

14 The repeated occurrence of the inundations has led to a multifaceted response from researchers, fisheries organisations, local and regional governance organizations, tourism bodies and others. This has included the organisation of conferences, technical workshops and webinars. These are described briefly below and summarised in the Annex.

5.1 Regional governance frameworks in the Wider Caribbean

The Regional Activity Centre for Specially Protected Areas and Wildlife (SPAW-RAC)

15 The SPAW-RAC is a Protocol under the Cartagena Convention, operating under the auspices of the UN Environment Caribbean Environment Programme (UNEP-CEP). The SPAW Secretariat is based in Guadeloupe, supported by the French Government. It has played a central role in the response to the *Sargassum* phenomenon in the Caribbean region, including acting as a clearing house for information dissemination and a focus for collaboration with other regional players[2].

Sargasso Sea Commission

16 The Commission[3] was formed in 2014 as a consequence of the 'Hamiliton Declaration on Collaboration for the Conservation of the Sargasso Sea', following the pioneering work of the Sargasso Sea Alliance (Laffoley et al. 2011). It does not have a legal management function but exists to provide a stewardship role, and encourages collaboration between interested parties.

Organization of Eastern Caribbean States (OECS).

17 The OECS was formed in 1981, originally consisting of seven member states. A further three states subsequently became associate members. The OECS promotes cooperation across a broad spectrum of social, economic, legal and environmental interests. The Ocean Governance and Fisheries Unit was established to '….*to maintain the benefits and functions of marine ecosystems for the communities dependent upon them and for human society as a whole* ….' including '… *to diagnose complex problems, determine the relative importance of different sources of stress, and establish priorities*'. The implementation of the Eastern Caribbean Regional Ocean Policy (ECROP) is expected to foster '… *more effective harmonization of data gathering and information sharing and support of stronger science-policy interface in ocean*.' Such mechanisms may be of great assistance in evaluating and responding to the *Sargassum* phenomenon.

Gulf and Caribbean Fisheries Institute (www.gfi.org).

18 The GCFI was founded in 1947 as an informal association of members, promoting information exchange on the management of marine resources in the region, becoming a not-for profit corporation in 1985. The 69th annual meeting in 2016 included a technical session on the *Sargassum* phenomenon[4], and the outcome was captured in a very informative video, available via Youtube.™[5].

5,2 Regional governance frameworks for the waters off Central West Africa

Abidjan Convention

19 The Abidjan Convention, supported by UN Environment, has been established for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa Region. The Secretariat has developed a Regional Strategy Document, coupled with an Implementation Plan and a GEF/PIF Form on *Sargassum* and invasive species for consideration by the Parties to the Convention in March 2017. The Secretariat is collaborating with SPAW-RAC under the coordination of UN[6].

[2] on-line forum: https://spawrac.teamwork.com/dashboard; http://www.car-spaw rac.org/?Regional-cooperation,654
[3] http://www.sargassoseacommission.org/about-the-commission
[4] http://www.car-spaw-rac.org/?GCFI-69th-session,697.
[5] (https://www.youtube.com/watch?v=728sHsgbl_Y).
[6] Aide memoir: Discussion on UN Environment's joint Caribbean-West Africa approach to the Sargassum management issue, 12th January 2017.

5.3 Examples of relevant research organisations and initiatives

20 There is a growing number of research organisations and concerned individuals directing their attention and the phenomenon, located in South America, the Wider Caribbean, North America, Africa and Europe (Table 1). Examples are provided below of some of the more established groups and initiatives.

Univ. Southern Mississippi, Gulf Coast Research Laboratory (GCRL)

21 The GCRL has played a key role in the early reporting of the 2011 *Sargassum* event (Franks et al. 2011) and in subsequent research activities (Franks et al. 2014, Johnson et al. 2012, 2013). It hosts a *Sargassum* reporting site[7].

Centre for Resource Management and Environmental Management (CERMES), University of the West Indies

22 Based at the Cave Hill Campus on Barbados, CERMES is another key organization in investigating the causes and impact of the *Sargassum* inundations. It has well established links with researchers at the GCRL and is collaborating with both the SPAW-RAC and GCFI on the issue (Hinds et al. 2016).

CC4FISH research project: Modelled growth and transport of pelagic Sargassum invasions in to the Eastern Caribbean and implications for pelagic fisheries

23 This FAO-funded project is a collaborative venture between CERMES and the GCRL. It has two main objectives:

1. Develop a model to describe pelagic *Sargassum* growth and transport within the North Equatorial Recirculation Region (NEER) and Eastern Caribbean using a numeric hydrological circulation model (global ocean Hybrid Coordinate Ocean Model, HYCOM), incorporating time-scaled pelagic sargassum growth rates.

2. Investigate the relationships between *Sargassum* events and two key pelagic species, dolphinfish and flyingfish, using official catch and effort data held by the fisheries divisions of the Eastern Caribbean islands over the past decade, and targeted interviews with pelagic fishers in the region.

IOC-UNESCO Harmful Algal Programme (GlobalHAB)

24 The phenomena of harmful algal blooms have increased in importance in recent decades both as a result of observed increases in occurrence and with the realisation of ecosystem impacts harm, especially with regard to human health. IOC-UNESCO responded in the 1980's with a series of initiatives that led to the formation of the GlobalHAB group[8], in conjunction with SCOR (Anderson et al. 2010). GlobalHAB has recently set up a *Sargassum* sub-committee.

[7] http://www.usm.edu/gcrl/sargassum/index.php
[8] http://hab.ioc-unesco.org/index.php?option=com_content&view=featured&Itemid=100001

5.4 Management options

25 A number of options have been proposed for cleaning up, harvesting or otherwise re-using the *Sargassum* deposits. What is clear is that any activity or enterprise needs to be designed to minimise environmental damage and be socially and economically sustainable. An excellent guide called the 'Sargassum Management Brief' has been produced by CERMES in conjunction with SPAW-RAC and the GCFI, describing best practice for cleaning up *Sargassum* from the shoreline and nearshore waters in the Caribbean (Hinds et al. 2016).

26 There has been some discussion on harvesting fresh *Sargassum* for the nutriceutical and food sector (Christopher Cox UNEP, personnel communication), and trials have been conducted to evaluate its potential as a source of energy via anaerobic digestion (CPI 2017). Informal trials have taken place to utilise the seaweed as a soil conditioner and fertiliser.

27 Optimising the management response, to minimise the negative environmental, social and economic impacts, and maximise any benefits, will require improved forecasting and a better understanding of the underlying variables controlling the phenomenon. Ideally this will span from seasonal/inter-annual synoptic forecasts (e.g. derived from CC4FISH) to more localised operational systems, for example the method described by Maréchal et al (2017), combining satellite imagery with model simulations (HYCOM) of surface currents to predict the landfall of specific inundation events.

6. Possible contributory factors to *Sargassum* inundations

28 Several tentative hypotheses have been put forward as to what might be contributing to the sudden appearance of the Sargassum phenomenon in 2011 and subsequent years. These revolve around the conditions for growth (e.g. supply of nutrients, sea surface temperature) and changes in the surface ocean circulation. These have been based largely on a combination of in-situ and remote observations and modelling exercises (e.g. Johnson et al. 2011, 2013; Wang and Hu 2016).

6.1 Variability in ocean circulation and ocean climate

29 There are a number of physical factors that may influence the occurrence of pelagic *Sargassum*:

i. Changes in the intensity of the mean meridional central and eastern equatorial Atlantic (Perez et al. 2013) and the position and intensity of the North Equatorial Recirculation Region (NERR) (Johnson et al 2011)
ii. Variability of the North Atlantic sub-tropical gyre;
iii. Variability in the outflow of the Amazon and the extent and position of the Amazon plume;
iv. Variability in the position and intensity of the North Brazil, Guyana and Antilles Currents in the western central Atlantic;
v. Variability in the position and intensity the Canary and Guinea Eastern Boundary Currents and associated upwelling systems in the eastern central Atlantic; and
vi. Seasonal and interannual variability in Sea Surface Temperature (SST) linked to variability in equatorial winds and upwelling (Johnson et al. 2013).

6.2 Variability in external nutrient inputs

30 The growth rate of pelagic Sargassum will be influenced by the availability of nutrients, from local or long-distance sources. This may be affected by:

i. Variability in riverine nutrient inputs from the Congo and Amazon (Wang & Hu 2016);

ii. Variability in the supply of iron due the atmospheric deposition of Saharan dust (Figure 6.1), with a possible link to changes in climate and increased desertification. This source has been implicated in the occurrence of red tides in the Gulf of Mexico (Walsh et al. 2010); and

iii. Increased land-based nutrients from sewage and nitrogen-based fertilizers

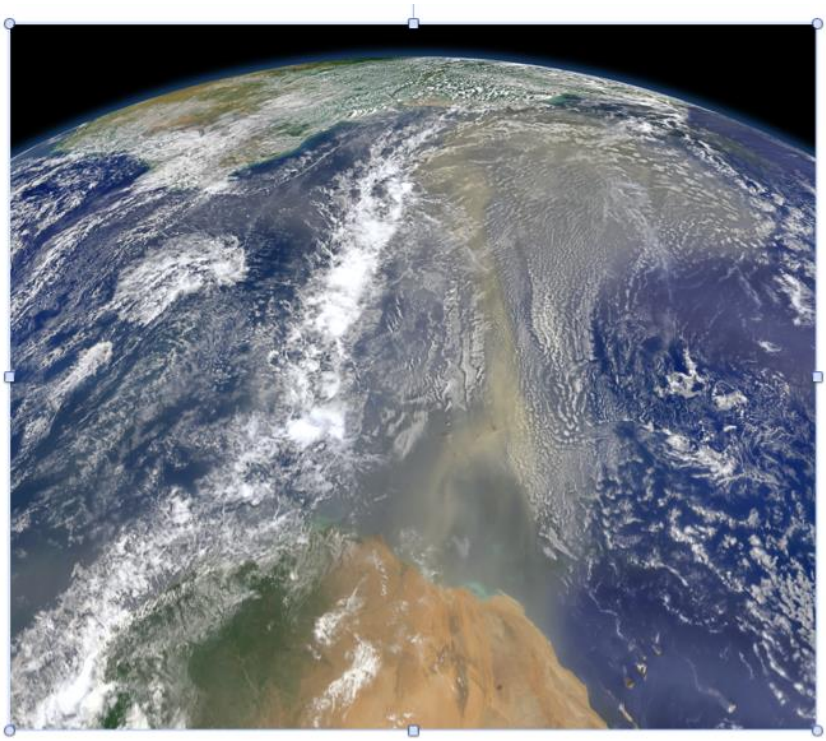

Figure 6.1. Advection of Saharan dust towards the coast of South American and the Gulf of Mexico (image taken from NASA)

7. Conclusions

31 It is clear that there was a very dynamic response to the initial 2011 *Sargassum* event, especially in the Caribbean, working through established research terms and governance structures. Progress is being made on quantifying the impact of the events and of developing management options, both to minimise the impacts and, potentially, exploit the *Sargassum* for social and economic benefit. Improved forecasting, at appropriate temporal and spatial scales, appears to be the most critical requirement to plan the most cost-effective responses in West African and Caribbean states. Some progress has been made, and more is planned under the CC4FISH project for example. However, the reliability of any modelled system is only as good as the accuracy of our understanding of the underlying drivers and the quality and completeness of the data to run the models.

32 The relatively large number of potentially contributory factors (section 6) - each of which has inherent uncertainties in space, time and magnitude - makes the task of fully understanding the causes and drivers of the *Sargassum* events intrinsically complex.

33 In terms of spatial extent, any study of the *Sargasssum* phenomenon should include, as a minimum:

1. Greater Caribbean region from Trinidad & Tobago to the Gulf of Mexico
2. West African coastal waters from Senegal to Gabon
3. Coastal waters off northern Brazil
4. North Equatorial Recirculation Region (NERR)

34 However, any analysis will need to take account of boundary conditions, such as: the outflows of major rivers (e.g. Amazon), the advection of Saharan dust, and variability in Atlantic climatology. In terms of temporal scales, there would be merit in examining historical records for previous occurrences, to place the recent examples in context in relation to potential underlying causes.

8. Potential role for GESAMP

35 GESAMP provides a forum for UN Agencies with responsibilities for marine matters to raise and discuss common issues, and facilitates the creation of mechanisms to carry out assessments of those issues in a cost-effective manner. This encourages collaboration and minimises duplication. Three GESAMP agencies have well described interests in the events: UN Environment (GPA), FAO (fisheries) and IOC-UNESCO (HABS, oceanographic processes). In addition, WMO is interested in dust transport from the Sahara (GESAMP Working Group 38, the atmospheric input of chemicals to the ocean); IMO has an interest in the Sargasso Sea, from the aspect of shipping, as an area of special interest with conservation status; UNDP has peripheral interests via the GEF and nutrient management in the Amazon Basin; and, the IAEA Marine Environmental Laboratory in Monaco has an interest from a science perspective. From this it can be concluded that the topic is well within the subject remit of GESAMP.

36 The main question is to whether GESAMP can add value to those existing or planned activities. There is also the practical issue of GESAMP's existing workload (seven Working Groups and an additional four Correspondence Groups) and whether there would be sufficient financial support to provide an adequate contribution.

37 At this stage in the GESAMP scoping exercise (April 2017), it is proposed to distribute this Progress Report to both the GESAMP Sponsoring Agencies and to the main management and research organisations to obtain a collective view as to whether GESAMP can make a significant and helpful contribution.

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Annex I Examples of initiatives related to the occurrence of massive accumulations of *Sargassum*

([a] Geographic focus: C – Greater Caribbean including Sargasso Sea, B – waters off Brazil and coast of NE South America, WA – coast of West Africa; [b] Science scope: B – biology including occurrence, ecology and ecological impacts of *Sargassum*, PC - underlying physics and chemistry influencing the occurrence of *Sargassum*, SE – socio-economic impacts of *Sargassum* accumulations)

Organisation(s)	**Initiative**	**Geographic scope[a]**			**Science focus[b]**			**Comments**	**References**	**Contact information**
		C	B	WA	B	PC	SE			
UN Environment GPA	GPA	Y	Y	Y	Y	Y	Y	Coordinating efforts within UN Environment, including Regional Seas (Cartega and Abidjan Conventions)	Paper presented at UNEA-2 side event Aide memoire – Discussion on UN Environment's joint Caribbean-West Africa approach to the Sargassum management issue (12 January 2017)	Christopher Cox (UN Environment)
UN Environment Regional Activity Centre for Specially Protected Areas and Wildlife, Caribbean Environment Programme (Cartagena Convention Secretariat, SPAW-RAC UNEP-CEP)		Y			Y	Y	Y	Acting as a hub for research activities in the Greater Caribbean:	sargassum.forum@gmail.com	Frédérique Fardin (SPAW-RAC) Sandrine Pivard (SPAW-RAC)
UN Environment The Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa				Y	Y	Y	Y	Focus on West African fisheries and other economic factors		Abou Bamba (Abidjan Conv),

Region (Abidjan Convention)										
Centre for Resource Management and Environmental Studies, Univ. West Indies (CERMES - UWI)		Y								Adrian Cashman (CEMES)
Univ. Southern Mississippi, Gulf Coast Res. Lab.		Y	?		Y			On-line reporting portal: http://gcrl.usm.edu/sargassum/index.php		James Franks (USM)
FAO	FAO CC4FISH	Y	?	Y	Y		Y	Modelling growth and transport of pelagic *Sargassum* invasions from West Africa into the Eastern Caribbean and implications for pelagic fisheries		James Franks & Donald Johnson (USM[9]) Hazel Oxonford (CERMES, UWI[10]) Iris Monneraeu (FAOSLC) Tarub Bahri (FAO)
GEF-funded (UNDP)	Several linked projects/proposals (partial follow-on from UNEP/OTCA/GEF-Amazonas)	Y	Y		Y	Y	Y	GEF-CReW2 Project in the Caribbean GEF-IWEco Project CLME+ (linked to Brazil Shelf LME) UNEP/OTCA/GEF-Amazonas http://otca.info/gef/boletines/noticia/62		Norbert Fenzl
SCOR-IOC-UNESCO	SCOR-IOC GlobalHAB (Sargassum sub-committee)	Y ?	Y ?	Y ?	Y	Y	?	Extending existing WG on Harmful Algal Blooms		Henrik Enevoldsen (IOC-UNESCO)
WMO	GESAMP WG 38	Y	Y	Y		Y		Atmospheric nutrient inputs		Robert Duce Tim Jickells (Univ. East Anglia, UK)

[9] USM - Univ. Southern Mississippi

[10] CERMES UWI -

IMO		Y						Special status of Sargasso Sea		Fredrik Haag (IMO)
Centre for Process Innovation (CPI UK) & the Caribbean Council	Anaerobic digestion feasibility study	Y					Y	Report commissioned by the UK Foreign & Commonwealth Office on generating energy from waste, sewage and *Sargassum* seaweed	Morrison, M. & Gray, D. (2017), Anaerobic digestion feasibility study: generating energy from waste, sewage and Sargassum seaweed in the OECS, CPI-SP-RP-141	Michelle Morrison, CPI Daniel Gray, Caribbean Council
Bantry Marine Research Station, Ireland		Y					Y	Hazard to shipping Potential uses including as a raw material for bio-plastics. Discussions between BMRS and Richard Branson		Julie Maguire (BMRS)
Gulf & Caribbean Fisheries Institute								69th annual meeting of the GCFI (November 2016) – informal event and technical session about the Sargassum influx. Very informative video available on Youtube	www.gcfi.org https://www.youtube.com/watch?v=728sHsgbl_Y	