C-GRASS: Coordinated Global Research Assessment Of Seagrass Systems

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1. Summary

Seagrasses provide the foundation of submerged coastal grassland ecosystems around the world but are threatened by human activities, with substantial declines in global cover over the last century. Seagrasses provide multiple valuable ecosystem services, particularly in the developing world. Yet obtaining an accurate understanding of seagrass status, trends, and responses to global change has been challenging due to the fragmented nature of available data. The time is opportune to solve these problems. Building on a recently completed Community White Paper and initial workshops to organize global seagrass researchers, we propose a series of SCOR workshops to collate and analyze existing data toward a scientific synthesis of the drivers and trajectories of seagrass ecosystems under global change, and to provide a framework for future coordinated observation and research on seagrass systems. Our Working Group (WG) engages a diverse community, spanning the globe and fields of technical expertise to: (1) collate and analyze existing data to publish an open-access scientific synthesis of current status, trends, and drivers of change in global seagrass systems; (2) establish common protocols and best practices for seagrass data collection, curation, and sharing, collated in a multi-media handbook of accepted protocols and best practices; (3) integrate seagrass data collection into international, open-access portals, with common frameworks for data vocabulary, metadata, management, and service to stakeholders; and (4) integrate ongoing seagrass monitoring and research into a global community of practice that incorporates diverse data types and informs diverse end users.

2. Scientific Background and Rationale

2.1. Global status of seagrass ecosystems

Seagrasses provide the foundation of submerged coastal grassland ecosystems around the world. They are among the most productive natural habitats on land or sea (1), store substantial quantities of carbon, and provide humanity with fishery habitat, coastal protection, erosion control, and other services (2). Seagrass nutrient cycling services alone have an estimated value of nearly $2 trillion per year (3), and Indonesian seagrass meadows provide fishery nursery areas that contribute an estimated 54% to 99% of daily protein intake for local communities (4). Seagrasses also serve as early warning indicators of anthropogenic perturbations in the coastal zone due to their sensitivity to changing water quality and fishing activities (5).

Seagrass habitats are threatened worldwide by human activities: a recent synthesis estimates that almost 30% of seagrass global cover has been lost over the last century (6) and 22 of the world's 72 seagrass species (31%) are in decline (2, 7), a trend widely considered a global crisis (8). Recognizing this, the Global Ocean Observing System (GOOS) has proposed seagrass cover and composition as one of seven Essential Ocean Variables (EOVs) defined by societal importance as reflected in reporting requirements for numerous international conventions and agreements that shape policy responses to global change (9).

Despite their importance, developing coordinated systems for observing seagrass status and trends has been challenging for several reasons. First is the fragmented nature of available in situ data. Data on seagrass systems are collected by numerous local and regional monitoring programs, and by two global programs: Seagrass-Watch (10, 11), SeagrassNet (12). These networks, together with the Smithsonian's newer MarineGEO program, have engaged hundreds of scientists and thousands of citizens in collecting data. But such programs often have different objectives, methods, and target variables, making inter-comparison and synthesis difficult. A second challenge is that field sampling is biased geographically, concentrated in North America and western Europe around major scientific organizations. As a result, syntheses of seagrass occurrence rely heavily on interpolation of expert knowledge and low-resolution point-based occurrence sampling, whereas seagrass extent is difficult to quantify and resolution is low in the regions where seagrasses are most diverse such as the western Pacific.

2.2. New opportunities in seagrass science and conservation

We are now poised to overcome these historical challenges, as illustrated by several recent developments. These include production of a consensus Community White Paper outlining criteria for a coordinated global seagrass observing system (13), convening of the International Seagrass Experts Network (ISEN)[1], an upcoming GOOS workshop to draft implementation plans for seagrass and mangrove observing, and participation in this WG of leaders of the two major global seagrass networks, Seagrass-Watch (WG member McKenzie) and SeagrassNet (WG member Short). Recent field initiatives have focused on seagrasses in the rich and understudied territories of southeast Asia and the coral triangle, including by members of this Working Group: Ambo-Rappe, Cullen-Unsworth, Fortes, Nordlund, Prathep, and Unsworth. While Africa remains poorly documented, WG member Uku is an authority in that region. This work promises to significantly expand geographic coverage of seagrass knowledge in understudied areas.

Additional opportunities to assemble a geographically comprehensive and well resolved understanding of global seagrass systems come from innovations in remote sensing; engagement of citizen scientists in field data collection; and community consensus around the need for standardization of protocols and data management (13). Our proposed working group (WG) aims to integrate and coordinate remote sensing and in situ sampling programs toward a more powerful scientific synthesis of global seagrass distribution and ecosystem characteristics. The WG will then extend this synthesis by coordinating seagrass ecosystem researchers worldwide toward consensus on comparable approaches for collecting and organizing data on seagrass cover, composition, and ecosystem characteristics. The WG will have the secondary benefit of providing a scientific and operational foundation to advance seagrass cover and composition as an Essential Ocean Variable (1).

2.3. Rationale for a SCOR working group

We propose a series of SCOR workshops that engage a diverse community of scientists and stakeholders to achieve the following goals: (1) collate and analyze data to produce a synthesis of the current status, trends, and drivers of change in global seagrass systems; (2) establish common protocols and best practices for seagrass data collection, curation, and sharing; (3) integrate existing and ongoing seagrass data collection into open-access portals, using a common schema; and (4) integrate existing seagrass monitoring and analysis into a unified, global

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[1] See: http://unseagrass.org/

community of practice. The proposed workshops will establish the community to continue the process into the future, and several participating institutions are committed to supporting achievement of the long-term goals.

Over the last few years seagrass researchers around the world have recognized the need for a more coordinated global response to understanding and publicizing seagrass degradation and have begun to coalesce around a shared vision for achieving this (8, 13). The time is ripe for a new global assessment of seagrass ecosystems. Achieving such a synthesis requires engaging expertise in seagrass physiology, field ecology, biogeochemistry, remote sensing, database architecture, geospatial science and mapping, social science, and digital knowledge product development and service. The proposed WG, and our large network of collaborators, spans this expertise. Foundations have been laid by incorporating seagrass cover as an Essential Ocean Variable by the Global Ocean Observing System (9), engaging the global community in the consensus Community White Paper (13), and formation of the ISEN.

The primary bottlenecks to a global seagrass database are comparability of protocols and accessibility of data. We will make rapid progress on the first of these as leaders of both major seagrass networks and the MarineGEO program are full members of this group (McKenzie, Short, Duffy). An achievable first step is to establish a public metadata portal to summarize what seagrass data exist and who holds them. We will then work to make as much of this data as possible accessible and will incorporate new data as they become available.

Candidate protocols and best practices have been developed, vetted, and formalized by Seagrass-Watch, SeagrassNet, the *Zostera* Experimental Network (14), MarineGEO[2], and other programs, providing a foundation for a global community of practice. Under the right conditions, satellite remote sensing (15) and lightweight drone technology (16) can obtain high-resolution maps of seagrass distribution and resolve variation in abundance, offering promise in linking regional and global-scale cover mapping, and validating these with strategically sited *in situ* measurements. We will evaluate the capabilities of remote sensing to conduct regional assessments on the health and cover of seagrass communities. Satellite images collected over the past 30 years provide an basis for evaluating change, yet it is not clear how this technology can be leveraged with new unmanned airborne systems and field efforts. WG Members Muller-Karger and Dierssen bring experience in these areas to the WG.

The accessibility of shallow-water seagrass meadows and their importance to local fisheries and ecosystems makes seagrass systems prime targets for application of citizen science monitoring, as done by Seagrass-Watch and the Seagrass Spotter phone app[3], co-developed by WG Member Unsworth. There is considerable potential to expand and integrate these activities. Through all these approaches, we are poised to achieve a previously unavailable synthesis of the changing distribution of global seagrass habitat, and the drivers of these trends. This process will also advance implementation of the seagrass EOV envisioned as part of GOOS.

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[2] Available at: https://marinegeo.github.io/seagrass.html

[3] Available at: https://seagrassspotter.org/

3. Terms of Reference

The objectives of the SCOR C-GRASS Working Group are:

Objective 1: Produce a scientific synthesis of status and trends in global seagrasses and the systems they support, via a comprehensive review of peer-reviewed and gray literature, and unpublished data, on seagrass occurrence, ecosystem characteristics, and benefits to human well-being.

Objective 2: Produce a handbook of standard protocols and best practices for collecting, curating, and sharing data on seagrass ecosystems among scientists and stakeholder groups, building on existing experience of scientists and end-users in management and conservation, and contributed to the Ocean Data Standards and Best Practices Project of IODE.

Objective 3: Promote development of standardized vocabularies for variables and data schemas specific to seagrass ecosystems, and integration of existing and new data into the Ocean Biodiversity Information System (OBIS) using the EVENT-DATA schema (17).

Objective 4: Organize an interdisciplinary community of practice to synthesize data on status, trends, and drivers of global change in seagrass ecosystems, building on and integrating existing resources.

4. Working plan

4.1. Objective 1: Produce a scientific synthesis of status and trends in global seagrass systems

The centerpiece of the Working Group will be assembling the existing global seagrass data into an updated scientific assessment, building on previous assessments of global seagrass occurrence (18). Collaboration of major global seagrass networks (WG members Short, McKenzie, Duffy) will achieve an unprecedented coordination and integration of data, knowledge, and practice. The data will be analyzed with ocean environmental data layers and data on human activities to quantify drivers of change in global seagrass systems. The results will be published in peer-reviewed paper(s), and integrated into the UNEP-WCMC Ocean+ initiative, which maintains a database of seagrass cover and produces maps and knowledge products that directly inform decision-making (available through Ocean Data Viewer[4]), including the *Global Distribution of Seagrasses*[5]. The synthesis will also link in situ seagrass data to remote sensing approaches (19) and quantification of seagrass ecosystem services (WG members Cullen-Unsworth and Nordlund) (20, 21).

4.2. Objective 2: Produce a handbook of standard protocols and best practices

[4] Available at: http://data.unep-wcmc.org.
[5] Available at: http://data.unep-wcmc.org/datasets/7.

Agreement on comparable protocols and best practices is key to coordinating monitoring across a distributed network and ensuring that data are comparable across space and time. We will assemble and analyze core measurements and protocols for in situ survey methods (22), remote-sensing approaches (15), and sampling designs, focusing on those that are fit to purpose, i.e., selected to provide information of appropriate resolution, quality, and scale to capture seagrass trends relevant to reporting requirements of nations and decision-makers. This process is facilitated because only two large networks dominate the field and leaders of both (McKenzie, Short) are members of our WG. The Working Group will produce a multi-media handbook, linked to training videos and online resources facilitating field data collection, data management, and curation methods accepted by community consensus. These products will accelerate data collection and integration across networks by making protocols and data more accessible, and by building capacity to collect and contribute data, also adding value to existing networks (as confirmed by participation of Short and McKenzie).

4.3. Objective 3: Promote development of standardized vocabularies and data schemas

Rigorous comparison of data among programs requires a common language. The recently developed EVENT-DATA OBIS schema uses a standard Darwin Core set of terms and accommodates sampling descriptions, environmental data, and biodiversity records. The WG will develop and compile a standardized vocabulary for seagrass systems via established OBIS collaborations developed by the MBON (WG member Muller-Karger) and Smithsonian MarineGEO (WG co-lead Duffy). We will integrate a substantial body of records of seagrass cover and species composition into OBIS, notably from SeagrassNet representing 33 countries, Seagrass-Watch representing 26 countries, and the 13 sites in the MarineGEO program.

Data access and ownership are key issues in the emerging networked data ecosystem. A key first step will be a metadata portal. We will promote availability of as much seagrass data as possible, building on the Seagrass-Watch model, which involves a tiered system of data sharing that respects the ownership of raw data, while making detailed summaries available via open access portals.

Objective 4: Organize an interdisciplinary community of practice

A dynamic observing system for seagrasses requires a coordinated effort, structures to manage ongoing data input and access to maintain inter-comparability, and engagement of diverse partners across the world, disciplinary expertise, and knowledge of the needs of policy- and decision-makers. We will focus on linking the web portals and protocols of the Seagrass-Watch, SeagrassNet, the Ocean Data Viewer, and MarineGEO programs, leveraging resources already invested in them and the continuing support of their secretariat institutions. Working Group members, including the UN Environment World Conservation Monitoring Centre (UNEP-WCMC, with leadership from co-chair Weatherdon) and GRID-Arendal (Maria Potouroglou) will assist in engaging end-users of the information products from the policy community, and in developing a communications strategy. UNEP-WCMC's existing seagrass layer has been used for environmental sensitivity mapping, marine spatial planning, high-level screening of biodiversity risk, and blue carbon assessments, and its application to ecosystem-based adaptation to climate change is in progress. We expect rapid uptake of our findings in development and refinement of global blue carbon inventories and development of blue carbon markets as several WG members play advisory roles in International Blue Carbon Partnership (collaborator Peter Macreadie), the IUCN Blue Carbon Initiative (Fourqurean, Fortes, Marba), the IPCC Guidelines for National Greenhouse Gas Inventories (Macreadie), and the Coastal Carbon Research Coordination Network (Duffy).

4.4. Timeline

Working Group meetings will be held in association with international conferences and we will work to leverage other funds to cover costs of participants; several participating institutions have offered financial or in-kind support. Likely venues for meetings include the 14^{th} International Seagrass Biology Workshop (2020, Washington DC); and international Ocean Science meetings.

Month 1: Working Group meeting 1. Hone goals, assign subgroups with leads for each of the four objectives. Begin to identify data sources and tractable synthesis goals, and to assemble data and metadata (Objective 1). Draft outline of best practices (Objective 2) and data schema (Objective 3).

Month 1-12: Subgroups work on collating data, integrating into the developing data schema (Objectives 1,3), and converge on best practices for handbook (Objective 2). Integrate sample data sets into OBIS using draft schema (Objectives 1,3).

Month 12: WG meeting 2. Present draft of best practices document (Objective 2) and data schema (Objective 3) for discussion by WG. Review data assembled, outline synthesis papers, and begin intensive data analysis (Objective 1).

Month 12-24: Continue work on best practices (Objective 2) and synthesis paper(s) (Objective 4). Introduce drafts to policy end-users and incorporate feedback.

Month 24: WG meeting 3. Complete best practices handbook (Objective 2) and synthesis papers (Objective 4). Report on data integration (Objectives 1, 3), challenges, and plans.

Month 24-36: Subgroups finish work on all four objectives.

Month 36: Meeting of selected WG members, lead authors, and data architects, to synthesize results toward the Objectives, finish products, and develop plans for long-term advancement. Official launch of products.

5. Deliverables

(1) Hold a town hall meeting at the 2020 Ocean Sciences meeting (and potentially others) to announce the Working Group effort and solicit broad input. Contributes to delivering all Objectives.

(2) Produce a peer-reviewed scientific synthesis of status, trends, and environmental and anthropogenic drivers of change in global seagrasses and the systems they support, based on a comprehensive review of peer-reviewed and gray literature and unpublished data available in major seagrass network databases. Delivers Objective 1.

(3) Integrate existing seagrass data, and ongoing monitoring data, into the Ocean Biodiversity Information System (OBIS) using a common data schema. Contributes to delivering Objectives 1 and 3.

(4) Produce a peer-reviewed handbook of inter-comparable protocols and best practices for seagrass field measurements and data management, published and contributed to the Ocean Data Standards and Best Practices Project of IODE. Delivers Objective 2.

6. Capacity Building

The community of practice built through this series of working groups will be advanced into the future in several ways. First, we engage seagrass researchers and stakeholders from a diverse range of backgrounds, geographic regions, and disciplines in this common, collaborative effort. Second, we intend to develop courses with support from IODE Ocean Teacher Global Academy (OTGA) of the International Oceanographic Data and Information Exchange (IODE) to spread the protocols, best practices and synthesis tools in seagrass research to a global community. We will liaise with the OTGA program to propose an OBIS course tailored for the seagrass community, and seek support from OTGA. Third, the several seagrass observation programs, including Seagrass-Watch (McKenzie), SeagrassNet (Short), the MarineGEO program (Duffy), and the MBON (Muller-Karger) conduct training and outreach activities that will promote the best practices developed by the WG. Finally, development of the handbook and other products will also focus on feeding information into international targets such as the UN Sustainable Development Goals and Aichi Targets, as well as the post-2020 biodiversity agenda, with leadership by UNEP-WCMC (Weatherdon) and GRID-Arendal (Potouroglou).

7. Working Group Composition

Our Working Group brings together ten Full Members (6 female, 4 male), representing 9 countries, and a range of career stages and disciplinary expertise from seagrass biology to biogeochemistry, remote sensing, fisheries, social science, and global conservation. Several Full and Associate Members are leaders in existing synthesis and coordination efforts in coastal marine and seagrass science. This diversity will help ensure that interdisciplinary products of the working group are effectively communicated to a wide audience and translated into practical applications.

7.1. Full Members

Name	Gender	Place of Work	Expertise
Emmett Duffy (co-chair)	M	Smithsonian Institution, USA	Marine ecology and biodiversity
Lauren Weatherdon (co-chair)	F	UN Environment World Conservation Monitoring Centre, UK	digital knowledge products, ocean biodiversity and spatial data
Rohani Ambo Rappe	F	Universitas Hasanuddin, Indonesia	Seagrass ecology, ecosystem services, seagrass restoration
Leanne Cullen-Unsworth	F	Cardiff University, Wales	Coupled social-ecological systems, seagrass ecosystem services
Miguel Fortes	M	University of the Philippines	Seagrass & mangrove ecology, blue carbon, policy & coastal resilience
Núria Marbà	F	Consejo Superior de Investigaciones Científicas, Spain	Seagrass ecology, global change
Len McKenzie	M	James Cook University, Australia	Seagrass status, management and sustainable use, founder Seagrass-Watch
Maria Potouroglou	F	GRID Arendal, Norway	Seagrass mapping, monitoring and ecosystem services assessment, coastal and marine policy
Fred Short	M	University of New Hampshire, USA	Seagrass ecology and restoration, founder SeagrassNet
Jacqueline Uku	F	Kenya Marine and Fisheries Research Institute	Seagrass physiology, ecology, community development

7.2. Associate Members

Name	Gender	Place of Work	Expertise
Rod Connolly	M	Griffith University, Australia	Seagrass ecosystem resilience, carbon

			pathways, fisheries food web
Maricela de la Torre Castro	F	Stockholm University, Sweden	Social-ecological systems analysis, governance, gender, sustainable resource use, resilience
Heidi Dierssen	F	University of Connecticut, USA	Remote sensing of seagrass extent, leaf area index, carbon
Carlos Duarte	M	King Abdullah University of Science and Technology, Saudi Arabia	Marine ecology and oceanography, expertise in all aspects of seagrass ecology
James W. Fourqurean	M	Florida International University, USA	Ecosystem ecology, biogeochemistry of seagrass systems
Margot Hessing-Lewis	F	Hakai Institute, Canada	Coastal marine ecology, focusing on seagrass systems
Frank Muller-Karger	M	University of South Florida, USA	Biological oceanography, remote sensing, global change
Masahiro Nakaoka	M	Hokkaido University, Japan	Coastal ecosystem dynamics, seagrass ecology
Anchana Prathep	F	Prince of Songkla University, Thailand	Seaweed and seagrass biodiversity and ecology; coastal climate change
Richard Unsworth	M	Swansea University, Wales	Seagrass ecology, conservation, and ecosystem services, co-founder Project Seagrass

8. Working Group contributions

Rohani Ambo Rappe is a seagrass ecologist, studying ecosystem services and seagrass restoration, with expertise in the seagrass systems of the coral triangle region, the most diverse marine systems in the world.

Leanne Cullen-Unsworth is a coupled social-ecological systems analyst focusing on seagrass ecosystem services, in particular seagrass fisheries and associated food security.

Emmett Duffy is a biodiversity scientist who founded the *Zostera* Experimental Network (ZEN) and is the first Director of the Smithsonian's Tennenbaum Marine Observatories Network and MarineGEO program. He is a member of MBON, the GOOS Biology and Ecosystem panel, and is lead development of specification sheet and implementation plan for the GOOS seagrass EOV.

Miguel D. Fortes is a coastal Ecologist, and specialist on Biodiversity, ICZM and Blue Carbon, focusing on seagrasses and mangroves. His works are major additions to seagrass science and policy in the tropics and are having major impacts in applications and in development of coastal resilience in the face of climate change and other environmental uncertainties.

Núria Marbà is a seagrass ecologist focusing on assessing sustainability and integrity of coastal ecosystems and ecosystem services as well as the impact of global change.

Len McKenzie is a seagrass and coastal ecosystems ecologist working to facilitate the protection, conservation, biological diversity, rehabilitation, management and sustainable development of seagrass resources. His research focuses on status and condition of seagrass resources, the role of disturbance, and identifying thresholds of concern and investigating resilience of seagrass ecosystems. Len directs the Seagrass-Watch program, one of the two major global seagrass observing networks.

Maria Potouroglou is a biologist with extensive experience in seagrass ecosystems science and policy in several Regional Seas programmes, including the Eastern Africa, Mediterranean, North-West Pacific, Western Africa and ROPME Sea regions. She leads the scientific strategy of the first ever seagrass project in West Africa, and co-ordinates the UN Environment/GRID-Arendal convened International Seagrass Experts Network.

Fred Short is a seagrass ecologist with expertise in restoration, global seagrass mapping and monitoring, eelgrass stressors including nitrogen loading, physical impacts and climate change. He established the global seagrass monitoring program SeagrassNet and co-edited the seminal book *Global Seagrass Research Methods* (2001).

Jacqueline Uku is a marine ecologist working on seagrass systems in Kenya and recently engaged in community development projects along the Kenyan Coast. She is current President and member of the Western Indian Ocean Marine Science Association (WIOMSA), providing linkage to the member countries of the Western Indian Ocean.

Lauren Weatherdon leads development of digital knowledge products that contribute to a step-change in global access to, and use of, ocean biodiversity information and spatial data. These products help to support the delivery of global ocean goals and targets, and to support marine spatial planning, conduct environmental impact assessments, produce ecosystem assessments, and enhance ocean literacy; she is also a member of MBON.

9. Relationship to other international programs and SCOR Working groups

This project builds on and synergizes with two initiatives already underway. First, in May 2019, UN Environment/GRID Arendal will convene an International Seagrass Experts Network to produce a report, led by member Potouroglou, highlighting the current state and threats to seagrass systems and their ecosystem services with relevance to policy. Second, in June 2019, Co-chair Duffy will co-lead a NASA-funded workshop to develop implementation plans for the GOOS seagrass and mangrove Essential Ocean Variables (EOVs). These two activities, which involve several of our members, will lay a strong foundation by identifying available data sources, conducting a qualitative review, and articulating a plan for coordinating seagrass research globally. Our proposed SCOR project will advance to the next, quantitative step by picking up where those efforts leave off: assembling, harmonizing, and analyzing the metadata and available data to produce a quantitative picture of global seagrass status, and the rates and drivers of change. A second major product will be an agreement among key seagrass constituencies around the world on terms of coordination, protocol comparability, and data sharing in future research. Together, these activities will facilitate rigorous global analyses of seagrass distribution, change, and responses to environmental and anthropogenic forcing.

The proposed WG has important relevance to several other interdisciplinary global change science efforts, and to the science-policy-society interface and communication initiatives. These other efforts are not specifically focused on seagrasses and would benefit from the research advanced by this SCOR WG on seagrasses. Among these are the following. The OceanObs Research Coordination Network is an NSF-sponsored effort to advance the integration of biological observations into ocean observing systems for societal benefit, co-led by WG member Muller-Karger. We have already submitted a Community White Paper on seagrasses to the OceanObs'19 meeting in Honolulu, Hawaii, September 2019. The Marine Biodiversity Observation Network (MBON, with WG members Muller-Karger and Duffy) is a thematic program under the Group on Earth Observations Biodiversity Observation Network or GEO BON to strengthen understanding of marine biodiversity and coordinate monitoring of associated changes over time by defining marine Essential Biodiversity Variables or EBVs. The Global Ocean Observing System (GOOS) Bio-Eco Panel (WG members Muller-Karger and Duffy) seeks to improve the availability of existing core biological variables and identify and prioritize additional cross-cutting biological and ecosystem observation needs by defining Essential Ocean Variables or EOVs for biology and to integrate these with physical and biogeochemical EOV and observing programs. Several members of the proposed C-GRASS WG are closely involved in each of these efforts and will work to integrate the WG's activities with their goals.

10. Key References

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11. Appendix—5 key publications for full members

Emmett Duffy

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