



A Suite of Field Manuals for Marine Sampling to Monitor Australian Waters

Rachel Przeslawski^{1*}, Scott Foster², Jacquomo Monk³, Neville Barrett³, Phil Bouchet^{4,5}, Andrew Carroll¹, Tim Langlois⁴, Vanessa Lucieer³, Joel Williams⁶ and Nicholas Bax^{2,7}

¹ National Earth and Marine Observations Branch, Geoscience Australia, Canberra, ACT, Australia, ² CSIRO Data61, Hobart, TAS, Australia, ³ Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS, Australia, ⁴ School of Biological Sciences, UWA Oceans Institute, The University of Western Australia, Crawley, WA, Australia, ⁵ School of Ocean Sciences, Bangor University, Bangor, United Kingdom, ⁶ NSW Department of Primary Industries, Taylors Beach, NSW, Australia, ⁷ CSIRO Oceans and Atmosphere, Hobart, TAS, Australia

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d'océanographie de Villefranche
(LOV), France

*Correspondence:

Rachel Przeslawski
rachel.przeslawski@ga.gov.au

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One of the main challenges in assessing marine biodiversity is the lack of consistent approaches to monitor it. This threatens to undermine ocean best practice in marine monitoring, as it impedes a reduction in the bias and variance of sampled data and restricts the confidence in the advice that can be given. In particular, there is potential for confounding between the monitoring methods, their measured ecological properties, and the questions they seek to answer. Australia has developed significant long-term marine monitoring and observing programs and has one of the largest marine estates, including the world's largest representative network of marine parks. This new network will require ongoing monitoring and evaluation, beyond what direct funding can support, which needs to be integrated in a standardized way with other national programs to develop sufficient monitoring capacity. The aim of this paper is to describe the process undertaken in developing a suite of field manuals that provide Standard Operating Procedures (SOPs) for marine sampling in Australian waters so that data are comparable over time and space, thereby supporting a robust, cost-effective, and objective national monitoring program. We encourage readers to refer to the complete manuals of interest at www.nespmarine.edu.au/field-manuals. We generally limit SOP development to benthic or demersal sampling, (multibeam, autonomous underwater vehicles, baited remoted underwater video (BRUV), towed imagery, grabs and box corers, sleds and trawls), with a few exceptions (e.g., pelagic BRUVs). Collaboration was a key characteristic of our approach so rather than single groups trying to impose their standards, more than 70 individuals from over 30 organizations contributed to the first version of this field manual package. We also discuss the challenges that arose while developing these national SOPs, the associated solutions that were implemented, and the plans for ensuring their long-term maintenance and national and international uptake. We anticipate that this paper will contribute to international collaborations by evoking valuable suggestions and sharing of lessons learnt from other national initiatives so that we might work toward a global ocean best practice for biological and geoscientific monitoring of the marine environment.

Keywords: multibeam, marine imaging, grab, box corer, epibenthic sled, autonomous under water vehicle, survey design, marine monitoring

INTRODUCTION

Australia has the world's third largest marine estate, characterized by vulnerable habitats with high biodiversity and a variety of endemic species extending across a wide latitudinal range (Butler et al., 2010). This marine estate is used by a range of industries including fisheries, energy, and shipping (Dunstan and Dambacher, 2019), in addition to traditional, cultural, scientific and recreational uses. Monitoring the impacts of human activities throughout this vast ocean space represents a massive shared responsibility that can only be achieved by making the best use of all available empirical information. The Commonwealth Government has recently established the Australian Marine Parks (AMPs), including 60 marine parks managed through six regional plans. This is the largest representative network of marine parks in the world, complementing existing networks in State and Territory waters (Cochrane, 2016). Australia now has a number of successful long-term marine monitoring and observing programs (e.g., GBRMPA, 2015; Stuart-Smith et al., 2017). There is also a national integrated marine observing system (Lara-Lopez et al., 2016) that incorporates an ocean data network¹ with well-established monitoring networks for the physical ocean that meet international standards and a desire to increase its biological coverage with comparable rigor (Boss et al., 2018). Without common and agreed standards for collecting marine data, the information collected will not be comparable between survey times either in the one area, or at the same time across multiple areas (Costello et al., 2017). This will reduce the value of such data over the short- and long-term for both regional and national management initiatives, marine asset inventory assessment and policy development, thereby ultimately reducing the relevance of science to decision makers and funders and *vice versa*.

Marine sampling standards have been adopted at a national scale by researchers for marine imagery classification (Althaus et al., 2015) and acoustic tracking of pelagic animals (Hoenner et al., 2018), but this had not been done on a national scale for most biological and geoscientific sampling platforms prior to the current program. A plan was therefore designed to develop, test, implement and adopt Standard Operating Procedures (SOPs) for monitoring in Australian marine waters, facilitated through an Australian Government funded national marine science collaboration².

One of the main challenges in assessing marine biodiversity is the lack of standardized approaches for monitoring (Duffy et al., 2013; Teixeira et al., 2016). Although not all sampling platforms are comparable, the overarching goal of ocean best practice in marine monitoring is to reduce the bias and variance in inference from sampled data and to reduce potential confounding that can be introduced with different sampling procedures (Albert et al., 2010). This ensures that inferred trends reflect true underlying processes at play within the observed community rather than sampling artifacts (Monk, 2014; Bates et al., 2015). If measured ecological variables (e.g., abundance,

diversity, and size) and the variation in sampling techniques are confounded, it is challenging, if not impossible, to objectively determine if observed changes are due to real ecological change or sampling technique (e.g., Goddard and Foster, 2002). If variability between sampling techniques is sufficiently high, real changes that would trigger appropriate management responses may not be detected, incorrect advice might be provided to decision-makers and the influence and opportunities for marine science, especially monitoring is reduced. The lack of effective marine environmental monitoring is recognized as a significant limitation to achieving progress against United Nations Sustainable Development Goal 14 (Oldekop et al., 2016).

The aim of this paper is to describe the process undertaken to develop a suite of field manuals that present SOPs for marine sampling so that data are comparable in time and through space, thereby supporting a robust and valuable national monitoring program. The SOPs are comprehensive rather than prescriptive, monitoring methods do not have to be identical, but they do need to be sufficiently well documented that process can be distinguished from trends during analysis, especially meta-analyses. We encourage readers to refer to the full content of the manuals at www.nespmarine.edu.au/field-manuals, as this paper focuses on the challenges that arose while developing national SOPs, the associated solutions that were implemented, and the plans for ensuring their long-term maintenance and uptake. We anticipate that this paper will contribute to international collaborations by evoking valuable suggestions and sharing of lessons learnt from other national initiatives so that we might work toward a global ocean best practice for geoscientific and biological monitoring.

DEVELOPMENT

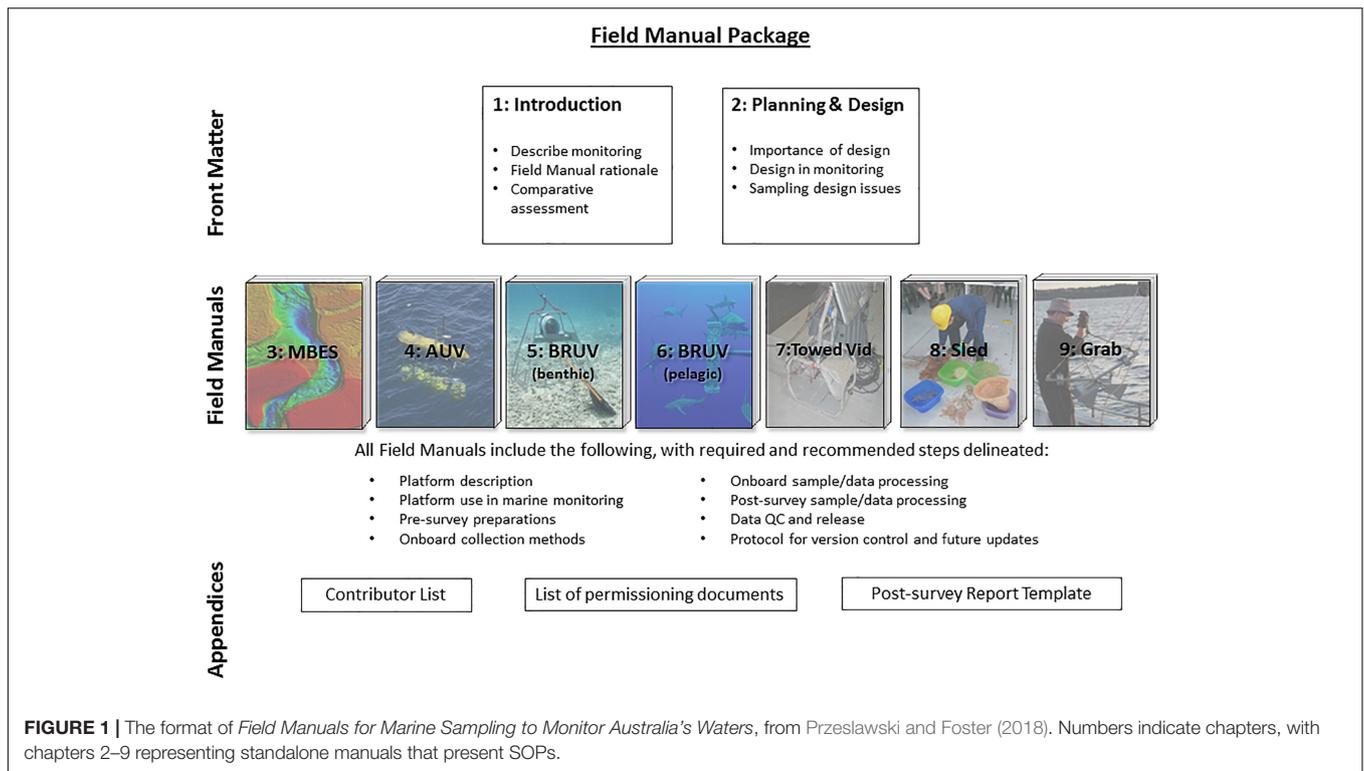
All field manuals followed the same general process of development which included three discrete stages: (i) identify the target sampling platforms, (ii) generate the content for each specific platform, (iii) and review and revise.

Identify Sampling Platforms

We identified preliminary sampling platforms for the field manuals based on their frequency of use in previous sampling and monitoring programs. An online questionnaire was used to canvas the Australian marine science community on their frequency of use and perceptions regarding each of the platforms (results presented in Przeslawski et al., 2018b). We used this information to identify seven marine sampling platforms for which we would develop SOPs (Figure 1). The developed SOPs represent a range of data targets and environments (Table 1), and each has inherent advantages and limitations (Table 2). We generally limited SOP development to benthic or demersal biological sampling, with a few exceptions [e.g., pelagic baited remote underwater video (BRUV) included as a proof-of-concept due to its similarity to benthic BRUV; water column, sedimentology, and geochemistry data included for comprehensiveness related to grabs and box corers]. During this process, it became clear that a separate manual on marine

¹ www.aodn.org.au

² www.nespmarine.edu.au



survey design was crucial to ensure that resulting data are appropriate for the research question, representative to facilitate population-level generalizations, and information-rich to reduce uncertainty (Figure 1).

Generate Content

In recognition of the multiple disciplines captured by the field manuals, we compartmentalized the project by allocating working group coordinators to each field manual. Working group coordinators had extensive field and analytical experience related to their respective platforms or topics and were therefore well-placed to invite potential collaborators and consider disparate opinions. Coordinators were responsible for forming their associated working group, developing content with this group, and liaising with the editors to keep the field manual within scope and on time. Using this approach, we made sure that each chapter was written in an appropriate style for the target

audience and contained the relevant information for performing the specific sampling tasks.

The Marine Sampling Field Manuals do not mandate the use of a particular sampling platform, supporting previous recognition that a top-down, one-size-fits-all approach to monitoring is unlikely to be effective in systems with large environmental variability (Fancy et al., 2009; Woodall et al., 2018). For a comparative assessment of benthic and pelagic sampling platforms, we refer readers to Przeslawski et al. (2018a); Bouchet et al. (2018), respectively. Rather, the field manuals focus on data acquisition and post-processing including data management (including quality control and post-processing), particularly as applied to marine monitoring. Standardization of sampling designs is also important and is accordingly addressed as a separate chapter. Data analysis and reporting are generally not included in the field manuals, although we direct users to useful methods or resources within each manual.

TABLE 1 | Summary of prioritized benthic sampling platforms and their acquisition targets, from Przeslawski and Foster (2018).

	Data type	Data target	Spatial coverage	Environment
MBES	Bathymetry, backscatter	Seafloor	Continuous	All
AUV	Imagery	Epibiota ¹	Continuous	All
BRUV	Imagery	Demersal and Pelagic fish ¹	Point/transect (qualitative)	All
Towed	Imagery	Epibiota ¹	Transect	All
Grab/Boxcore	Biological and sediment samples	Macrofauna, infauna, sediments	Point	Unconsolidated substrate
Sled/Trawl	Biological and sediment samples	Megafauna, epifauna	Transect (qualitative)	Consolidated substrate

MBES, multibeam echosounder; AUV, autonomous underwater vehicle; BRUV, baited remote underwater video. ¹Substrate, relief, and habitat information can also be extracted from imagery, but this is usually a secondary data target.

TABLE 2 | Advantages of prioritized benthic sampling platforms, from Przeslawski and Foster (2018).

	MBES	AUV	BRUV	Towed	Grab/Boxcore	Sled/Trawl
Continuous (i.e., grid) broad-scale spatial coverage	X					
Continuous (i.e., grid) fine-scale spatial coverage		X				
Non-extractive	X	X	X	X		
Able to revisit exact location (repeatability)	X	X				
Able to sample over variety of environments	X	X	X	X		
Species-level identifications ¹					X	X
Genetic, morphological etc., analysis possible					X	X
Behavior observed			X	X		
Cryptofauna included					X	X
Quantitative	X	X	X	X	X	
Concurrent physical and biological data		X		X	X	
Minimal technical expertise			X	X	X	X
Vessel flexibility			X	X	X	

¹ Refers to identifications able to be made with unknown or cryptic species (i.e., well-known, distinctive species can be identified via imagery).

Overall, these field manuals are meant to cover the foundational steps and key considerations, with agency- and gear-specific SOPs supplemented as needed by individual researchers. Detailed and gear-specific SOPs are outside the scope of this field manual package due to the large number of existing SOPs and the variety of gear currently employed by researchers. In this first version of the field manuals, it is impractical that researchers would agree on detailed SOPs (and associated gear). Rather, we developed the manuals with the intension of reaching a consensus about as many issues as possible, while noting discrepancies. The reporting requirements for using the SOPs record the individual differences of the approaches so that they can then be assessed in future analyses, and issues can then be addressed when they contribute to large amounts of variation in the data. Wherever possible, however, we have mandated or recommended specifications (e.g., imagery resolution) that should be used in future equipment upgrades or purchases.

Further summaries of the content of each manual are given in the **Supplementary Material**.

Review and Revise

The editors and working group coordinators managed the review process, which required at least one external reviewer for each chapter, as well as several others who assessed the entire package. In some cases, reviewers voluntarily provided such extensive contributions that they will be included as co-authors in the next version of the field manuals.

Ultimately, over 70 individuals from more than 30 organizations contributed to the field manual package. By engaging researchers, managers, and technicians from multiple agencies with a variety of experience, sea time, and subject matter expertise, we strove to ensure the field manuals represented an accurate and comprehensive cross-section of the broader marine science community of Australia. This not only improved the content but also increased the potential for adoption of the SOPs across multiple agencies and monitoring programs. Further details on the development of the field manuals are discussed below as they relate to particular challenges.

CHALLENGES

Establishing Scope

Establishing, justifying and communicating the scope of the field manuals were essential to expedite development, manage expectations, and distinguish from previous SOPs. The initial project scope included benthic biological sampling platforms relevant to monitoring. During content development, detailed and gear-specific SOPs (e.g., Smith MacIntyre grab, brand name systems) were assessed for inclusion in the field manuals. Ultimately, these were determined to be outside the scope of this field manual package due to the large number of existing SOPs and the variety of equipment currently employed by researchers. It was deemed impractical that researchers would agree on detailed SOPs (and associated gear) in this first version of the field manuals. Rather, we strove to reach a consensus about as many aspects as possible, while noting the differences due to agency- and gear-specific needs. These differences can then be assessed in the future (e.g., they may not correspond to large amounts of variation in data), and addressed if need be. Wherever possible, however, we have mandated or recommended specifications (e.g., imagery resolution) that should be used in future equipment upgrades or purchases.

Reaching Consensus

One of the strengths of these field manuals is the large number of collaborators involved, but this also proved to be one of the greatest challenges regarding reaching a consensus. The content development stage included ample opportunities for dissenting views to be presented to the whole group, with subsequent discussion and debate encouraged. These open forums ensured that the working group clearly justified the methods that were eventually advocated in the field manuals. In the few cases where agreement did not occur, the decisions were made by the working group coordinator and editors, who again provided a rationale for their choice.

The review process also proved valuable in reaching consensus. Reviewers noted when they disagreed with a

recommendation or didn't understand the underlying rationale. In these cases, the lead author or editors were able to take these comments back to the working group to further refine the SOPs or associated text in the field manuals.

Promoting Data Discoverability and Accessibility

All field manuals, excluding the manual on survey design, include a section titled "Data Release," which describes ways to ensure public discoverability and accessibility of collected data, thereby abiding by the FAIR (findable, accessible, interoperable, reusable) principles (Wilkinson et al., 2016). We recognize that in the first version these sections do not provide a clear national standard and instead refer to anticipated improvements in subsequent versions. This vagueness is due to the current lack of established national data infrastructure able to incorporate appropriate or comprehensive information produced from the sampling platforms. For example, Squidle+³ and GlobalArchive⁴ are currently recommended in the field manuals as the national platforms to ensure discoverability and accessibility of marine imagery, but the platforms currently have no long-term support and other platforms are being used that have potential to achieve similar discoverability and accessibility goals (e.g., Benthobox⁵). Similarly, species occurrence data from sled-collected specimens eventually appears on the Atlas of Living Australia⁶ or Ocean Biogeographic Information System⁷, but this is an often circuitous route through museums and very rarely includes species absence or sampling effort information crucial for ecological and monitoring purposes (but see Coro et al., 2016 for a statistical method to estimate marine species absences from OBIS).

To meet these challenges related to data discoverability and accessibility, a series of workshops were held in the months following the field manuals release (July – September 2018), including focused workshops on bathymetry data, marine imagery, and biological specimen data. The bathymetry data release protocols will depend on new digital infrastructure being scoped as part of the AusSeabed program⁸. In contrast, marine imagery and biological specimen data are linked to the existing platforms mentioned above so priorities are to establish appropriate workflows linking these platforms with the data collection phase, and to find the resources needed to ensure they can be developed and maintained.

Ensuring Uptake

The uptake of the SOPs described by the field manuals was a concern for two reasons. Firstly, agency-specific sampling protocols are integral to several ongoing monitoring programs (e.g., the Long-Term Monitoring Program of the Australian Institute of Marine Science in De'ath et al., 2012), and attempts

to alter or change methods associated with these may jeopardize data comparability. Secondly, switching to a new protocol may be costly and laborious, making individuals or agencies unwilling or unable to adapt. These challenges meant the field manuals had to balance being overly prescriptive (such that people prefer to follow their own protocol and ignore the manuals) and overly flexible (such that data are not consistent and therefore not comparable). A collaborative approach to developing the manuals was therefore paramount, and to that end, representatives from agencies involved in ongoing monitoring programs, including marine managers from all Australian states and territories, were engaged. This ensured that methods could accommodate existing programs and differences were clearly explained in relation to marine monitoring in state and Commonwealth waters.

Nonetheless, challenges remain with promoting uptake in certain sectors, namely private consultancies and the petroleum industry. These sectors are often strongly linked, with consultants engaged by industry to undertake various environmental characterisations and impact assessments, each of which uses their own methods (Gray et al., 1999). We accentuated the commercial value to industry in adopting standards, including access to larger spatial and temporal range of comparable data to provide regional context to potentially impacted locations, and this has been promoted by the national offshore petroleum regulator (NOPSEMA, 2018). However, this premise depends on the sharing of data (e.g., Marine Data Exchange in ocean renewable industry). This has proven challenging to implement among the petroleum industry in Australia, although there have been some efforts for meta-data sharing through the Industry-government Environmental Meta-database (IGEM) by the Western Australian Marine Science Institution.

Field manuals were released and promoted on the Marine Biodiversity Hub⁹, an Australian Government-funded collaboration of marine research institutions with a mandate to improve provision of marine biodiversity information nationally. During release and promotions, we emphasized that the current package of field manuals is not meant to immediately replace most existing protocols, but rather to complement them for national monitoring purposes. At the same time, we hope that marine monitoring programs will also identify opportunities to adjust current practices to increase national consistency, and that the SOPs will provide an opportunity for industry and industry consultants to contribute to national monitoring through standardizing their ongoing activities.

Promoting International Relevance

The SOPs were developed for use in Australia's Exclusive Economic Zone, but due to the diversity of habitats and communities included in this area, they are applicable to other oceanic regions. The SOPs have been made available internationally through the Ocean Best Practice portal¹⁰; however, it is clear that further work will be required to promote international uptake. Discussions have been held

³www.squidle.org

⁴www.globalarchive.org

⁵https://benthobox.com

⁶www.ala.org.au

⁷www.obis.org.au

⁸www.ausseabed.gov.au

⁹www.nespmarine.edu.au

¹⁰www.oceanbestpractices.org

with the IOC-UNESCO Global Ocean Observing System on how these SOPs can support global monitoring through the Essential Ocean Variables (Miloslavich et al., 2018), and they have been made available to the Group on Earth Observations Biodiversity Observation Networks' "Biodiversity Observation in a BOX" (boninabox.geobon.org). Further coordination of the global marine community is essential if the results of monitoring are to have the impact that is needed to inform the diverse set of international conventions, agreements and products including (to name just 4 out of more than 20), the Convention on Biological Diversity's Aichi Targets, the United Nations (UN) Sustainable Development Goals, the second UN World Ocean Assessment, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services regional assessments. At present, many of these agreements rely on indicators derived from highly aggregated data that poorly reflects management outcomes. This is a symptom of both a lack of monitoring capacity, especially in the developing countries, but also the lack of marine scientists working together globally to emphasize their common message. SOPs are one way to start increasing the relevance of marine science to the global decision-making community.

FUTURE DIRECTIONS

For the potential of these field manuals to be fully realized, they must be maintained, updated, and their use and impact measured. In the immediate future, version 2 of all manuals will be released in 2019. At the moment, potential users should contact the lead author of this paper for further information, but in the next version of manuals we anticipate that a general contact point or help desk will be created. Review cycles beyond the development of Version 2 have yet to be developed. A plan for long-term maintenance will ensure that the field manuals remain accessible and topical. The latter point is particularly applicable to sampling platforms that are technologically complex (e.g., autonomous underwater vehicles) or new, but even platforms that have been established for decades (e.g., sleds, trawls, grabs, and box corers) may require periodic updates related to data release as digital infrastructure continues to evolve and our understanding of new areas such as microplastics, the microbial community or e-DNA become sufficiently mature for regular monitoring. Major updates must be documented in each new version with appropriate version control. One of the main actions needed to ensure longevity of the field manuals is the establishment of an oversight committee that can provide long-term and multi-institutional support. This responsibility will be further explored with Australia's National Marine Science Committee and its associated working groups.

Measuring the impact of SOPs can help inform future versions, identify gaps or problems, and ensure future support and funding. In recognition of the importance of this task, the original Marine Biodiversity Hub project has been extended with a milestone focused on assessing uptake and impact. Formal impact assessment frameworks such as CSIRO's Impact Evaluation Guide (CSIRO, 2015) will be scoped, as well as

informal assessments stemming from an online questionnaire and periodic literature searches.

We anticipate that the national standards for marine sampling developed here may either be adapted for use in countries without national SOPs or mapped to SOPs in countries that have already developed them (e.g., Joint Nature Conservation Committee in Burns et al., 2018), thus contributing to globally consistent datasets. The ocean observing community is rapidly moving toward globally consistent standards (Bax et al., 2018), but the biological community and the marine benthic sampling community in particular have been constrained to regional or national efforts. This is due to the fine-scale biogeography of many benthic communities and the need for tailored sampling and analyses among different habitats, as well as the technological capacity and scientific development in different countries. SOPs are urgently needed to increase the impact of marine science on global policy and decisions. The UN Decade of Ocean Science for Sustainable Development includes improved marine monitoring as one of its key objectives to support Agenda 2030 (Visbeck, 2018). We hope that the process of SOP development described in the current paper, as well as the SOPs themselves, can provide the start of a discussion that marine biologists need to have to maximize our impact in the next decade.

AUTHOR CONTRIBUTIONS

All authors lead or significantly contributed to the development of one or more of the of the field manuals upon which this manuscript is based. All authors contributed to the writing of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2019.00177/full#supplementary-material>

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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