CoNCENSUS: Are global indicators of COastal and Nearshore benthic fish assemblage status in agreement if derived from disparate visual CENSUS techniques?

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1 Summary

Fish are essential components of coastal and nearshore benthic ecosystems, and provide nutrition and livelihoods for millions of people. Yet, they are threatened by climate change and anthropogenic impacts that compromise ecosystem functioning and undermine service provision. To improve our understanding of the role fish play in ecosystems and the impacts of current threats, global scale datasets are required as they can distinguish local and regional phenomena from the global context. Research on coastal and nearshore benthic fish is common, but typically carried out in isolation with limited standardisation in sampling methods and approaches among projects and organisations. Due to methodological bias, the lack of standardisation compromises the ability to merge datasets and investigate regional or global scales questions. To identify the extent of this problem, we propose a SCOR Working Group that will determine the interoperability of data collected by different methods and investigate solutions to mitigate the effects of sampling method on our understanding of the status of coastal and nearshore benthic fish assemblages and the processes structuring them. To overcome this problem, we will establish standardised best practice guidelines, and provide recommendations on how best to utilise data to address scientific questions of local and global importance. Furthermore, the Working Group will develop workflows for the management, publication and visualisation of open-access data. In achieving this, we will lay the foundation for relevant and sustained research that encourages capacity development, furthers our fundamental understanding of coastal benthic ecosystems and provides essential support for policy and decision makers.

2 Scientific background and rationale

2.1 Research history and methods

The proximity of coastal and nearshore ecosystems to land has facilitated extensive research on benthic fish assemblages. This has advanced our understanding of their functioning (1-3), value (4, 5), vulnerability (6-8) and resilience (9, 10). Many of the recent advances have come from the use of global scale datasets, as they allow unprecedented opportunities to distinguish local and regional phenomena from the global context. However, the bulk of the research in these ecosystems has taken place in isolation with limited standardisation among different studies or locations.

A variety of methods has been used to census benthic fishes (11). This includes destructive techniques, such as trawling and line-fishing, with data obtained either from fisheries or independently through research organisations. Nowadays, non-destructive techniques are preferred, due partly to availability of technology (such as SCUBA, remotely operated video cameras and environmental DNA) and reduced costs (12-13), but also greater awareness of research impacts, and the need to limit further damage to severely degraded areas and maintain conditions in protected areas (14). The ecosystem-based approaches to biodiversity and fisheries management have increased the need for ecosystem-level knowledge (15), rather than only species or component level, and this has favoured methods that can sample multiple components of an ecosystem simultaneously. The most widely applied methods that meet these requirements are SCUBA based underwater visual census (UVC), diver operated video (DOV) and baited remote underwater video systems (BRUVs). With technological advances, these methods have become affordable and available throughout the world. The techniques are fundamentally different, but all rely on visual census (either *in situ* or from videos) to measure fish diversity, abundance and size structure, and collect ancillary data on habitat characteristics. Decisions on which method and sampling approach to use are typically based on equipment availability and research expertise, both of which vary among organisations (16). Consequently, there is large variability in the methods chosen, and sampling approaches followed among research programmes. It is widely accepted that data collected with different methods and sampling approaches are not always directly comparable, due to differences in the species detected, areas covered and methods for estimating species abundance and biomass (11). This jeopardises the potential to combine data from different programmes to address larger scale research questions (16).

There are, however, several examples of well-coordinated global research programmes collecting comparable data (e.g. Reef Life Survey, Global FinPrint) that have led to significant high-profile research outputs (e.g. 17-20). There are also examples at the regional level in the Long-Term Ecological Research and Marine Protected Area Networks. The global Marine Biodiversity Observation Network (MBON) and the Global Ocean Observing System Biology and Ecosystem Panel (GOOS BioEco) work through broad global partnerships to ensure relevant research and observations inform sustainable use and protection of marine resources. Such centrally coordinated research programmes lay the ideal foundation to address global scale research questions. However, due to their scale, they are typically not replicated frequently though time. This reduces their ability to provide up-to-date data to address research or management challenges (21).

Global programmes only constitute a small fraction of the data collected in nearshore and coastal environments. Greater levels of standardisation among the many diverse local research programmes could drastically increase the spatial coverage, volume and frequency of data being contributed to a global observation network. To achieve this, we need to better understand the synergies and scope of data, identify and agree on minimum levels of methodological standardisation and develop data schema and vocabularies that ensure synergistic aggregation, availability and persistence of data. In achieving this, we will significantly improve the spatial and temporal resolution of the data and frequency at which it can be used for global science questions and reporting.

2.2 Indicators and the need for standardised global networks

Across all continental margins, the important services provided by coastal and nearshore benthic fish and their ecosystems are being compromised by anthropogenic disturbances (6). Global initiatives, such as the Convention on Biological Diversity strategic plan for Biodiversity, and the United Nations Sustainable Development Goals, Decade of Ocean Science for Sustainable Development and Decade of Ecosystem Restoration, provide opportunities to improve management and reduce impacts on ecosystem functioning. However, the success of these global initiatives hinges on identifying essential variables that are standardised, scalable and indicative of ecosystem or population state (21-23).

Many indicators have been used to report the status and vulnerability of fish populations and diversity (24, 25). However, indicators of ecosystem and assemblage status that are applicable at a global scale have typically been developed from data collected by a specific method. For example, the Large Reef Fish Indicator and Reef Fish Thermal Index (https://www.bipindicators.net/) are indicators specific to the UVC method (26). Their precision and sensitivity if calculated using other methods are unknown. Due to inherent biases and strengths associated with a particular method (11), our understanding of the information that the indicator conveys may not be valid when using different methods. More general indicators, based on diversity, total abundance or biomass data, may be possible to report on for a larger range of methods, but may not respond as predictably or sensitively to pressures, and the responses may still heavily depend on the method and spatial scale of sampling. Thus, targeted research is required to investigate the trade-offs between the sensitivity and information content provided by the most promising indicators and their applicability to data collected using different methods, over different spatial scales.

2.3 The challenge

To advance our ability to address scientific hypotheses on the dynamics and status of coastal benthic fish assemblages, we need to determine the extent to which datasets collected with a consistent method, but inconsistent sampling approaches, can be merged to expand the spatial and temporal coverage. Furthermore, to accommodate the use of different methods, there is a need to determine which indicators of population, assemblage or ecosystem state are robust to differences in sampling equipment or can be used in metadata analyses to address broader questions.

The goals of the CoNCENSUS Working Group (WG) are thus to build a community that addresses this challenge and advances standardisation within the different sampling techniques, provides direction on how to collectively use data from the different methods to enable scientifically robust research over various spatial scales, and develops infrastructure and workflows for the management and publication of open-access data.

In achieving these goals, we will lay the foundation for relevant and sustained research that encourages capacity development, furthers our fundamental understanding of coastal benthic ecosystems and provides essential support for policy and decision makers.

2.4 Why is SCOR the appropriate platform?

The CoNCENSUS WG will be an international collaboration focussed on solving methodological and conceptual problems that hinder research in an area of critical importance to marine biodiversity and the blue economy. A constraint on the degree to which biological data are used to address global scale questions, or report progress against agreed international goals, is a lack of consistency in data collection and limited publication of open-access data onto platforms, such as the Ocean Biogeographic Information System (OBIS). The CoNCENSUS WG will establish standardised best practice guidelines, determine the scope and interoperability of data and provide guidance on how best to utilise data from the UVC, BRUV and DOV sampling methods to address scientific questions of local and global importance. Furthermore, the WG will develop workflows for the management, publication and visualisation of open-access data. In doing this, CoNCENSUS will contribute significantly to capacity development and contribute towards other projects and initiatives implemented by the United Nations, GOOS, Partnership for Observation of the Global Ocean and Group on Earth Observation, including MBON and Blue Planet.

3 Terms of Reference

1: Determine the extent to which data obtained from different methods (UVC, DOV and BRUVs) and sampling approaches can be used in conjunction to measure and report on the status of coastal and nearshore benthic fish assemblages at a global scale. This will be achieved by identifying and analysing appropriate data sources to compare trends in indicators against known drivers of ecological condition, and by exploring solutions to mitigate the effects of sampling method and approach.

2: Endorse and, where necessary, publish best practice guidelines for ethics (including CARE principals for indigenous data governance), survey design, sampling techniques, data analysis and archival, and agree on a common base level of data and metadata collection required to enable data to be comparable, useful for reporting on key indicators and reusable in the future.

3: Develop data schema and vocabularies relevant to the visual census techniques, establish and implement data management protocols aligned with FAIR (Findable, Accessible, Interoperable, Reusable) and open-access principles, and establish infrastructure and workflows for open-access data to be published on OBIS and dedicated web-based platforms.

4: Determine priority areas and methods for engagement, capacity development and research to enhance coverage and strengthen the global network by carrying out a gap analysis on the appropriate data sources and peer-reviewed published literature.

5: Establish a global community of practice willing to employ the agreed minimum methods in programmes with demonstrated sustainability, and who are willing to share data through the agreed workflow and web-based platforms.

4 Working plan

4.1 TOR 1: Determining the extent of interoperability for data from different methods.

TOR 1 forms the basis of the WG and will underpin the strong and sustained collaboration. The WG is comprised of key members that can provide data and have expertise in data management, analysis, ecological theory and global policy requirements. To achieve this TOR, the following activities will be undertaken:

i. Identify suitable datasets and merge into a data framework permitting preliminary exploratory analyses. Work on the development of data schema and common vocabularies for the data, based on Darwin Core Standards to feed into TOR 3.
ii. Agree on detailed scope of research questions based on properties of available data. Additional research questions may emerge from this process and will be explored.
iii. Identify a suite of indicators that measure the status of the fish assemblages and, where applicable develop new indicators that best accommodate variable data sources and sampling methods.
iv. Run analyses and draft manuscripts for peer-reviewed publication.

4.2 TOR 2: Development of minimum data standards and best practice guidelines for measuring indicators.

Fundamental to the WG is agreement on the most appropriate methods and sampling approaches, as well as the minimum resolution of biodiversity data and metadata, required to meaningfully report on indicators of assemblage status. Considerations relating to ethics and indigenous data co-management will be incorporated into the best practices. The required activities are to:

i. Agree on the optimal and minimum requirements for sampling.
ii. Identify and/or develop best practice guidelines for the methods to carry out visual census research, and analyse and report on the findings.
iii. Distribute guidelines for external review by the broader research community.
iv. Publish the endorsed guidelines on the Oceans Best Practices website.

4.3 TOR 3: Establish and implement a data management policy.

i. Agree on the minimum standards, data schema and vocabularies for metadata and biodiversity data in accordance with Darwin Core standard and FAIR principals to ensure interoperability and persistence of data.
ii. Engage with OBIS staff and relevant national-level biodiversity information managers to develop workflows that enable the seamless publication of data into OBIS via integrated publishing toolkits, to create an enabling environment for data discovery and access.
iii. Identify and utilise established web-based applications (e.g. Reef Life Survey), and/or enable the expansion of existing systems (e.g. Global Archive) that allow discovery and automatic modelling and visualisation of the data to maximise the value for scientists, managers and policymakers.

4.4 TOR 4: Develop a roadmap to address the gaps in the coverage of methods and data.

Mapping a way forward to expand the potential global coverage and relevance of data collected is critical to advancing a coordinated and global approach to the visual census of benthic ecosystems. Here we will:

i. Determine the spatial extent of data coverage and identify priority gaps where capacity development can be implemented, and identify programmes that with minor changes to protocols could contribute data.

ii. Provide direction for future research by producing a systematic review of peer-reviewed literature demonstrating the broader research coverage within the field, primary research questions and priority research gaps.
iii. Draft a strategic plan to strengthen the global network and tackle priority areas for engagement, capacity development and research.

4.5 TOR 5: Establish a global community of practice.

The formation of the WG with the proposed TOR and capacity development will represent the foundation of the community of practice. Through the provision of best practice resources, capacity development and open-access data, the network will create an open, productive and enabling environment that encourages participation. This will assist in generating sustainability and long-term participation in and benefits from the WG after the completion of this project.

4.6 Timeline

The project will run over three years with a WG meeting held each year. The first two meetings will coincide with international or regional conferences (e.g. North Pacific Marine Science Meetings Western Indian Ocean Marine Science Symposium, Temperate Reef Symposium, GEO Blue Planet Symposium). The third WG meeting will take place at a location identified as critical for capacity development, and will be followed by a training workshop. Regular online meetings will be held to review progress and identify areas that need additional capacity.

Months 1-6: Key members to identify and prepare datasets to be used for TOR 1, to streamline the initial activities at the kick-off meeting.

Month 6: *Kick-off meeting* – Review TOR and further develop activities required to meet TOR; Assign leads and subgroups for each TOR. Assign co-leads (either early-career or post-graduate students) for each TOR to facilitate capacity development within the WG. Determine the detailed scope and questions that can be achieved under TOR 1 and determine a way forward to prepare the datasets for analysis. WG will agree on the optimal and minimum standards for sampling and data management required for TOR 2 and 3 and establish workplans.

Months 6-18: Subgroups for TOR 1 and 3 to work together on completing the dataset, run preliminary analyses and drafting a data schema and workflow. Subgroup working on TOR 3 to engage with OBIS and local biodiversity information managers. Subgroup working on TOR 2 to identify existing best practices and draft a framework for further guideline development.

Month 18: *2nd WG meeting* – Subgroups to report on progress and plans, with discussions on the best way forward. The conceptual structure of the roadmap document (TOR 4) and the community of practice (TOR 5) to be decided.

Months 19-30: Subgroup working on TOR 1 to complete analysis and produce a draft manuscript for WG review. Subgroup working on TOR 2 and 3 to have completed the work required to meet the TORs prior to the 3rd WG meeting. Subgroup working on TOR 4 to determine the data spatial coverage and produce a draft systematic review for review by WG.

Month 30: *3rd WG meeting* – Discuss draft manuscript (TOR 1) and the completed products for TOR 2 and 3. Subgroup working on TOR 4 to present progress with the systematic review and roadmap. WG to critically review the outcomes of all TOR and identify areas of success, shortcoming and future opportunities. Determine a plan to engage the broader community within the community of practice (TOR 5) and work towards continuation.

Months 31-36: Manuscript from TOR 1 and 4 submitted for peer-review, endorsed best-practice guidelines available on the Ocean Best Practice (OBPS) website and data published on OBIS and visible on selected web-based applications. Subgroup working on TOR 4 to complete roadmap document.

Month 36: All products to be complete.

5 Deliverables

(1) Open-access peer-reviewed paper testing the level of agreement in trends of key ecological indicators when calculated using data from different sampling methods.
(2) Endorsed best practice guidelines for methods (including standardized vocabularies) and data management published on the Ocean Best Practices (OBPS) website.
(3) Open-access data available on OBIS, and RLS and Global Archive.
(4) An open-access peer-reviewed global systematic-review of the status and trends of coastal benthic fish assemblages, identifying priority research gaps and future directions.
(5) Roadmap document on the vision and priority areas for capacity development and research within coastal and nearshore benthic environments.

6 Capacity Building

Capacity building will be coordinated through three key areas: internal capacity building will focus on skills transfer within the WG; focussed training activities will be provided to researchers outside the WG; and open-access resources will be published to enable independent learning and self-development.

The WG is a mixture of established and emerging researchers from diverse backgrounds and disciplines. As far as possible, the established researchers leading the TORs will be paired with emerging researchers to facilitate knowledge transfer. Where possible, group members will allow senior post-graduate students (PhD or post-docs) to participate in the WG activities, and provisions will be made to allow students to incorporate components of the WG TOR into their research theses and lead resulting publications.

The WG will develop training materials (including video and printed tutorials) and host them on open-access web-based platforms. We will work with the Ocean Teacher Global Academy (OTGA) of the International Oceanographic Data and Information Exchange (IODE) to formalise the training materials, and get support to provide training at regional training centres; we will also explore opportunities to co-locate trainings with MBON regional workshops towards integration of these approaches in global MBON, and at Blue Planet meetings and symposia. The third WG meeting is planned to take place at a location identified as critical for capacity development, and a focussed training course will be provided to relevant stakeholders at this site. In addition, the WG will actively apply for funding from national (e.g. Knowledge Interchange and Collaboration grants, South Africa), regional (e.g. WIOMSA MASMA Grants for Workshops and Training Courses) and international (e.g. SCOR visiting scholar) bodies to provide training to advance capacity and grow the global network.

WG members include researchers actively engaged with the GOOS Biology and Ecosystems Panel, the POGO Biological Observations Working Group, GEOBON MBON, MarineGEO and the IOC Ocean Best Practice portal. Standards and procedures developed as part of this WG inform these groups and become part of their ongoing research and monitoring infrastructure.

Finally, the establishment of a community of practice, agreement and publication of best-practice guidelines, development of on-line training materials, open-access data and web-based applications to visualise the data will all enable independent learning and research.

7 Working group composition

Our working group includes ten full members (5 female, 5 male) covering a range of careers stages and representing eight countries. All members have appropriate experience in the study of benthic fishes using UVC, DOV and BRUVs. In addition, the member have expertise in method development, data management, global indicators, data analysis, management, policy and education. The diverse range of stills and experiences will ensure the WG achieve its OR.

7.1 Full members

Name	**Gender**	**Place of work**	**Expertise**
Anthony Bernard (co-chair)	M	South African Institute for Aquatic Biodiversity, *South Africa*	Marine ecology and conservation, stereo-BRUVs
Rick Stuart-Smith (co-chair)	M	University of Tasmania, *Australia*	UVC, Reef Life Survey, global indicators
Rene Abesamis	M	Silliman University, *Philippines*	Coral reef ecology and conservation
Emily Darling	F	Wildlife Conservation Society, *United States of America*	Coral Reefs, Conservation, Climate Refuges, Social-Ecological Systems
Jordan Goetze	M	Department of Biodiversity Conservation and Attractions (DBCA), Western Australia, *Australia*	Field surveys with Stereo-BRUVs/DOVs, UVC; Global FinPrint, Global Archive
Aaron MacNeil	M	Dalhousie University, *Canada*	Bayesian data analysis, reef ecology, fisheries
Eva Maire	F	Lancaster University, *England*	Socio-ecology, conservation, functional ecology
Ana Carolina Mazzuco	F	Universidade Federal do Espiritu Santo, *Brazil*	Biodiversity data management and marine ecology
Christy Pattengill-Semmens	F	REEF, *USA*	Marine biology, citizen science, education
Melita Samoilys	F	CORDIO East Africa, *Kenya*	Coral reef ecology, management and fisheries

7.2 Associate members

Name	Gender	Place of work	Expertise
Rusty Brainard	M	King Abdullah University of Science and Technology (KAUST), *Saudi Arabia*	Coral Reef Ecosystems, Climate Change, Ocean Acidification, Fisheries, Biodiversity
Pascale Chabanet	F	French Institute of Research for sustainable Development (IRD), *Reunion Island*	Coral reef ecology, extensive field experience with UVC and video for fish census
Emmett Duffy	M	Smithsonian Institution, *USA*	Marine ecology and Biodiversity, Co-lead on C-GRASS SCOR working group
Reiji Masuda	M	Maizuru Fisheries Research Station of Kyoto University, *Japan*	Subtidal fish ecology, fish behaviour, UVC long term-monitoring
Peter Mitchel	M	Centre for Environment Fisheries and Aquaculture Science, *England*	Marine ecologist, specialising in mapping benthic habitats and fish assemblages.
David Obura	M	CORDIO East Africa, *Kenya*	Coral reef resilience, biogeography, management and policy.
Alejandro Perez-Matus	M	Pontificia Universidad Católica de Chile, *Chile*	Fish and kelp ecology. Field experience in UVC and BRUVS.
Fernanda Rolim	F	São Paulo State University, *Brazil*	Marine ecology and management
Peter Walsh	M	University of Tasmania, *Australia*	Marine and terrestrial biodiversity data management and information systems.

8 Working group contributions

Rene Abesamis is a marine biologist with more than 20 years experience in coral reef ecology and conservation. He is part of a wide network of UVC practitioners in the Philippines – the global epicentre of fish biodiversity. He advocates for more extensive use of BRUV in this network.

Anthony Bernard is a marine biologist focussing on the ecology and conservation of rocky and coral reef ecosystems in the Western Indian Ocean (WIO). He manages the stereo-BRUVs Platform at

SAIAB, which supports research projects in the WIO, and is a member of the GOOS Biology and Ecosystems panel.

Emily Darling is a Conservation Scientist with the Wildlife Conservation Society, where she leads a global coral reef monitoring program to investigate how tropical coral reefs are changing in the face of our climate crisis. She is passionate about collaborative big data to reveal new solutions for coral reef conservation.

Jordan Goetze is an early career researcher, with experience describing and comparing the methods proposed here, as well as storing and synthesising such data over global/continental scales. He has assisted in the development of GlobalArchive and worked across nine countries as a part of the Global FinPrint project.

Aaron MacNeil is a marine biologist with interests in integrating datasets to address fisheries conservation and management problems, from small to global scales. He is Associate Professor and Canada Research Chair in Fisheries Ecology, leading a 10-person team in the Integrated Fisheries Lab at Dalhousie University, with research covering sharks, coral reefs, and small-scale fisheries around the world.

Eva Maire is a marine ecologist exploring how humans affect the dynamics of coral reef systems and the structure of fish communities using both ecological and social-ecological approaches in the Indian Ocean and globally. She is experienced in using data from both UVC and BRUVs from across the world.

Ana Carolina Mazzuco is an early career researcher at the Universidade Federal of Espírito Santo, who is leading the ILTER data acquisition, curation, and scientific outputs. She has experience in biological oceanography, data science, and research management. She also collaborates as Data Manager for the Ocean Biogeographic Information System Brazil Node and is a member of the MBON Pole to Pole.

Christy Pattengill-Semmens is a marine biologist whose work as Executive Director of Reef Environmental Education Foundation (REEF) intersects citizen science, data management, education, and conservation. She oversees all aspects of REEF's Volunteer Fish Survey Project, one of the longest-running and largest marine life sightings programs.

Melita Samoilys is a co-Director of CORDIO East Africa. She has worked in coral reef and fisheries research, management and conservation in East Africa, elsewhere in the Indian Ocean and also in the Pacific and Red Sea. She is a member of three IUCN Species Specialist Groups - Groupers and Wrasses, Shark, Snapper Seabream and Grunt.

Rick Stuart-Smith is a field ecologist with interests that include identifying the most informative biodiversity indicators for reporting on ecological state of reefs at global scales. He is co-founder and president of Reef Life Survey, which uses standardised visual census methods on tropical coral and temperate reefs, with open-access data.

9 Relationship to other international programmes and SCOR working groups

9.1 Other SCOR working groups

The TOR proposed for the CoNCENSUS WG align and can contribute to TOR proposed for the DeepSeaDecade WG (WG 159). We have already initiated contact with WG member (Dr Kerry Sink) begin this process. The work developing best-practices and data management systems done by the C-GRASS WG (WG 158) can provide a starting point for the CoNCENSUS WG to address TORs 2 and 3. The co-lead of the C-GRASS WG, Emmett Duffy, is an associate member of the CoNCENSUS WG will provide support, in this regard.

9.2 GOOS, POGO and MBON

The GOOS Biology and Ecosystem panel, the MBON and the POGO Biological Observation task force operate synergistically within the space of global biodiversity observing systems, and aim to strengthen coordination and monitoring of essential variables for reporting on the status of biodiversity and ecosystems by defining appropriate indicators, and developing tools and capacity to measure and report on the indicators. The proposed TOR for this WG will directly benefit these programmes and advance their high-level objectives. Members of the CoNCENSUS WG, Anthony Bernard, Rick Stuart-Smith, David Obura and Emmett Duffy, work closely with these programmes and will ensure the WG activities are embedded in their goals.

10 Key references

1. Mourier J, Maynard J, Parravicini V, Ballesta L, Clua E, Domeier ML, Planes S (2016) Extreme inverted trophic pyramid of reef sharks supported by spawning groupers. *Current Biology*, 26: 2011-2016.
2. Darling ES, Graham NAJ, Januchowski-Hartley FA, Nash KL, Pratchett MS, Wilson SK (2017) Relationships between structural complexity, coral traits and reef fish assemblage. *Coral Reefs*, 36: 561-575.
3. Lefcheck JS, Hughes BB, Johnson AJ, Pfirrmann BW, Rasher DB, Smyth AR, Williams BL, Beck MW, Orth RJ (2019) Are coastal habitats important nurseries? A meta-analysis. *Conservation Letters*, DOI: 10.1111/conl.12645.
4. Teh LSL, Teh LCL, Rashid-Sumaila U (2013) A global estimate of the number of coral reef fishers. *PLoS ONE*, 8(6): e65397. Doi:10.1371/journal.pone.0065397.
5. Kritzer JP, Delucia M, Greene E, Shumway C, Topolski MF, Thomas-Blate J, Chiarella LA, Davy KB, Smith K (2016) The importance of benthic habitats for coastal fisheries. *BioScience*, 66: 274-284.
6. Worm B, Barbier EB, Beaumont N, Duffy JM, Folke C, Halpern BS, Jackson JB, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314: 787-790.
7. Graham NAJ, Chabanet P, Evans RD, Jennings S, Letourneur Y, MacNeil MA, McClanahan TR, Ohman MC, Polunin NVC, Wilson SK (2011) Extinction vulnerability of coral reef fishes. *Ecological letters*, 14: 341-348.
8. Mouillot D, Villeger S, Parravicini V, Kulbicki M, Arias-Gonzalez JE, Bender M, Chabanet P, Floeter SR, Friedlander A, Vigliola L, Bellwood DR (2014) Functional over-redundancy and high functional vulnerability in global fish faunas n tropical reefs. *Proceedings of the National Academy of Sciences*, 111: 13757-13762.
9. Duffy JE, Lefcheck JS, Stuart-Smith RD, Navarrete SA, Edgar GJ (2016) Biodiversity enhances reef fish biomass and resistance to climate change. *Proceedings of the National Academy of Sciences*, 113: 6230-6235.
10. Bates AE, Cooke RSC, Duncan MI, Edgar GJ, Bruno JF, Benedetti-Cecchi L, Cote IM, Lefcheck JS, Costello MJ, Barrett N, Bird TJ, Fenberg PB, Stuart-Smith RD (2019) Climate resilience in marine protected areas and the “Protection Paradox”. *Biological Conservation*, 236: 305-314.
11. Costello MJ, Basher Z, McLeod L, Asaad I, Claus S, Vandepitte L, Yasuhara M, Gislason H, Edwards, M, Appeltans W, Enevoldsen H, Edgar GJ, Milslavich P, De Monte S, Sousa Pino I, Obura D, Bates AE (2017) Methods for the Study of Marine Biodiversity. In: Walters M., Scholes R. (eds) The GEO Handbook on Biodiversity Observation Networks. Springer, Cham.

12. Murphy HM, Jenkins GP (2010) Observational methods used in marine spatial monitoring of fishes and associated habitats: a review. Marine and Freshwater Research 61: 236-252.
13. Mallet D, Pelletier D (2014) Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952-2012). *Fisheries Research*, 154: 44-62.
14. Costello MJ, Beard KH, Corlett RT, Cumming G, Devictor V, Loyola R, Maas B, Miller-Rushing AJ, Pakeman R, Primack RB (2016) Field work ethics in biological research. *Biological Conservation* 203, 268-271.
15. Pikitch EK, Santora C, Babcock EA, Bakun A, Bonfil R, Conover DO, Dayton P, Doukakis P, Fluharty D, Heneman B, Houde ED, Link J, Livingston PA, Mangel M, McAllister MK, Pope J, Sainsbury KJ (2004) Ecosystem-based fishery management. *Science*, 305: 346-347.
16. Caldwell ZR, Zgliczynski BJ, Williams GJ, Sandin SA (2016) Reef Fish Survey Techniques: Assessing the Potential for Standardizing Methodologies. *PLoS ONE*, 11(4): e0153066. doi:10.1371/journal.pone.0153066.
17. Edgar GJ, Stuart-Smith RD et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506: 216–220.
18. Stuart-Smith RD, Edgar GJ, Barrett NS, Kininmonth S, Bates AE (2015). Thermal biases and vulnerability to warming in the world's marine fauna. *Nature* 528: 88-92.
19. Dwyer RG, Krueck NC, Udyawer V, Heupel MR, Chapman D, Pratt HL, Garla R, Simpfendorfer CA (2020) Individual and Population Benefits of Marine Reserves for Reef Sharks. *Current Biology*, 30: 480-489.e485.
20. MacNeil MA, Chapman D, Heupel M, Simpfendorfer CA, Heithaus M, Meekan M, Harvey E, et al. 2020. Global Status and Conservation Potential of Reef Sharks. *Nature*. In press.
21. Muller-Karger FE, Miloslavich P, Bax NJ, Simmons S, Costello MJ, Sousa Pinto I, Canonico G, Turner W, Gill M, Montes E, Best BD, Pearlman J, Halpin P, Dunn D, Benson A, Martin CS, Weatherdon LV, Appeltans W, Provoost P, Klein E, Kelble CR, Miller RJ, Chaves FP, Iken K, Chiba S, Obura D, Mavarro LM, Pereira HM, Allain V, Batten S, Benedetti-Cchecchi L, Duffy JM, Kudela RM, Rebelo LM, Shin Y, Geller G (2018) Advancing marine biological observations and data requirements of the complementary essential ocean variables (EOVs) and the essential biodiversity variables (EBVs) frameworks. *Frontiers in Marine Science*, 5: 211. Doi: 10.3389/fmars.2018.00211.
22. Benson A, Brooks CM, Canonico G, Duffy E, Muller-Karger F, Sosik HM, Miloslavich P, Klein E (2018) Integrated observations and informatics improve understanding of changing marine ecosystems. *Frontiers in Marine Science*, 5:428. Doi: 10.3389/fmars.218.00428.
23. Miloslavich P, Bax NJ, Simmons SE, Klein E, Appeltans W, Aburto-Oropeza O, Anderson Garcia M, Batten SD, Benedetti-Cecchi L, Checkley DM, Chiba S, Duffy JE, Dunn DC, Fischer A, Gunn J, Kudela R, Marsac F, Muller-Karger FE, Obura D, Shin YJ (2018) Essential Ocean Variables for global sustained observations of biodiversity and ecosystem changes. *Global Change Biology*, 24: 2416-2433.
24. Nash KL, Graham NAJ (2016) Ecological indicators for coral reef fisheries management. *Fish and Fisheries*, 17: 1029-1054.
25. Coll M, et al (2016) Ecological indicators to capture the effects of fishing on biodiversity and conservation status of marine ecosystems. *Ecological Indicators*, 60: 947-962.
26. Stuart-Smith RD, Edgar GJ, Barrett NS, Bates AE, Baker SC, Bax NJ, Becerro MA, Berkhout J, Blanchard JL, Brock DJ, Clark GF, Cooper AT, Davis TR, Day PB, Duffy JE, Holmes TH, Howe SA, Jordan A, Kininmonth S, Knott AN, Lefcheck JS, Ling SD, Parr A, Strain E, Sweatman H, Thomson R (2017) Assessing National Biodiversity Trends for Rocky and Coral Reefs through the Integration of Citizen Science and Scientific Monitoring Programs. *Bioscience*, 67:134-146.

11 Appendix: 5 papers per full member

Anthony Bernard

1. Dames V, **Bernard ATF**, Floros C, Mann B, Speed C, Maggs J, Lainge S, Meekan M, Olbers J (2020) Zonation and reef size significantly influence fish population structure in an established marine protected area, iSimangaliso Wetland Park, South Africa. *Ocean and Coastal Management*, 185: 105040.
2. Heyns-Veale ER, **Bernard ATF**, Gotz A, Mann BQ, Maggs JQ, Smith MKS (2019) Community-wide effects of protection reveal insights into marine protected areas effectiveness for reef fish. *Marine Ecology Progress Series*, 620: 99-117.
3. Parker D, Winker H, **Bernard ATF**, Gotz A (2016) Evaluating long-term monitoring of temperate reef fishes: A simulation testing framework. Ecological Modelling 333: 1-10.
4. Heyns-Veale ER, **Bernard ATF**, Richoux NB, Parker D, Langlois TJ, Harvey ES, Gotz A (2016) Depth and Habitat determine assemblage structure of South Africa's warm-temperate reef fish. *Marine Biology*, 163: 1-17.
5. Edgar GJ, Banks S, Barrett NS, Becerro MA, **Bernard ATF**, Berkhout J, Buxton CD, Cambell SJ, Cooper AT, Davey M, Edgar SC, Forsterra G, Galvan DE, Irigoyen AJ, Kininmonth S , Kushner DJ, Moura R, Parnell PE, Shears NT, Soler G, Strain EMA, Thompson RJ, Willis TJ, Stuart-Smith RD (2014) Five critical features maximize the conservation potential of marine protected areas. *Nature*, 506: 216–220.

Rick Stuart-Smith

1. **Stuart-Smith RD**, Brown C, Ceccarelli D, Edgar GJ (2018) Ecosystem restructuring along the Great Barrier Reef following mass coral bleaching. *Nature* 560, 92-96.
2. **Stuart-Smith RD**, Edgar GJ, Barrett NS, Bates AE, Baker SC, Bax NJ, Becerro MA, Berkhout J, Blanchard JL, Brock DJ, Clark GF, Cooper AT, Davis TR, Day PB, Duffy JE, Holmes TH, Howe SA, Jordan A, Kininmonth S, Knott AN, Lefcheck JS, Ling SD, Parr A, Strain E, Sweatman H, Thomson R (2017) Assessing National Biodiversity Trends for Rocky and Coral Reefs through the Integration of Citizen Science and Scientific Monitoring Programs. *Bioscience*, 67:134-146.
3. **Stuart-Smith RD**, Edgar GJ, Barrett NS, Kininmonth S, Bates AE (2015) Thermal biases and vulnerability to warming in the world's marine fauna. *Nature*, 528: 88-92.
4. **Stuart-Smith, RD** et al. (2013) Integrating abundance and functional traits reveals new global hotspots of fish diversity. *Nature*, 501: 539-542.
5. Edgar GJ, **Stuart-Smith RD** et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature*, 506: 216–220.

Rene Abesamis

1. **Abesamis RA**, Russ GR (2010) Patterns of recruitment of coral reef fishes in a monsoonal environment. *Coral Reefs*, 29: 911-921.
2. **Abesamis RA**, Stockwell BL, Bernardo LPC, Villanoy CL, Russ GR (2016) Predicting connectivity from biogeographic patterns and larval dispersal modelling to inform the development of marine reserve networks. *Ecological Indicators*, 66: 534-544.
3. **Abesamis RA**, Langlois T, Birt M, Thillainath E, Bucol AB, Arceo HO, Russ GR (2018) Benthic habitat and fish assemblage structure from shallow to mesophotic depths in a storm-impacted marine protected area. *Coral Reefs*, 37: 81-97.
4. Russ GR, Payne CS, Bergseth BJ, Rizzari JR, **Abesamis RA**, Alcala AC (2018) Decadal-scale response of detritivorous surgeonfishes (family Acanthuridae) to no-take marine reserve protection and changes in benthic habitat. *Journal of Fish Biology*, 93: 887-900.

5. Pinheiro HT, Shepherd B, Castillo C, **Abesamis RA**, Copus JM, Pyle RL, Greene BD, Coleman RR, Whitton RK, Thillainath E, Bucol AA, Birt M, Catania D, Bell MV, Rocha LA (2019) Deep reef fishes in the world's epicentre of marine biodiversity. *Coral Reefs*, 38: 985-995.

Emily Darling

1. Brandl SJ, Rasher DB, Côté IM, Casey JM, **Darling ES**, Lefcheck, J, Duffy JE (2019) Coral reef ecosystem functioning: eight core processes and the role of biodiversity. *Frontiers in Ecology and the Environmen*t, 17: 445-454.
2. Villon S, Mouillot D, Chaumont M, **Darling ES**, Subsol G, Claverie T, Villéger Y (2018) A Deep Learning method for accurate and fast identification of coral reef fishes from underwater videos. *Ecological Informatics*, 48: 238-244.
3. **Darling ES** and Côté IM (2018) Seeking resilience in marine ecosystems. *Science*, 359: 986-7.
4. **Darling ES** and D'agata S (2017) Coral Reefs: Fishing for Sustainability. *Current Biology*, 27: R57-R76.
5. Madin JS, Hoogenboom M, Connolly S, **Darling ES**, Falster D, Huang D, Keith S, Mizerek T, Pandolfi JM, Putnam H, Baird AH (2016) A trait-based approach to advance coral reef science. *Trends in Ecology and Evolution*, 31: 419-428.

Jordan Goetze

1. Schramm KD, Harvey ES, **Goetze JS**, Travers MJ, Warnock B, Saunders BJ (2020) A comparison of stereo-BRUV, diver operated and remote stereo-video transects for assessing reef fish assemblages. *Journal of Experimental Marine Biology and Ecology*, 524: 151273.
2. **Goetze JS**, Bond T, McLean DL, Saunders BJ, Langlois TJ, Lindfield S, Fullwood LAF, Driessen D, Shedrawi G, Harvey ES (2019) A field and video analysis guide for diver operated stereo-video. *Methods in Ecology and Evolution*, 10: 1083–1090.
3. Carvalho PG, Jupiter SD, Januchowski-Hartley FA, **Goetze J**, Claudet J, Weeks R, Humphries A, White C (2019) Optimising fishing through periodically harvested closures. Journal of Applied Ecology, 56: 1927-1936.
4. **Goetze JS**, Claudet J, Januchowski-Hartley F, Langlois TJ, Wilson SK, White C, Weeks R, Jupiter SD (2018) Demonstrating multiple benefits from periodically harvested fisheries closures. *Journal of Applied Ecology*, 55: 1102–1113.
5. **Goetze JS**, Jupiter SD, Langlois TJ, Wilson SK, Harvey ES, Bond T, Naisilisili W (2015) Diver operated video most accurately detects the impacts of fishing within periodically harvested closures. *Journal of Experimental Marine Biology and Ecology*, 426: 74-82.

Aaron MacNeil

1. **MacNeil MA**, Chapman D, Heupel M, Simpfendorfer CA, Heithaus M, Meekan M, Harvey E, et al. (2020) Global Status and Conservation Potential of Reef Sharks. *Nature*, *In press*.
2. Cinner JE, Gurney G, Hutchery C, Graham NAJ, **MacNeil MA** et al. (2020) Meeting multiple goals for the worlds coral reefs. *Science*, 368: 307311.
3. Hicks CC, Cohen PJ, Graham NAJ, **MacNeil MA**, Nash KL, Allison EH, DLima C, Mills D, Roscher M, Thilsted S, Thorne-Lyman A (2019) Malnourished in a sea of micro-nutrients: harnessing global fisheries to tackle micronutrient deficiencies. *Nature*, 574: 95-98.
4. Cinner JE, Hutchery C, **MacNeil MA**, Graham NAJ, McClanahan TR et al. (2016) Bright spots among the world's coral reefs. *Nature*, 535: 416-419.

5. **MacNeil MA**, Graham NAJ, Cinner JE, Wilson SK, Williams ID, Maina J, Newman S, Friedlander AM, Jupiter S, Polunin, NVC, McClanahan TR (2015) Recovery potential of the world's coral reef fishes. *Nature*, 520: 341-344.

Eva Maire

1. Letessier TB, Mouillot D, Bouchet PJ, Vigliola L, Fernandes MC, Thompson C, Boussarie G, Turner J, Juhel J, **Maire E**, Caley MJ, Koldewey HJ, Friedlander A, Sala E, Meeuwig JJ (2019) Remote reefs and seamounts are the last refuges for marine predators across the Indo-Pacific. *PLOS Biology* 17: e3000366, doi: 10.1371/journal.pbio.3000366.
2. **Maire E**, Villéger S, Graham NAJ, Hoey A, Cinner J, Ferse S, Aliaume C, Booth D, Feary D, Kulbicki M, Sandin S, Vigliola L, Mouillot D (2018) Community-wide scan flags fish species associated to coral reef services globally. *Proceedings of the Royal Society B*, 285, 20181167, doi: 10.1098/rspb.2018.1167.
3. Cinner JE, Hutchery C, MacNeil MA, Graham NAJ, McClanahan TR, **Maire E** et al. (2016) Bright spots among the world's coral reefs. *Nature*, 535: 416-419
4. Cinner JE, **Maire E**, Huchery C, MacNeil MA et al. (2018) Gravity of human impacts mediates coral reef conservation gains. *Proceeding of the National Academy of Sciences*, 115: E6116-E6125.
5. Cinner JE, Gurney G, Hutchery C, Graham NAJ, MacNeil MA, **Maire E** et al. (2020) Meeting multiple goals for the worlds coral reefs. *Science*, 368: 307311.

Ana Carolina Mazzuco

1. **Mazzuco ACA**, Stelzer PS, Bernardino AF (2020) Substrate rugosity and temperature matters: patterns of benthic diversity at tropical intertidal reefs in the SW Atlantic. *PeerJ Life & Environment,* PeerJ 8:e8289. DOI: 10.7717/peerj.8289.
2. Fassina CM, Telles DHQ, **Mazzuco ACA** (2020) Governance challenges for the newest Brazilian marine protected areas: Preliminary considerations for stakeholder participation. *Ocean and Coastal Management*, 185: 105067. DOI: 10.1016/j.ocecoaman.2019.105067
3. Bernardino AF, Pais FS, Oliveira LS, Gabriel FA, Ferreira TO, Queiroz HM, **Mazzuco ACA** (2019) Chronic trace metals effects of mine tailings on estuarine assemblages revealed by environmental DNA. *PeerJ*, 7:e8042. DOI: 10.7717/peerj.8042
4. Bernardino AF, Gama, RN, **Mazzuco ACA**, Omena EP, Lavrado, H (2019) Submarine canyons support distinct microfaunal assemblages on the deep SE Brazil Margin. *Deep-Sea Research Part I: Oceanographic Research Papers*, 149: 103052. DOI: 10.1016/j.dsr.2019.05.012
5. **Mazzuco ACA**, Stelzer PS, Donadia G, Bernardino JV, Joyeux J, Bernardino AF (2019) Lower diversity of recruits in coastal reef assemblages are associated with higher sea temperatures in the tropical South Atlantic. *Marine Environmental Research*, 148: 87-98. DOI: 10.1016/j.marenvres.2019.05.008

Melita Samoilys

1. **Samoilys MA**, Osuka K, Mussa J, Rosendo S, Riddell M, Diade M, Mbugua J, Kawaka J, Hill N, Koldewey H (2019) An integrated assessment of coastal fisheries in Mozambique for conservation planning. *Ocean and Coastal Management*, 182: 104924
2. Queiroz N, Humphries NE, Couto A, Vedor M, da Costa I, … **Samoilys M**, …. Sims D (2019) Global spatial risk assessment of sharks under the footprint of fisheries. *Nature*, 572: 461-466
3. **Samoilys MA**, Halford A, Osuka K (2019) Disentangling drivers of the abundance of coral reef fishes in the Western Indian Ocean. *Ecology and Evolution*, 9: 4149-4167.

4. Sale PF, Agardy T, Ainsworth CH, Feist BE, Bell JD, …. **Samoilys MA** et al. (2014) Transforming management of tropical coastal seas to cope with challenges of the 21st century. *Marine Pollution Bulletin*, 88: 8-23.
5. Sadovy de Mitcheson Y, Craig MT, Bertoncini AA, Carpenter KE, Cheung WWL, Choat JH, Cornish AS, Fennessy ST, Ferreira BP, Heemstra PC, Liu M, Myers RF, Pollard DA, Rhodes KL, Rocha LA, Russell BC, **Samoilys MA**, Sanciangco J (2012) Fishing groupers towards extinction: A global assessment of threats and extinction risk in a billion dollar fishery. *Fish and Fisheries*, 12: 119-136.

Christy Pattengill-Semmens

1. Waterhouse L, Heppell SA, **Pattengill-Semmens CV**, McCoy C, Bush P, Johnson BC, Semmens BX (2020) Recovery of the critically endangered Nassau grouper (*Epinephelus striatus*) in the Cayman Islands following targeted conservation actions. *Proceedings of the National Academy of Sciences*, 17: 1587-1595.
2. Gruss A, Perryman HA, Babcock EA, Sagarese SR, Thorson JT, Ainsworth CH, Anderson EJ, Brennan K, Campbell MD, Christman MC, Cross S, Drexler MD, Drymon JM, Gardner CL, Hanisko DS, Hendon J, Koenig CC, Love M, Martinez-Andrade F, Morris J, Noble BT, Nuttall MA, Osborne J, **Pettengill-Semmens C**, Pollack AG, Sutton TT, Switzer TS (2018) Monitoring programs of the U.S. Gulf of Mexico: inventory, development and use of a large monitoring database to map fish and invertebrate spatial distributions. *Reviews in Fish Biology and Fisheries*, 28: 667-691.
3. Thorson JT, Scheuerell MD, Semmens BX, **Pattengill-Semmens CV** (2014) Demographic modelling of citizen science data informs habitat preferences and population dynamics of recovering fishes. *Ecology*, 95: 3251-3258.
4. Heppell SA, Semmens BX, Archer SK, **Pattengill-Semmens CV**, Bush PG, McCoy CM, Heppell SS, Johnson BC (2012) Documenting recovery of a spawning aggregation through size frequency analysis from underwater laser calipers measurements. *Biological Conservation*, 155: 119-127.
5. Ward-Paige CA, **Pattengill-Semmens C**, Myers RA, Lotze HK (2010) Spatial and temporal trends in yellow stingray abundance: evidence from diver surveys. *Environmental Biology of Fishes*, 90: 263-276.