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# Summary Report: Review of Corals Injured by the *Deepwater Horizon* Oil Spill in the Gulf of Mexico, with Recommendations for Coral Propagation and Genetic Assessment

## Coral Propagation Technique Development Project

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For more information on MDBC Restoration, please visit:

https://coastalscience.noaa.gov/project/scientific-support-for-mesophotic-and-deep-benthic-community-restoration-in-the-gulf-of-mexico/

and

https://www.fisheries.noaa.gov/southeast/habitat-conservation/mesophotic-and-deep-benthic-communities-restoration

## Disclaimer

## ***Deepwater Horizon* Mesophotic and Deep Benthic Communities Restoration**

This report is part of the NOAA Mesophotic and Deep Benthic Communities (MDBC) Series of publications that share the results of work conducted by the *Deepwater Horizon* MDBC restoration projects.

The 2010 *Deepwater Horizon* oil spill was an unprecedented event. Approximately 3.2 million barrels of oil were released into the deep ocean over nearly three months. The plume of oil moved throughout the water column, formed surface slicks that cumulatively covered an area the size of Virginia, and washed oil onto at least 1,300 miles of shoreline habitats. More than 770 square miles (2,000 square kilometers) of deep benthic habitat were injured by the oil spill, including areas surrounding the *Deepwater Horizon* wellhead and parts of the Pinnacles Trend mesophotic reef complex, located at the edge of the continental shelf.

Under the Oil Pollution Act, state and federal natural resource trustees conducted a Natural Resource Damage Assessment (NRDA). The Trustees assessed damages, quantifying the unprecedented injuries to natural resources and lost services. They also developed a programmatic restoration plan to restore injured resources and compensate the public for lost services.

In April 2016, a settlement was finalized that included up to $8.8 billion in funding for the *Deepwater Horizon* Trustees to restore the natural resource injuries caused by the oil spill as described in their programmatic restoration plan, Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. The *Deepwater Horizon* Open Ocean Trustee Implementation Group is responsible for restoring natural resources and their services within the Open Ocean Restoration Area that were injured by the oil spill. The Open Ocean Trustees include NOAA, U.S. Department of the Interior, U.S. Environmental Protection Agency, and U.S. Department of Agriculture.

In 2019, the Open Ocean Trustee Implementation Group committed more than $126 million to implement four restoration projects to address the injury to MDBC. The MDBC projects are: Mapping, Ground-Truthing, and Predictive Habitat Modeling; Habitat Assessment and Evaluation; Coral Propagation Technique Development; and Active Management and Protection. NOAA and the Department of the Interior are implementing the projects, in cooperation with a range of partners, over eight years.

Together, the projects take a phased approach to meet the challenges involved in restoring deep-sea habitats. Challenges to restoration include a limited scientific understanding of these communities, limited experience with restoration at the depths at which these communities occur, and remote locations that limit accessibility.

More information about *Deepwater Horizon* restoration and the MDBC restoration projects is available at: www.gulfspillrestoration.noaa.gov.

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**List of Acronyms**

CPT - Coral Propagation Technique Development project
DWH - Deepwater Horizon
GOM - Gulf of Mexico
HAE - Habitat Assessment and Evaluation project
MDBC - Mesophotic and Deep Benthic Communities

# Executive Summary

This tech memo reports on the results of multiple analyses conducted by the Data Inventory and Analysis (DIA) team during the first year of the Coral Propagation Techniques Development (CPT) Project. Two prioritization exercises were conducted: a literature review for coral species prioritization and a genetic status of knowledge assessment. A team of 10 subject-matter experts (SMEs) reviewed the information and provided feedback during a two-hour focus group meeting held virtually in December of 2021. Key points discussed during the meeting and a summary of post-meeting SME feedback are also reported here.

This DIA task is an important foundational component of all MDBC projects, including the CPT Project. This task ran parallel with other inventory analyses undertaken by the Habitat Assessment and Evaluation (HAE) and Mapping, Ground-truthing, and Predictive Habitat Modeling (MGM) Projects. This report summarizes the methods and results of the analyses and summarizes input from subject matter experts. The results presented herein will guide and direct the subsequent implementation of project activities for several years; specifically, the project will focus on investigating the most effective and practical techniques for mesophotic and deep coral propagation in the northern Gulf of Mexico, including which species to propagate and analyze for population connectivity and genetic barcoding.

# 1. Coral Propagation Technique Development (CPT) Project

The Coral Propagation Technique Development (CPT) project is one of four projects selected to help restore mesophotic and deep benthic communities (MDBC) impacted by the *Deepwater Horizon* (DWH) oil spill. The primary goal of the CPT project is to directly compensate for injuries caused to mesophotic and deep sea coral habitats in the Gulf of Mexico (GOM) by the DWH oil spill, in order to allow recovery of invertebrate and fish abundance and biomass that depends upon these habitats.

As described in the Trustees' Open Ocean Restoration Plan 2 (OORP2), this project contributes to the Trustees' goal of restoring mesophotic and deep benthic invertebrate and fish abundance and biomass for injured species through development of coral propagation techniques. This project is focused on the direct restoration of habitat-forming corals.

The specific project objectives identified in the project Monitoring and Adaptive Management plan are to:

- Develop methods and techniques for effective enhancement of coral recruitment and growth and recommend successful methods to be implemented at a large scale for restoration.
- Propagate target coral species to directly compensate for loss of MDBC corals and associated benthic and water column communities impacted by the DWH oil spill

This project is responsible for establishing priority coral species targeted for propagation efforts and quantifying benefits to those target species, while the separate MDBC Habitat Assessment and Evaluation (HAE) Project is responsible for documenting the benefits provided by MDBC habitats to fish and invertebrate communities.

The CPT project has identified tasks, duration and timelines of various CPT activities. The results presented in this report are related to the "Data Inventory, Literature review, and Data Analysis" activity which was to be completed in the first two years (planning phase) of the project. This inventory, analysis, and feedback from subject matter experts (SMEs) will inform the implementation phase (years 3–7) of coral propagation and substrate placement in the field.

# 2. Data Inventory and Analysis Methods

## 2.1. Literature Review of DWH Coral Injury

The CPT project was tasked to assemble a comprehensive bibliography of coral injury resulting from the DWH oil spill. From this bibliography, a list of coral species known to be injured was compiled, as well as other species known to be present in areas of injury. The species list was incorporated into a prioritization matrix (Appendix A) and annotated according to particular criteria relevant to coral propagation (degree of injury, relevance to management, and frequency of occurrence). The goal was to identify the top species for propagation in deep and mesophotic waters, and to rank them in terms of their potential success for maintaining in the lab and outplanting in the field.

This analysis began with a compilation of a small group of peer-reviewed papers that were recent, authoritative, and relevant specifically to coral injury observed from the DWH oil spill. These papers were reviewed and a list of coral taxa injured and injury counts were documented. The bibliography was reviewed by the U.S. Geological Survey (USGS) Biology Team. The resulting 'DWH Coral Injury Bibliography' consisted of 16 papers.

## 2.2. Species Prioritization Matrix

A species ranking exercise was undertaken in order to address the question: which are the most meaningful species (injured, relevant to management, and observed frequently) to compensate for injury incurred related to DWH and what is the order of magnitude that must be compensated?

The species and information gathered in the DWH Coral Injury Bibliography was adapted into a table (Appendix A) to form the basis for the species prioritization exercise. Criteria were assigned as columns in this matrix for: presence of injury (yes/no/not assessed), counts of incidences of injury (enumerated from literature), and whether or not it was listed in the OORP2 (yes/no, hereafter Y/N), targeted by NOAA RESTORE Science Program's research projects (Y/N), or of interest to regional fishery management councils (Y/N). A comments column was used for notes on species taxonomy and/or documented injury. The resulting Species Prioritization Matrix contains 40 coral taxa to date.

MDBC portfolio team members were the species prioritization matrix as described above, along with a table of counts by genera (downloaded from the NOAA Deep Sea Coral Research and Technology portal, https://deepseacoraldata.noaa.gov). The ranking exercise was completed by three separate standing teams for the MDBC portfolio: the CPT project team, An MDBC cross-project team, and a higher-level technical team. A total of 14 individuals participated in the exercise.

## 2.3. Status of Knowledge of Mesophotic and Deepwater Coral Species Genetics

This assessment serves as a cross-project deliverable for both the CPT and Habitat Assessment and Evaluation (HAE) projects.

A total of 228 deep-sea coral species across 114 genera were researched on the NCBI GenBank website. The list of taxa was retrieved from Table 1 of Etnoyer, Shuler, and Cairns (2020), which is an annex to the U.S. Gulf of Mexico chapter in "The State of Deep-Sea Coral Ecosystems in the United States." The table provides a list of all deep-sea coral taxa from the Anthozoa and Hydrozoa classes that occur in GOM waters. It provides depth ranges as well as geographic extent of each species. Only species present in the northern GOM were included in the genetic assessment (i.e., species present only in southern regions of the GOM but not in the north were excluded).

Each species was researched on GenBank and information gathered included: mitochondrial barcode availability (Y/N and which gene regions), nuclear barcode availability (Y/N and which gene regions), mitogenome availability (Y/N), population connectivity data availability (Y/N), and published references associated with all the above. Population connectivity data was considered available if there were microsatellite sequences available, or if there were results in the SRA database. Mitochondrial and nuclear barcodes, and mitogenomes, were searched for in the nucleotides database.

Similar to the species priority matrix, all taxa were ranked based on 'best available' genetic data. The ranking criteria for this assessment was as follows:

- 0 = Population-level genetic/genomic data (RADseq, target capture, microsatellites) is available. These are the most useful for population connectivity/differentiation and species delimitation studies.
- 1 = Both the mitogenome and 28S gene region are available. This is good to a point for species delimitation and phylogenetics, but not as good as score of 0; added benefit of examining genome rearrangements, selection of mitogenome, etc.
- 2 = Mitogenome is available
- 3 = mutS, 28S, 16S, COI, 18S, or cox2-IGR-cox1 is available (encompasses octocorals, black corals, stony corals, stylasterids). These are useful barcodes to resolve approximately 80% of species or genera at the least. Use of several of these genes together can be useful, to a point, for phylogenetics.
- 4 = no genetic data available

Taxa with a score of zero were ranked lowest priority for further genetic sampling and those with a score of 4 were ranked highest priority, in order to prioritize species for which there is the least available information.

## 2.4. Focus Group

Once the extensive literature review and status of knowledge assessment was completed, the CPT project requested input from experts within the coral propagation community. A focus group meeting consisting of ten subject-matter experts was held virtually in early December 2021. The experts were selected because of their extensive experience with coral biology, population genetics, and/or research in the GOM. The list of participants can be found in Appendix B. The purpose of the focus group meeting was to present and discuss the results of the DWH coral injury literature review, species prioritization for propagation, and status of knowledge genetics assessment.

In advance of the focus group meeting, participants were sent the following three analytical products for review, with accompanying discussion questions:

1. **<u>DWH Coral Injury Bibliography</u>**
- Is the bibliography complete for DWH coral injury?
- Are we missing any important literature, or other relevant information, that needs to be considered?

2. **<u>Species Prioritization Matrix</u>**
- Do participants agree with the species priorities identified for propagation, and the criteria used to rank them?
- What changes, if any, should be made to the criteria used to rank the target species?
- Based on the known information, do the target numbers (injury counts; n = 619 corals) for propagation in the implementation phase need to be changed?
- What factors need to be considered to achieve target numbers, e.g., mortality, recruitment, and how should target numbers be adjusted to compensate?
- How do we restore hundreds of corals? What kind of studies need to be done to estimate these factors?

3. **<u>Status of Knowledge of Mesophotic and Deepwater Coral Species Genetics</u>**
- Does this appear comprehensive and accurate? Is there any relevant and important information missing?
- Do participants agree with the species priorities identified for genetic analyses, and the criteria used to rank them?
- Are there caveats to consider, improvements we could make, or recommendations for further analyses?
- Which genetic analyses (e.g. barcoding, target capture, mitogenome, etc.) should we prioritize?

## 2.5. Follow-up Survey from Subject Matter Experts

Approximately two weeks after the focus group meeting was held, a brief follow-up survey was sent to all focus group participants via Google Forms, in order to gather any further thoughts or ideas they had after a chance to think about what was discussed in the focus group meeting. Participants were asked questions related to their research experience with corals and the GOM, and their thoughts on how best to propagate mesophotic and deep sea corals and where, how to manage risks, knowledge priorities, and action priorities. The results of this survey are discussed in Section 3.4.

# 3. Results

## 3.1. Species Prioritization Ranking Exercise

There are an estimated 619 coral colonies across 14 octocoral, black coral, and stony coral genera documented as injured in the DWH survey literature. These totals do not include injuries at control sites.

The species prioritization ranking exercise resulted in strong consensus among the top three taxa—*Muricea pendula*, *Swiftia exserta*, and *Paramuricea biscaya*, and good consensus on the top 12 (Table 1).

## 3.2. Status of Knowledge of Mesophotic and Deepwater Coral Species Genetics

The status of knowledge genetic assessment revealed that there are 118 deep sea coral species (57 octocorals, 46 scleractinians, nine black corals, and six pennatulaceans) present in the northern GOM without any publicly available genetic information. Of the 114 genera examined, 42 are lacking genetic information. Five of the injured species have no genetic data associated with them and another 15 injured taxa have little genetic data available (Table 2). Greatest priority for further genetic sampling and analyses is given to these taxa.

**Table 1.** Table of highest ranking taxa from species prioritization exercise. Colors denote priority target species for propagation. Orange = mesophotic taxa; blue = deep-sea taxa.

| Order | Species | Average Rank | Injury Counts | Frequency of Occurrence |
|---|---|---|---|---|
| Alcyonacea | *Muricea pendula* | 1 | 182 | 1432 |
| Alcyonacea | *Swiftia exserta* | 1 | 82 | 1477 |
| Alcyonacea | *Paramuricea biscaya* | 1 | 166 | 819 |
| Alcyonacea | *Bebryce* spp. | 2 | 76 | 1402 |
| Alcyonacea | *Thesea nivea* | 3 | 64 | 509 |
| Antipatharia | *Antipathes atlantica* | 4 | 24 | 1150 |
| Alcyonacea | *Paramuricea* sp. B3 | 4 | 3 | 819 |
| Alcyonacea | *Placogorgia* sp. | 4 | 5 | 771 |
| Antipatharia | *Bathypathes cf. patula* | 4 | 2 | 135 |
| Antipatharia | *Leiopathes glaberrima* | 4 | 0 | 2288 |
| Alcyonacea | *Callogorgia delta* | 4 | 0 | 908 |
| Scleractinia | *Lophelia pertusa* | 4 | 0 | 8564 |

**Table 2.** DWH-injured coral taxa with little to no genetic data available. A ranking of 4 signified no genetic information available. See ranking criteria description in Section 2.3.

| Order | Species | Ranking |
|---|---|---|
| Alcyonacea | *Bebryce cinerea* | 4 |
| Alcyonacea | *Bebryce grandis* | 4 |
| Alcyonacea | *Placogorgia rudis* | 4 |
| Alcyonacea | *Thesea nivea* | 4 |
| Alcyonacea | *Thesea rubra* | 4 |
| Alcyonacea | *Thesea* spp. | 3.9 |
| Alcyonacea | *Muriceides* spp. | 3.5 |
| Alcyonacea | *Placogorgia* spp. | 3.5 |
| Alcyonacea | *Acanthogorgia* spp. | 3.3 |
| Alcyonacea | *Bebryce* spp. | 3 |
| Alcyonacea | *Ellisella elongata/barbadensis* | 3 |
| Alcyonacea | *Keratoisis* sp. | 3 |
| Alcyonacea | *Muriceides hirta* | 3 |
| Alcyonacea | *Paragorgia regalis* | 3 |
| Alcyonacea | *Placogorgia tenuis* | 3 |
| Alcyonacea | *Clavularia* sp. | 3 |
| Antipatharia | *Stichopathes* spp. | 3 |
| Alcyonacea | *Paramuricea* sp. | 3 |
| Alcyonacea | *Keratoisis* spp. | 3 |
| Alcyonacea | *Acanthogorgia aspera* | 3 |
| Alcyonacea | *Ellisella* spp. | 2.8 |
| Antipatharia | *Antipathes* spp. | 2.75 |

A spreadsheet with results contains a few lists and tables, including lists of species with no genetic data available, organized by order (octocorals, stony corals, black corals, sea pens), a table of every species and their ranking score, and a table of all genera and their averaged ranking score (Appendix C). A table of all injured taxa (from injury bibliography and species matrix) that have little to no genetic data available (scores of 2.75 to 4) is provided on Table 2.

## 3.3. Focus Group

Key discussion points, feedback, and recommendations are listed below, according to each analytical product reviewed by focus group participants.

**1. DWH Coral Injury Bibliography**

- Is the bibliography complete for DWH coral injury? Are we missing any important literature, or other relevant information, that needs to be considered?

    - Participants suggested five additional papers for inclusion in the bibliography. The suggested documents were added and can be found in the revised bibliography (Appendix D).
    - Participants identified papers that discuss lab-based studies of the effects of petroleum, dispersants, and their by-products on mesophotic or deep water coral species for inclusion in the bibliography in addition to field based injury studies.

**2. Species Prioritization Matrix**

- Do participants agree with the species priorities identified for propagation, and the criteria used to rank them?
    - Top 3 priority taxa are obvious based on frequency of occurrence and injury observed: *Swiftia, Muricea, Paramuricea*.
    - Species that are good propagation candidates are fast-growing and good wound healers.
    - Consider prioritizing taxa that were less abundant after spill.
    - Consider breaking up into two lists - ones we know we can propagate and ones we aren't sure about. Experiment with the latter.
    - Consider scleractinians such as *Lophelia*, which do well with fragmentation.
- What changes, if any, should be made to the criteria used to rank the target species?
    - Injury is difficult to rank as a Y/N question. Some of the injuries observed could be within normal range. Additionally, some taxa marked as not injured were present at damaged sites and we probably just missed the injuries. Others could've been injured and recovered by the time damage assessment was conducted.
    - Consider marking all species present at sites exposed to oil and dispersant as injured.
- Based on the known information, do the target numbers (injury counts, n=619 corals) for propagation in the implementation phase need to be changed?
    - Consider rather than only directly compensating observed injuries, a larger ecosystem-based approach, to the extent that the proposed protocols can be scaled up to meaningful areas affected. This is possible with substrate placement.
    - Number of damaged individuals is definitely underestimated.
- What factors need to be considered to achieve target numbers, e.g., mortality, recruitment, and how should target numbers be adjusted to compensate?
    - Potential damage to deepwater species (below 800–900 m) is a huge concern. It is possible that they won't survive after being removed and placed back. Other labs have shown deep water taxa only last in the lab for a few days. Additionally, they don't survive the higher temperatures of shallower depths. Is the potential damage worth trying this?
    - Survivability of species. To improve survivability, different approaches were mentioned:
        - Experiment with species to understand survivability after propagation
        - Consider lab methods that may improve survivability and growth
        - Bring up to ship, fragment, and put back down
    - Natural density of colonies
    - Allee effects; failed reproduction caused by loss of colonies

    - Time frame of project—would you see a positive effect from propagation during the length of the project? Would you see juvenile growth?
    - Understanding reproductive modes and development is key to this project.
    - Preservation of genetic diversity (reducing clonality)—need to make sure we are not only fragmenting males, for example—how do we do this?
- What is regulating populations and what are the natural levels of mortality? Understanding this is necessary to put into restoration context.
    - Better taxonomy—poor species IDs, need more work in morphology and genetics
    - Size of fragment and proportion of colony—how big or small should a fragment be and how much of the mother colony should we be conserving?
- How do we restore hundreds of corals? What kind of studies need to be done to estimate these factors?
    - Consider artificial corals as substrate for other corals.
    - There are many caveats to consider *for in-situ* fragmentation, and many different approaches to consider (e.g. using tech divers, pressure vessels, etc.)
    - Lab experiments must be conducted to understand growth and survivability of fragmented corals.

**3. Status of Knowledge of Mesophotic and Deepwater Coral Species Genetics**

- Does this appear comprehensive and accurate?
    - This is the only discussion question for which we didn't receive a clear response during the meeting. No objections or obvious missing data were stated, but may need to follow-up with a future brief discussion.
    - Do participants agree with the species priorities identified for genetic analyses, and the criteria used to rank them?
    - Need to differentiate what the different goals are—if the goal is to understand diversity, then prioritize taxa with little to no data. For propagation purposes, higher priority should be to increase the knowledge of population genetics and species diversity of target injured taxa
- Are there caveats to consider, improvements we could make, or recommendations for further analyses?
    - If we want information on kinship among colonies we are trying to outplant, it will require different numbers of individuals and more genomic data than some simpler genetic analyses (e.g. barcoding).
    - Taxonomy is a mess and understanding cryptic species is critical. *Paramuricea biscaya*, one of the target priorities for propagation, may be two species, both impacted. Need to use museum samples and move away from popular mitochondrial and nuclear barcodes. Additionally, cryptic species are usually occupying slightly different habitats and depths, so restoring blindly could increase mortality.
    - Need the best set of genetic data possible on the species we plan to propagate. Need to maintain good representation of the population, not just use one genotype to populate. We also don't know which genotypes were more injured. The goal should be to restore the pre-spill populations that were injured, but we don't really have the data to show

which ones were more or less impacted. Corals moved into injured sites could also be injured. There could be a reason that populations are different.
    - Fill data gaps highlighted in newest Herrera et al. paper about *Paramuricea* population differences and connectivity.
    - Unknown diseases—don't want to introduce bad bugs to injured sites
    - Demography and size frequency histograms of species
    - Need more morphology work. Need to be able to identify species accurately when collecting, but mostly not possible. MBARI is developing new tools to look at coral morphology via video, even down to sclerites. Kakani Katja at Monterey Bay Aquarium Research Institute (MBARI) is developing some new imagery tools
    - To ensure accurate species ID, can place a marker, bring snip up, ID, and then put back down
    - Do whole genome sequencing for critical species. Need to understand mortality rates to determine if you try fragmentation in situ versus the in the lab.
- Which genetic analyses should we prioritize? Which other taxa should we prioritize?
    - Move away from traditional barcoding.
    - Better to use RAD-seq or target capture to get much more data. Can use target capture and then spike with genomic DNA to get the mitochondrial and nuclear barcodes of interest.
    - Combination of "genome skimming" should be used to get a complete mitochondrial genome with ribosomal operon, in addition to target capture
    - Prioritize target capture (and spiking with genomic DNA) for species relationships, leveraging museum samples, and delineating between cryptic species. Prioritize RAD-seq for population genetics, but can also use target capture.
    - Improving taxonomy and phylogeny is a must.
    - Understanding population connectivity is a must for the species we plan to propagate.

## 3.4. Follow-up Survey to Subject Matter Experts

All survey results can be found in Appendix E. A summary of results is below. This feedback will help inform the 5-year implementation plan for the CPT project.

**1. Focus Group 1 had 100% survey response rate from a very experienced group**

Of the twelve respondents, 83% have more than 10 years of experience working with corals, 75% published more than 10 peer reviewed journal articles about corals, and 50% have worked in the GOM for 10 years or more.

**2. Survey results were unanimous about propagation activities in the mesophotic zone**

The consensus was to 'take action' in the mesophotic (meso) zone first. Risk and cost of work in the mesophotic is not as great as in the deep. Respondents votes to attempt propagation in the field and lab, using the coral gardening techniques 'assuming small numbers of locally adapted individuals distributed across local gradients (*sensu* Baums et al. 2019). There was some difference of opinion about whether to introduce substrate; two-thirds agreed we should introduce substrate. Of those, 75% favored natural and engineered and 25% prefer natural substrate only. No one favored only using engineered substrates.

**3. There was some difference of opinion about propagation activities in the deep sea**

There was consensus to act, since no one selected 'take no action'. Sixty-six percent recommended we attempt propagation, 'assuming locally adapted individuals in small numbers across local gradients (*sensu* Baums et al. 2019). Eighty-three percent agreed we should introduce natural and engineered substrate in the deep-sea. Forty-two percent of respondents believe the risk of propagation in the deep-sea 'is too great' and 16% believe the costs are too high. There was some concern that these techniques should be evaluated further. Regarding the best way to go about restoration in the deep sea, one-third said to attempt work in the field and lab using the coral gardening techniques with locally adapted individuals, one-third said to work in the field only, and one-third said to start small and be cautious.

**4. There was some difference of opinion about where to propagate corals**

The majority (70%) said we should propagate at sites of injury; and 25% said not to. Seventy-five percent said we should propagate at adjacent reference sites; and 25% said not to. Some of the free text comments indicated more nuance than a simple yes/no.

**5. There was some difference of opinion about best locations of reference sites**

A total of 58% think we should propagate at other reference sites; 41% said not to. Of the 71% who think we should propagate at other reference sites say sites should be in the Northern Gulf; 28% say sites anywhere in the Gulf. No one who thought we should propagate at reference sites thought we should include the entire West Atlantic.

**6. Knowledge priorities were clearly identified**

Highest ranked knowledge priorities, in order of priority were reproductive biology, genetic diversity, settlement substrates, and growth. Middle ranked were microbial ecology and transport modeling. Lowest ranked were metabolism, feeding and disease resistance. Other recommendations included local adaptation, predation, environmental requirements, survival rate of recruits and population genetic structure.

**7. Most promising actions in the short term (2–3 years, mesophotic and deep)**

Highest ranked action priorities were to conduct studies of biology, fragment corals in situ, and outplant fragments and genets. Lower ranked actions were to deploy natural substrates (low in meso), followed by deploy engineered substrates. One participant included to 'monitor for natural recovery/loss' (deep).

**8. Most promising actions in the long term (5–7 years, mesophotic and deep)**

Highest ranked action priorities were to outplant fragments/genets (meso) and conduct studies of biology. Middle ranks were to fragment in situ (low in meso*)*, deploy natural substrates (deep) and deploy engineered substrates (deep). Lowest ranked were to deploy natural substrates (meso) and engineered substrates (meso).

# 4. Conclusions and Next Steps

The results generated from the DIA analyses suggest our top target coral species for propagation should be *Swiftia exserta*, *Muricea pendula*, and *Thesea nivea* in the mesophotic zone, and *Paramuricea biscaya* in the deep sea. This is a result of the work from the literature review of DWH coral injury and the species prioritization matrix and ranking exercise.  There was no disagreement on these targets from participants of the focus group.

Feedback from the focus group reiterates the importance of managing risk in the deep sea, and understanding the population connectivity, microbial biology, and intraspecific diversity of coral species we wish to outplant. It is also critical to understand the modes of reproduction of target corals. Lastly, restoration attempts should start in the mesophotic zone and with small numbers of corals, using technical divers.

Using the results presented here, along with the advice and recommendations of SMEs, future CPT activities will:

- Develop methods and metrics to monitor coral health and growth, both in the laboratory and in situ
- Conduct field and lab work to test a variety of different substrates/techniques as potential colonization substrates and transplant methods, including direct in situ transplants, and use of laboratory grown coral fragments
- Conduct lab work to develop coral husbandry techniques and specialized analyses of biological and environmental samples.
- Work with internal and external partners to conduct genetic and taxonomic studies of target coral species for propagation

# Appendices

## Appendix A. Species Prioritization Matrix

Table A.1. List of species incorporated into the prioritization matrix. Meso – mesophotic; NA – not applicable.

| Order | Zone | Species | Injured? | Counts of injury | Management Relevance | | |
|---|---|---|---|---|---|---|---|
| | | | | | OORP2 | RESTORE or CRP funded | Council priority |
| Antipatharia | Meso | *Stichopathes sp.* | Y | 13 | N | Y | Y |
| Antipatharia | Meso | *Antipathes atlantica* | Y | 24 | N | Y | Y |
| Octocoralllia | Meso | *Acanthogorgia* sp. | NA | NA | N | N | N |
| Octocorallia | Meso | *Bebryce* spp. | Y | 76 | Y | N | N |
| Octocorallia | Meso | *Ellisella elongata/barbadensis* | Y | 0 | N | N | N |
| Octocorallia | Meso | *Leptogorgia violacea* | NA | | N | N | N |
| Octocorallia | Meso | *Muricea pendula* | Y | 18-182 | Y | Y | N |
| Octocorallia | Meso | *Muriceides hirta* | Y | | Y | N | N |
| Octocorallia | Meso | *Nicella americana* | NA | NA | N | N | N |
| Octocorallia | Meso | *Nicella* sp. | NA | NA | N | N | N |
| Octocorallia | Meso | *Paramuricea* sp. | Y | | Y | N | N |
| Octocorallia | Meso | *Placogorgia* spp. | Y | 5 | Y | N | N |
| Octocorallia | Meso | *Scleracis guadalupensis* | NA | NA | N | N | N |
| Octocorallia | Meso | *Scleracis* sp. | NA | NA | N | N | N |
| Octocorallia | Meso | *Swiftia exserta* | Y | 81-82 | Y | Y | N |
| Octocorallia | Meso | *Thesea citrina* | NA | NA | N | N | N |
| Octocorallia | Meso | *Thesea granulosa* | NA | NA | N | N | N |
| Octocorallia | Meso | *Thesea hebes* | NA | NA | N | N | N |
| Octocorallia | Meso | *Thesea nivea* | Y | 36-64 | Y | N | N |
| Octocorallia | Meso | *Thesea parviflora* | NA | NA | Y | N | N |
| Octocorallia | Meso | *Thesea rubra* | Y | | Y | N | N |
| Octocorallia | Meso | *Villogorgia nigrescens* | NA | NA | N | N | N |
| Scleractinia | Meso | *Madracis* spp. | N | 0 | Y | N | Y |
| Scleractinia | Meso | *Oculina diffusa* | N | 0 | Y | N | Y |
| Scleractinia | Meso | *Oculina tenella* | N | 0 | Y | N | Y |
| Scleractinia | Meso | *Oculina varicosa* | N | 0 | Y | N | Y |
| Antipatharia | Deep | *Bathypathes* spp. | Y | 0-2 | Y | N | Y |
| Antipatharia | Deep | *Leiopathes glaberrima* | N | NA | Y | N | Y |
| Octocorallia | Deep | *Acanthogorgia aspera* | Y | 0-1 | N | N | N |
| Octocorallia | Deep | *Callogorgia delta* | N | NA | Y | Y | N |
| Octocorallia | Deep | *Chrysogorgia* spp. | NA | 0 | Y | N | N |
| Octocorallia | Deep | *Clavularia* | Y | NA | N | N | N |
| Octocorallia | Deep | *Paragorgia regalis* | Y | 0-1 | N | N | N |
| Octocorallia | Deep | *Swiftia pallida* | Y | 1-2 | N | N | N |
| Octocorallia | Deep | *Paramuricea biscaya* | Y | 39 - 166 | Y | Y | N |
| Octocorallia | Deep | *Paramuricea* sp. B3. | Y | 3 | Y | Y | N |
| Octocorallia | Deep | *Keratoisis* sp. | Y | 0-3 | N | N | N |
| Scleractinia | Deep | *Lophelia pertusa* | N | NA | Y | N | Y |
| Scleractinia | Deep | *Madrepora carolina* | NA | NA | Y | N | Y |
| Scleractinia | Deep | *Madrepora oculata* | NA | NA | Y | N | Y |

## Appendix B: List of Focus Group Participants

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## Appendix C: Status of Knowledge of Mesophotic and Deepwater Coral Species Genetics – Additional Results

### *Octocorals with no genetic data available (n=57)*

*Acanella aurelia*
*Acanthogorgia schrammi*
*Anthothela quattriniae*
*Anthothela tropicalis*
*Bebryce cinerea*
*Bebryce grandis*
*Bebryce parastellata*
*Callipodium rubens*
*Callogorgia linguimaris*
*Chironephthya agassizii* (= *Siphonogorgia agassizi*)
*Chrysogorgia desbonni*
*Chrysogorgia elegans*
*Chrysogorgia fewkesii*
*Chrysogorgia multiflora*
*Chrysogorgia spiculosa*
*Ellisella atlantica* (= *Ctenocella* (*Viminella*) *atlantica*)
*Ellisella funiculina*
*Epiphaxum breve*
*Iridogorgia pourtalesii*
*Leptogorgia cardinalis*
*Leptogorgia medusa*
*Metallogorgia* sp. *j*
*Muriceides kukenthali*
*Narella spectabilis*
*Nicella deichmannae*
*Nicella flagellum*
*Nicella guadalupensis*
*Nicella hebes*
*Nicella robusta*
*Nicella spicula*
*Nidalia deichmannae*
*Nidalia occidentalis*
*Placogorgia mirabilis*
*Placogorgia rudis*
*Plumarella dichotoma*
*Pseudoanthomastus* sp.
*Riisea paniculata*
*Scleracis petrosa*
*Scleranthelia rugosa* var. *musiva*
*Scleranthelia rugosa* var. *rugosa*
*Spinimuricea atlantica* (= *Echinomuricea atlantica*)
*Stenisis humilis*
*Stereotelesto corallina*
*Telesto flavula*
*Telesto fruticulosa*
*Telesto sanguinea*
*Thesea citrina*
*Thesea grandiflora*
*Thesea granulosa*
*Thesea guadalupensis*
*Thesea hebes*
*Thesea nivea*
*Thesea parviflora*
*Thesea rubra*
*Thesea rugosa*
*Thesea solitaria*
*Villogorgia nigrescens*

### *Scleractinians with no genetic data available (n=46)*

*Anomocora fecunda*
*Anomocora marchadi*
*Anomocora prolifera*
*Astrangia solitaria*
*Balanophyllia floridana*
*Balanophyllia palifera*
*Bathypsammia tintinnabulum*
*Caryophyllia ambrosia caribbeana*
*Caryophyllia antillarum*
*Caryophyllia barbadensis*
*Caryophyllia berteriana*
*Caryophyllia horologium*
*Caryophyllia polygona*
*Cladocora debilis*
*Coenocyathus caribbeana*
*Coenocyathus parvulus*
*Coenosmilia arbuscula*
*Concentrotheca laevigata*
*Dasmosmilia variegata*
*Deltocyathoides stimpsonii* (= *Peponocyathus stimpsonii*)
*Deltocyathus calcar*
*Deltocyathus eccentricus*
*Deltocyathus italicus*
*Eguchipsammia cornucopia* (= *Dendrophyllia cornucopia*)
*Flabellum* (*Ulocyathus*) *moseleyi*
*Flabellum floridanum* (= *Flabellum fragile*)

*Fungiacyathus* (*Bathyactis*) *crispus*
*Labyrinthocyathus langae*
*Madracis asperula*
*Madracis brueggemanni*
*Madrepora carolina*
*Oculina tenella*
*Oxysmilia rotundiflora*
*Phacelocyathus flos*
*Phyllangia americana americana*
*Phyllangia pequegnatae*
*Polycyathus senegalensis*
*Polymyces fragilis* (= *Rhizotrochus fragilis*)
*Pourtalocyathus hispidus*
*Pourtalosmilia conferta*
*Premocyathus cornuformis*
*Rhizopsammia goesi*
*Schizocyathus fissilis*
*Stephanocyathus paliferus*
*Tethocyathus cylindraceus*
*Trochocyathus rawsonii*

### *Black corals w/no genetic data available (n=9)*

*Acanthopathes humilis*
*Antipathes gracilis*
*Antipathes lenta*
*Aphanipathes salix*
*Parantipathes tetrasticha*
*Stichopathes pourtalesi*
*Stylopathes americana* (= *Antipathes americana*)
*Stylopathes columnaris*
*Tanacetipathes hirta*

### *Pennatulaceans w/ no genetic data available (n=6)*

*Acanthoptilum agassizii*
*Acanthoptilum oligacis*
*Protoptilum thomsoni*
*Stylatula antillarum*
*Umbellula guentheri*
*Virgularia presbytes*

Table C.1. All species examined and their ranking score (see section 2.3. for ranking criteria)

| All species | Ranking | All species | Ranking | All species | Ranking |
|---|---|---|---|---|---|
| *Acanella aurelia* | 4 | *Chrysogorgia fewkesii* | 4 | *Nicella flagellum* | 4 |
| *Acanthogorgia schrammi* | 4 | *Chrysogorgia multiflora* | 4 | *Nicella guadalupensis* | 4 |
| *Acanthopathes humilis* | 4 | *Chrysogorgia spiculosa* | 4 | *Nicella hebes* | 4 |
| *Acanthoptilum agassizii* | 4 | *Cladocora debilis* | 4 | *Nicella robusta* | 4 |
| *Acanthoptilum oligacis* | 4 | *Coenocyathus caribbeana* | 4 | *Nicella spicula* | 4 |
| *Anomocora fecunda* | 4 | *Coenocyathus parvulus* | 4 | *Nidalia deichmannae* | 4 |
| *Anomocora marchadi* | 4 | *Coenosmilia arbuscula* | 4 | *Nidalia occidentalis* | 4 |
| *Anomocora prolifera* | 4 | *Concentrotheca laevigata* | 4 | *Oculina tenella* | 4 |
| *Anthothela quattriniae* | 4 | *Dasmosmilia variegata* | 4 | *Oxysmilia rotundiflora* | 4 |
| *Anthothela tropicalis* | 4 | *Deltocyathoides stimpsonii* (= *Peponocyathus stimpsonii)* | 4 | *Parantipathes tetrasticha* | 4 |
| *Antipathes gracilis* | 4 | *Deltocyathus calcar* | 4 | *Phacelocyathus flos* | 4 |
| *Antipathes lenta* | 4 | *Deltocyathus eccentricus* | 4 | *Phyllangia americana americana* | 4 |
| *Aphanipathes salix* | 4 | *Deltocyathus italicus* | 4 | *Phyllangia pequegnatae* | 4 |
| *Astrangia solitaria* | 4 | *Eguchipsammia cornucopia* (= *Dendrophyllia cornucopia)* | 4 | *Placogorgia mirabilis* | 4 |
| *Balanophyllia floridana* | 4 | *Ellisella atlantica* (= *Ctenocella (Viminella) atlantica)* | 4 | *Placogorgia rudis* | 4 |
| *Balanophyllia palifera* | 4 | *Ellisella funiculina* | 4 | *Plumarella dichotoma* | 4 |
| *Bathypsammia tintinnabulum* | 4 | *Epiphaxum breve* | 4 | *Polycyathus senegalensis* | 4 |
| *Bebryce cinerea* | 4 | *Flabellum (Ulocyathus) moseleyi* | 4 | *Polymyces fragilis* (= *Rhizotrochus fragilis)* | 4 |
| *Bebryce grandis* | 4 | *Flabellum floridanu* (= *Flabellum fragile)* | 4 | *Pourtalocyathus hispidus* | 4 |
| *Bebryce parastellata* | 4 | *Fungiacyathus (Bathyactis) crispus* | 4 | *Pourtalosmilia conferta* | 4 |
| *Callipodium rubens* | 4 | *Iridogorgia pourtalesii* | 4 | *Premocyathus cornuformis* | 4 |
| *Callogorgia linguimaris* | 4 | *Labyrinthocyathus langae* | 4 | *Protoptilum thomsoni* | 4 |
| *Caryophyllia ambrosia caribbeana* | 4 | *Leptogorgia cardinalis* | 4 | *Pseudoanthomastus* sp. | 4 |
| *Caryophyllia antillarum* | 4 | *Leptogorgia medusa* | 4 | *Rhizopsammia goesi* | 4 |
| *Caryophyllia barbadensis* | 4 | *Madracis asperula* | 4 | *Riisea paniculata* | 4 |
| *Caryophyllia berteriana* | 4 | *Madracis brueggemanni* | 4 | *Schizocyathus fissilis* | 4 |
| *Caryophyllia horologium* | 4 | *Madrepora carolina* | 4 | *Scleracis petrosa* | 4 |
| *Caryophyllia polygona* | 4 | *Metallogorgia* sp. j | 4 | *Scleranthelia rugosa* var. *musiva* | 4 |
| *Chironephthya agassizii* (= *Siphonogorgia agassizi)* | 4 | *Muriceides kukenthali* | 4 | *Scleranthelia rugosa* var. *rugosa* | 4 |
| *Chrysogorgia desbonni* | 4 | *Narella spectabilis* | 4 | *Stenisis humilis* | 4 |
| *Chrysogorgia elegans* | 4 | *Nicella deichmannae* | 4 | *Stephanocyathus paliferus* | 4 |

| All species | Ranking | All species | Ranking | All species | Ranking |
|---|---|---|---|---|---|
| *Stereotelesto corallina* | 4 | *Caliacis nutans (= Thesea nutans)* | 3 | *Nicella toeplitzae* | 3 |
| *Stichopathes pourtalesi* | 4 | *Cladopsammia manuelensis (= Rhizopsammia manuelensis)* | 3 | *Nidalia dissidens* | 3 |
| *Stylatula antillarum* | 4 | *Clavularia rudis* | 3 | *Oculina diffusa* | 3 |
| *Stylopathes Americana (= Antipathes americana)* | 4 | *Cladopsammia manuelensis (= Rhizopsammia manuelensis)* | 3 | *Paracalyptrophora carinata* | 3 |
| *Stylopathes columnaris* | 4 | *Clavularia rudis* | 3 | *Paracyathus pulchellus* | 3 |
| *Tanacetipathes hirta* | 4 | *Dasmosmilia lymani* | 3 | *Paragorgia regalis* | 3 |
| *Telesto flavula* | 4 | *Dendrophyllia alternata* | 3 | *Paramuricea multispina* | 3 |
| *Telesto fruticulosa* | 4 | *Distichopathes hickersonae* | 3 | *Paramuricea placomus* | 3 |
| *Telesto sanguinea* | 4 | *Ellisella elongata/barbadensis* | 3 | *Paramuricea* sp. | 3 |
| *Tethocyathus cylindraceus* | 4 | *Ellisella schmitti (= Ctenocella (Ellisella) schmitti)* | 3 | *Phanopathes expansa* | 3 |
| *Thesea citrina* | 4 | *Guynia annulata* | 3 | *Phanopathes rigida (= Antipathes rigida)* | 3 |
| *Thesea grandiflora* | 4 | *Hemicorallium Niobe (= Corallium niobe)* | 3 | *Placogorgia* sp. | 3 |
| *Thesea granulosa* | 4 | *Iridogorgia magnispiralis* | 3 | *Placogorgia tenuis* | 3 |
| *Thesea guadalupensis* | 4 | *Javania cailleti* | 3 | *Plumapathes pennacea* | 3 |
| *Thesea hebes* | 4 | *Keratoisis flexibilis* | 3 | *Rhizosmilia maculata* | 3 |
| *Thesea nivea* | 4 | *Keratoisis* sp. | 3 | *Scleracis guadalupensis* | 3 |
| *Thesea parviflora* | 4 | *Labyrinthocyathus facetus* | 3 | *Scleracis* sp. | 3 |
| *Thesea rubra* | 4 | *Lateothela grandiflora* | 3 | *Sibopathes macrospina* | 3 |
| *Thesea rugosa* | 4 | *Leptogorgia euryale* | 3 | *Spinimuricea atlantica (= Echinomuricea atlantica)* | 3 |
| *Thesea solitaria* | 4 | *Leptogorgia stheno* | 3 | *Stenocyathus vermiformis* | 3 |
| *Trochocyathus rawsonii* | 4 | *Leptogorgia violacea* | 3 | *Stephanocyathus (Odontocyathus) coronatus* | 3 |
| *Umbellula guentheri* | 4 | *Lytreia plana* | 3 | *Stephanocyathus (Stephanocyathus) diadema* | 3 |
| *Villogorgia nigrescens* | 4 | *Madracis pharensis* | 3 | *Stichopathes occidentalis* | 3 |
| *Virgularia presbytes* | 4 | *Muricea laxa* | 3 | *Stylaster duchassaingi* | 3 |
| *Acanthogorgia armata* | 3 | *Muriceides hirta* | 3 | *Stylopathes litocrada* | 3 |
| *Acanthogorgia aspera* | 3 | *Narella pauciflora* | 3 | *Swiftia casta* | 3 |
| *Allopathes desbonni* | 3 | *Nicella americana* | 3 | *Swiftia koreni* | 3 |
| *Antipathes furcata* | 3 | *Nicella goreaui* | 3 | *Tanacetipathes barbadensis* | 3 |
| *Astrangia poculata* | 3 | *Nicella obesa* | 3 | *Tanacetipathes tanacetum* | 3 |
| *Bathyalcyon robustum delta (= Anthomastus (Bathyalcyon) robustus delta)* | | *Nicella* sp. | 3 | *Thalamophyllia riisei* | 3 |

| All species | Ranking | All species | Ranking | All species | Ranking |
|---|---|---|---|---|---|
| *Thecopsammia socialis* | 3 | *Aphanipathes pedata* | 0 | *Enallopsammia rostrata* | 0 |
| *Thesea* sp. | 3 | *Bathypathes patula* | 0 | *Heteropathes americana* | 0 |
| *Villogorgia* sp. | 3 | *Bebryce* sp. | 0 | *Iridogorgia splendens* | 0 |
| *Acanella arbuscula* (*= Acanella eburnean)* | 2 | *Callogorgia delta* | 0 | *Leiopathes glaberrima* | 0 |
| *Anthoptilum grandiflorum* | 2 | *Candidella imbricata* | 0 | *Lophelia pertusa* | 0 |
| *Funiculina quadrangularis* | 2 | *Carijoa riisei* | 0 | *Madracis myriaster* | 0 |
| *Stichopathes luetkeni* | 2 | *Chelidonisis aurantiaca mexicana* | 0 | *Madrepora oculata* | 0 |
| *Tanacetipathes thamnea* | 2 | *Chrysogorgia averta* | 0 | *Muricea pendula* (*= Hypnogorgia pendula)* | 0 |
| *Bathypathes* sp. | 1 | *Chrysogorgia sp.* | 0 | *Oculina varicosa* | 0 |
| *Leptogorgia virgulata* | 1 | *Desmophyllum dianthus* | 0 | *Paragorgia johnsoni* | 0 |
| *Swiftia pallida* | 1 | *Diodogorgia nodulifera* | 0 | *Paramuricea biscaya* | 0 |
| *Virgularia mirabilis* | 1 | *Distichopathes filix* | 0 | *Paramuricea* sp. B3 | 0 |
| *Acanthopathes thyoides* | 0 | *Elatopathes abietina* | 0 | *Sibogagorgia cauliflora* | 0 |
| *Antipathes atlantica* | 0 | *Ellisella* sp. | 0 | *Swiftia exserta* | 0 |
| *Antipathes atlantica* | 0 | *Enallopsammia profunda* | 0 | | |

Table C.2. All genera examined and their average species ranking score (see Section 2.3. for ranking criteria)

| All genera | Avg. ranking | All genera | Avg. ranking | All genera | Avg. ranking | All genera | Avg. ranking |
|---|---|---|---|---|---|---|---|
| Acanella | 3.0 | Concentrotheca | 4.0 | Metallogorgia | 4.0 | Scleracis | 3.3 |
| Acanthogorgia | 3.3 | Dasmosmilia | 4.0 | Muricea | 1.5 | Scleranthelia | 4.0 |
| Acanthopathes | 2.0 | Deltocyathoides | 4.0 | Muriceides | 3.5 | Sibogagorgia | 0.0 |
| Acanthoptilum | 4.0 | Deltocyathus | 4.0 | Narella | 3.5 | Sibopathes | 3.0 |
| Allopathes | 3.0 | Dendrophyllia | 3.0 | Nicella | 3.5 | Spinimuricea | 3.0 |
| Anomocora | 4.0 | Desmophyllum | 0.0 | Nidalia | 3.7 | Stenisis | 4.0 |
| Anthoptilum | 2.0 | Diodogorgia | 0.0 | Oculina | 2.3 | Stenocyathus | 3.0 |
| Anthothela | 4.0 | Disthichopathes | 1.5 | Oxysmilia | 4.0 | Stephanocyathus | 3.3 |
| Antipathes | 2.8 | Eguchipsammia | 4.0 | Paracalyptrophora | 3.0 | Stereotelesto | 4.0 |
| Aphanipathes | 2.0 | Elatopathes | 0.0 | Paracyathus | 3.0 | Stichopathes | 3.0 |
| Astrangia | 3.5 | Ellisella | 2.8 | Paragorgia | 1.5 | Stylaster | 3.0 |
| Balanophyllia | 4.0 | Enallopsammia | 0.0 | Paramuricea | 1.8 | Stylatula | 4.0 |
| Bathyalcyon | 3.0 | Epiphaxum | 4.0 | Parantipathes | 4.0 | Stylopathes | 3.7 |
| Bathypathes | 0.5 | Flabellum | 4.0 | Phacelocyathus | 4.0 | Swiftia | 1.8 |
| Bathypsammia | 4.0 | Fungiacyathus | 4.0 | Phanopathes | 3.0 | Tanacetipathes | 3.0 |
| Bebryce | 3.0 | Funiculina | 2.0 | Phyllangia | 4.0 | Telesto | 4.0 |
| Caliacis | 3.0 | Guynia | 3.0 | Placogorgia | 3.5 | Tethocyathus | 4.0 |
| Callipodium | 4.0 | Hemicorallium | 3.0 | Plumapathes | 3.0 | Thalamophyllia | 3.0 |
| Callogorgia | 2.5 | Heteropathes | 0.0 | Plumarella | 4.0 | Thecopsammia | 3.0 |
| Candidella | 0.0 | Iridogorgia | 2.3 | Polycyathus | 4.0 | Thesea | 3.9 |
| Carijoa | 0.0 | Javania | 3.0 | Polymyces | 4.0 | Trochocyathus | 4.0 |
| Caryophyllia | 4.0 | Keratoisis | 3.0 | Pourtalocyathus | 4.0 | Umbellula | 4.0 |
| Chelidonisis | 0.0 | Labyrinthocyathus | 3.5 | Pourtalosmilia | 4.0 | Villogorgia | 3.5 |
| Chironephthya | 3.5 | Lateothela | 3.0 | Premocyathus | 4.0 | Virgularia | 2.5 |
| Chrysogorgia | 2.9 | Leiopathes | 0.0 | Protoptilum | 4.0 | | |
| Cladocora | 4.0 | Leptogorgia | 2.6 | Pseudoanthomastus | 4.0 | | |
| Cladopsammia | 3.0 | Lophelia | 0.0 | Rhizopsammia | 4.0 | | |
| Clavularia | 3.0 | Lytreia | 3.0 | Rhizosmilia | 3.0 | | |
| Coenocyathus | 4.0 | Madracis | 2.8 | Riisea | 4.0 | | |
| Coenosmilia | 4.0 | Madrepora | 2.0 | Schizocyathus | 4.0 | | |

## Appendix D: DWH Coral Injury Bibliography (revised)

### *Field observations of coral injury*


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# Appendix E: Follow-up Expert Survey Results

Results from the follow-up expert surveys.

## E.1. Demographics

Results from question related to the demographic information of the subject matter experts surveyed.

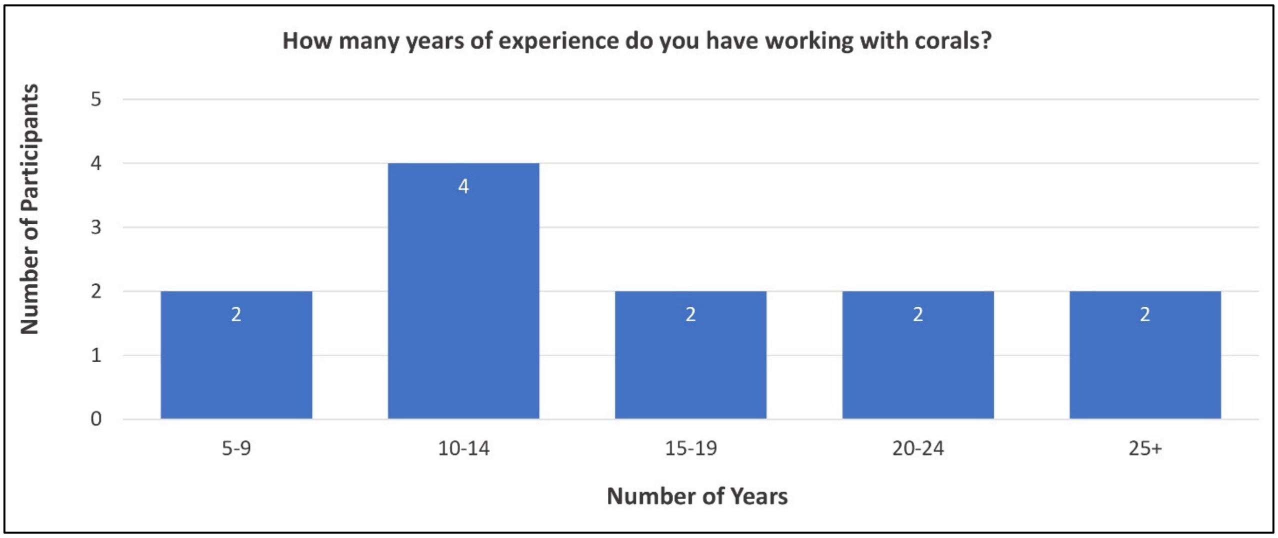


Figure E.1. Bar graph showing responses from 12 participants regarding the number of years spent working with corals.

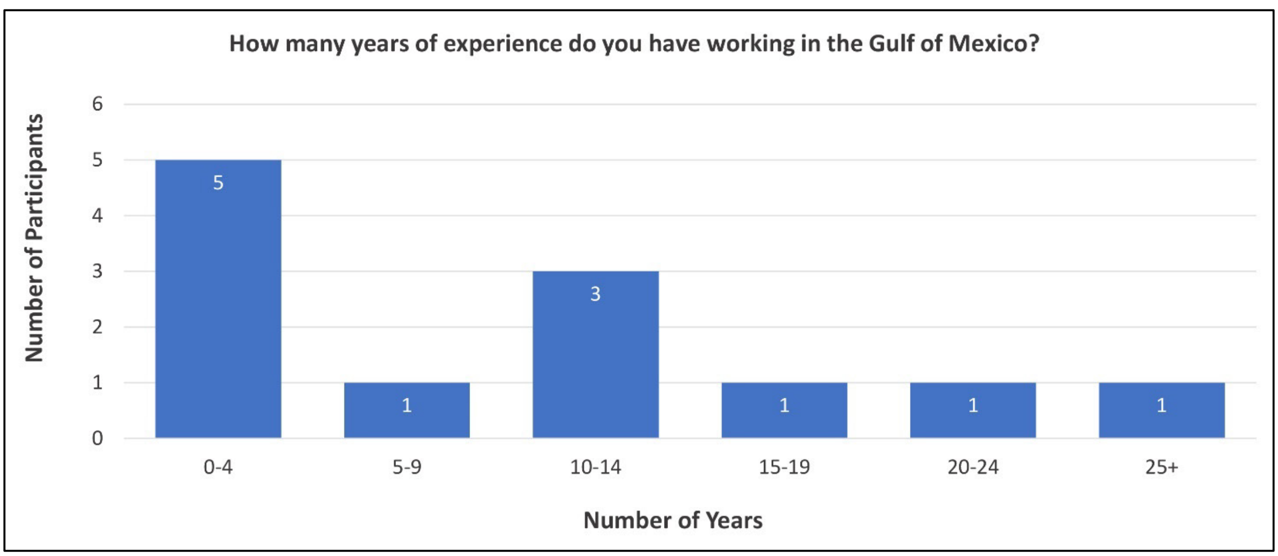


Figure E.2. Bar graph showing responses from 12 participants regarding the number of years spent working in Gulf of Mexico research.

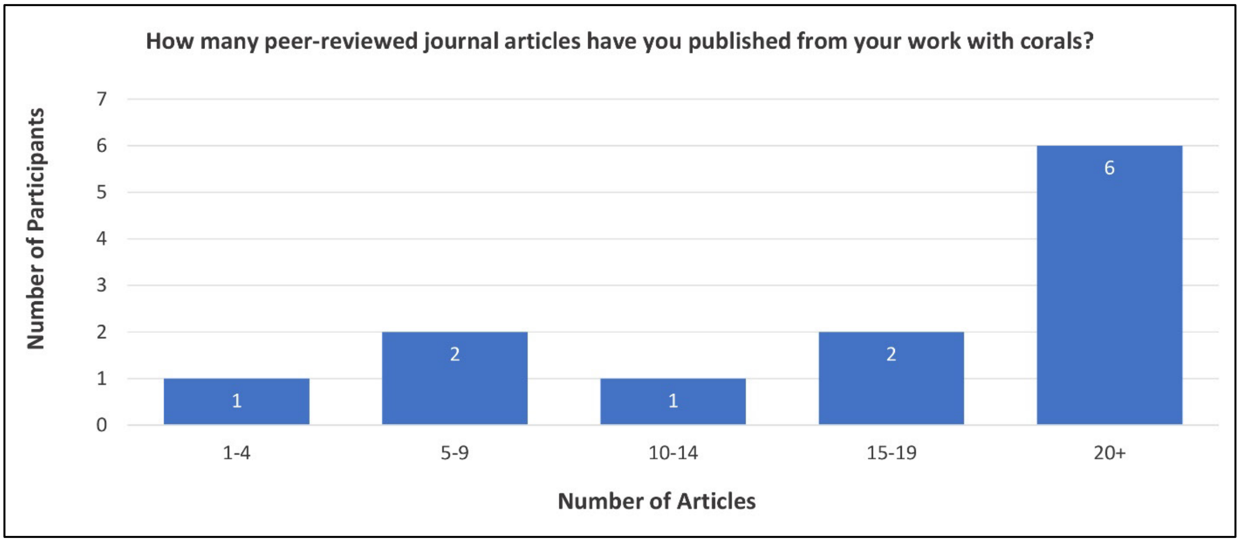


Figure E.3. Bar graph showing responses from 12 participants regarding the number of peer-reviewed articles published related to their coral research.

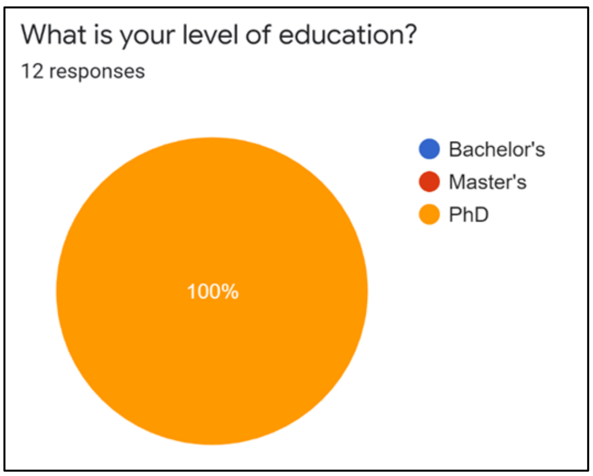


Figure E.4. Pie chart showing all 12 participants hold a Ph.D degree.

## E.2. Subject-related Questions

### E.2.1. Unanimous Responses

Questions resulting in unanimous responses. Overall, there was more agreement revolving around working in the mesophotic zone.

**Question: In your opinion, what is the best way to propagate corals in the MESOPHOTIC zone?**

Options:

- Take no action, let nature run its course
- Attempt work in the lab only (learn the biology)
- Attempt work in the field only (learn the habitat)
- Attempt work in the field and the lab (coral gardening)

CONSENSUS: Attempt work in the field and the lab (coral gardening)

**Question: Should we attempt propagation in the MESOPHOTIC? (assume locally adapted individuals [*sensu* Baums et al. 2019] in small numbers across local gradients)**

Options:

- Yes
- No

CONSENSUS**:** Yes

**Question: Are the risks of propagation too great in the MESOPHOTIC zone?**

Options:

- Yes
- No

CONSENSUS**:** No

**Question: Are the costs of propagation too great in the MESOPHOTIC? (assume ship time and assets are paid under NRDA settlement)**

Options:

- Yes
- No

CONSENSUS**:** No

### E.2.2. Divided Responses

Questions resulting in divided responses; particularly those that related to propagating in the deep sea resulted in divided opinions.

**Question: In your opinion, what is the best way to propagate corals in the DEEP SEA? (Figure E.5)**

Options were:

- Take no action, let nature run its course - 0 votes
- Attempt work in the lab only (learn the biology) - 0 votes
- Attempt work in the field only (learn the habitat) – 4 votes
- Attempt work in the field & the lab (coral gardening) – 4 votes
- Other* – 4 votes

*Other responses were as follows:

- "Attempt work in the mesophotic zone and below 1000 m first"
- "Start with lab/shallow water pilot programs and then apply those lessons to in situ experiments"
- "Gardening, but only at a very small scale first, plus artificial substrates"

- "I favor lab and field approaches that take incorporate the risk of damages induced by propagation into their design. My guess is that propagation for deep-sea species will likely be extremely difficult, based on our current knowledge."

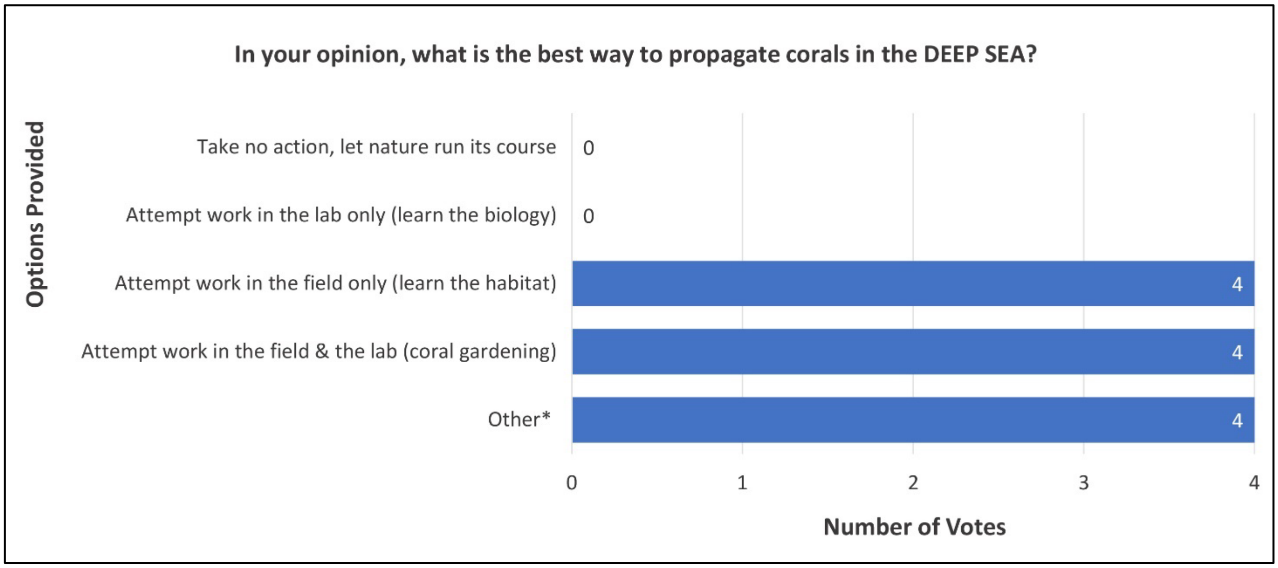


Figure E.5. Bar graph showing the amount of votes received for each propagation option provide.

**Question: Should we attempt propagation in the DEEP SEA? (assume locally adapted individuals [*sensu* Baums et al. 2019] in small numbers across local gradients)(Figure E.6)**

Options:

- Yes—66.7%
- No—33.3%

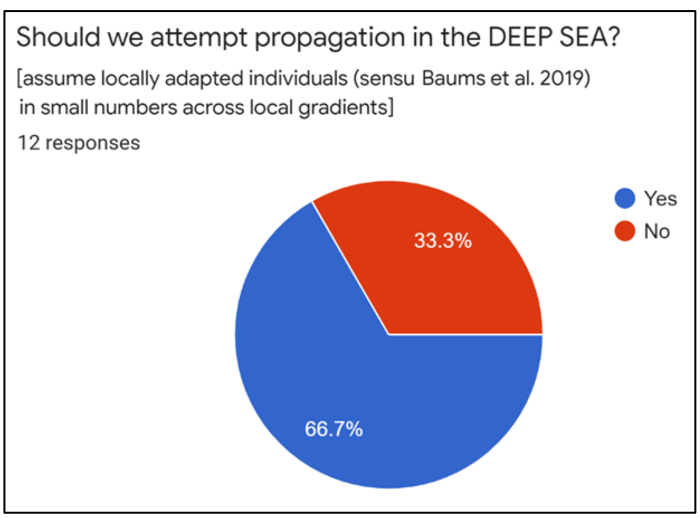


Figure E.6. Pie chart showing higher proportion of participants indicates we should attempt propagation in the deep sea.

**Question: Are the risks of propagation too great in the DEEP SEA? (Figure E.7)**

Options:

- Yes—41.7%
- No—58.3%

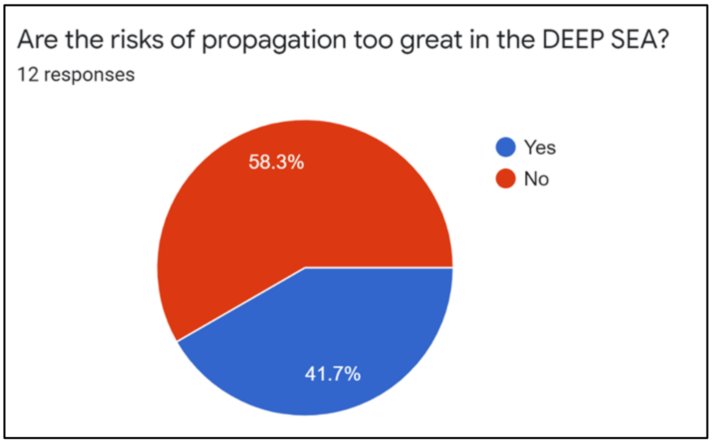


Figure E.7. Pie chart showing majority of participants believe the risks of propagation are too great in the deep sea.

**Question: Are the costs of propagation too great in the DEEP SEA? (assume ship time and assets are paid under NRDA settlement) (Figure E.8)**

Options:

- Yes—16.7%
- No—83.3%

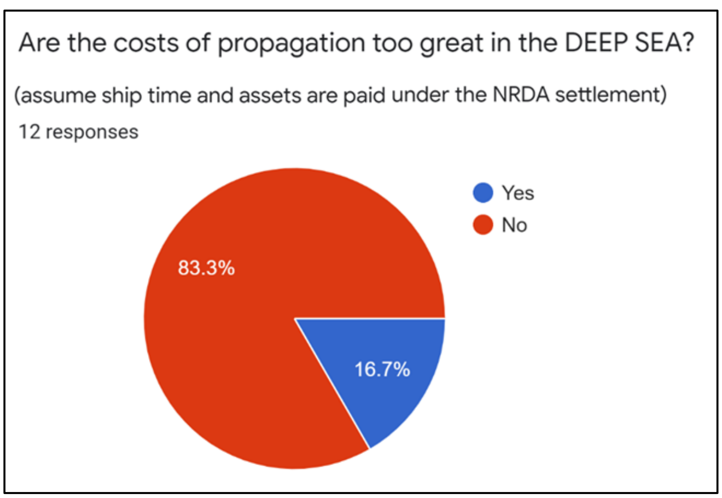


Figure E.8. Pie chart showing majority of participants do not believe the costs of propagation are too great in the deep sea.

**NOTE:** these same three questions (Figures E.6-E.8) received a unanimous response for the mesophotic zone (yes and no, respectively; Section E.1.).

**Question: Should we introduce substrate in the DEEP SEA? (Figure E.9)**

Options:

- Yes—83.3%
- No—16.7%

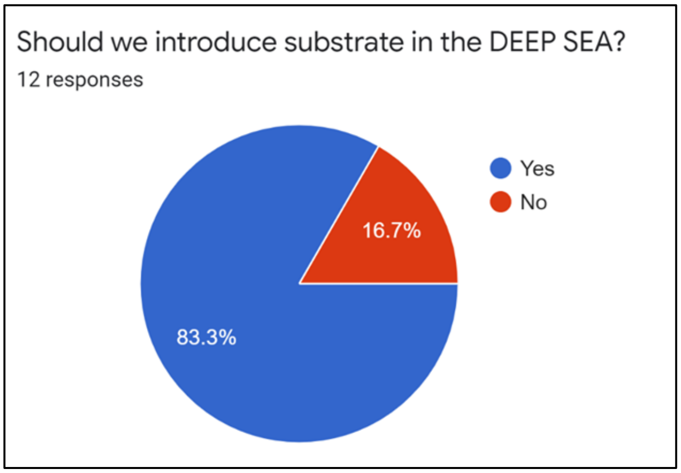


Figure E.9. Pie chart showing majority of participants believe we should introduce substrate in the deep sea.

**Question: If you answered yes (Figure E.9), which type of substrate? (Figure E.10)**

Options:

- Natural—10%
- Engineered—0%
- Both—90%

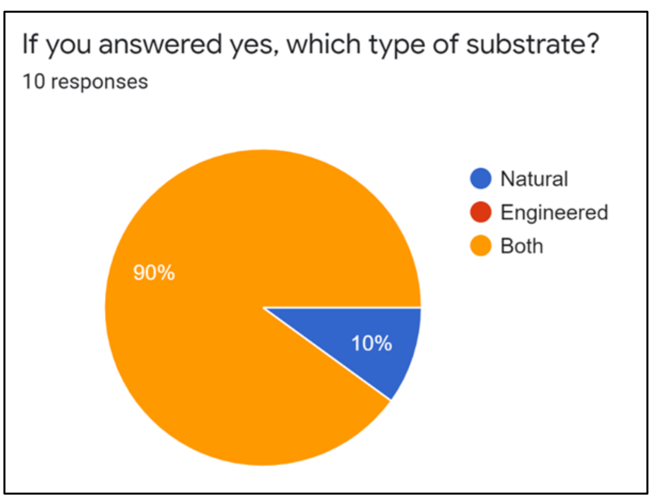


Figure E.10. Pie chart showing that participants who believe substrate should be introduced in the deep sea prefer the use of both natural and engineered substrates.

**Question: Should we introduce substrate in the MESOPHOTIC? (Figure E.11)**

Options:

- Yes—66.7%
- No—33.3%

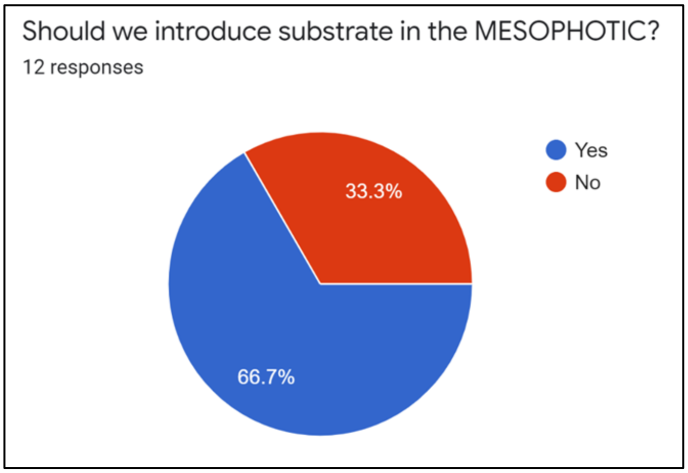


Figure E.11. Pie chart showing majority of participants believe we should introduce substrate in the mesophotic zone.

**Question: If you answered yes (Figure E.11), which type of substrate? (Figure E.12)**

Options:

- Natural—25%
- Engineered—0%
- Both—75%

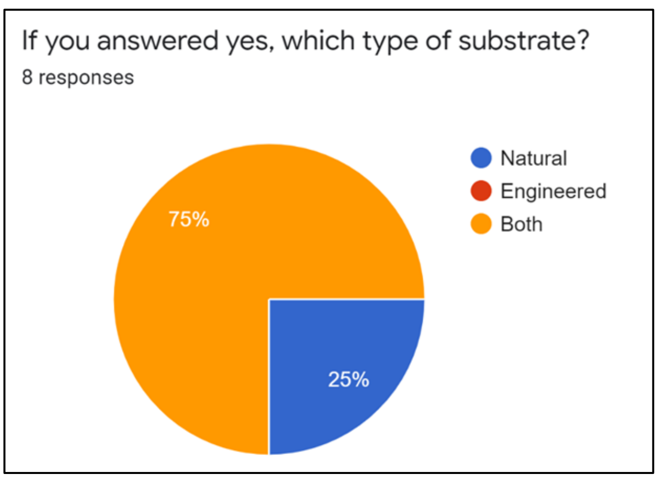


Figure E.12. Pie chart showing that participants who believe substrate should be introduced in the mesophotic zone prefer the use of both natural and engineered substrates.

**Question: Where should we seek to propagate corals?**

The following results are responses to the specific topics under the overall question of 'Where should we seek to propagate corals?" (Figures E.13–E16).

*Subquestion: Local sites of injury?* (Figure E.13)

Options:

- Yes—75%
- No—25%

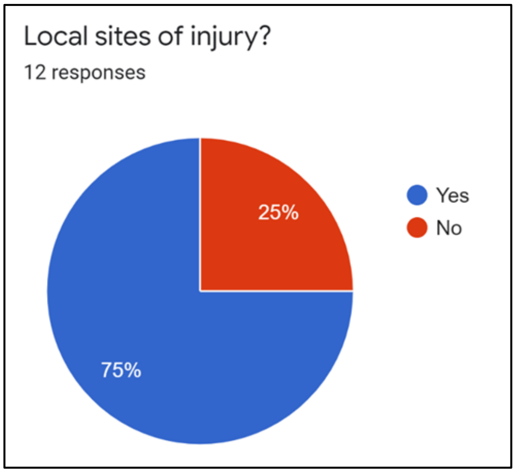


Figure E.13. Pie chart indicating most participants believe corals should be propagated at local sites of injury.

*Subquestion: Reference sites adjacent to area of injury? (reference sites are places with high abundance of target species no injured by DWH)*(Figure E.14)

Options:

- Yes—75%
- No—25%

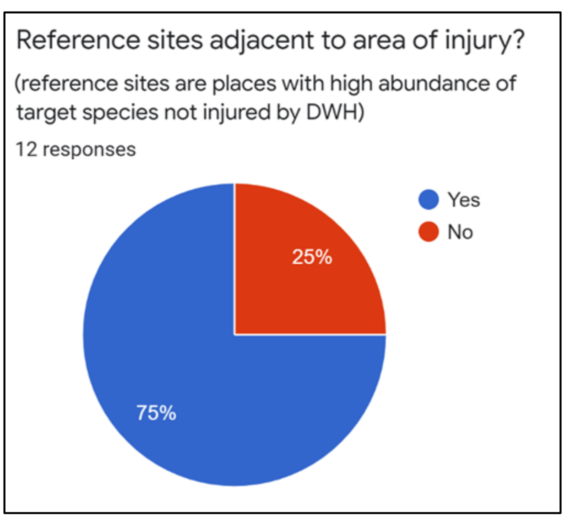


Figure E.14. Pie chart indicating most participants believe corals should be propagated at reference sites adjacent to area of injury.

*Subquestion: Other reference sites? (this includes known, unknown, and predicted places)* (Figure E.15)

Options:

- Yes—58.3%
- No—41.7%

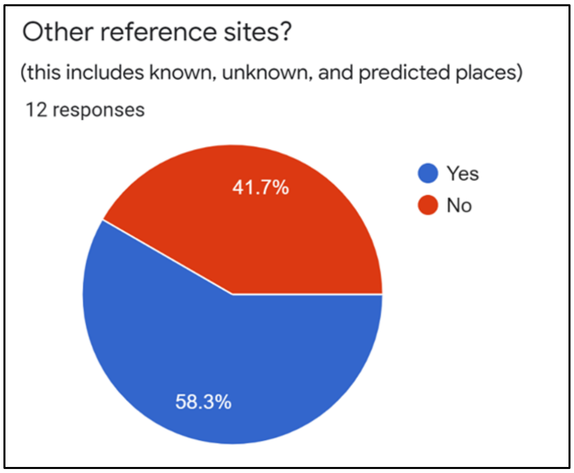


Figure E.15. Pie chart indicating most participants believe corals should be propagated at other reference sites.

*Subquestion: If you answered yes to other reference sites, where?* (Figure E.16)

Options:

- In the Northern Gulf—74.1%
- Anywhere in the Gulf—28.6%
- Anywhere in the West Atlantic—0%

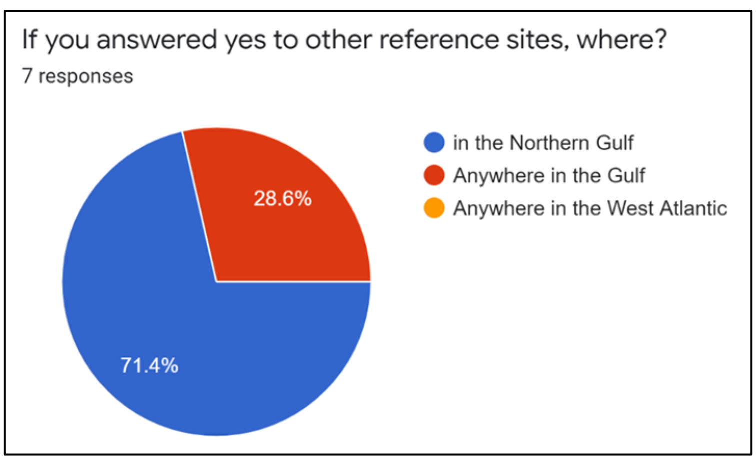


Figure E.16. Pie chart indicating most participants who believe corals should be propagated at other reference sites believe the sites should be in the northern Gulf of Mexico.

## E.3. Priority-related Questions

Questions targeting the priorities of the experts surveyed.

### E.3.1. Knowledge Priorities

**Question: Which are the MOST important in terms of priority knowledge to propagate deep corals? Pick three. (Figure E.17)**

Options were:

- Disease resistance
- Feeding
- Genetic diversity
- Growth rates
- Metabolism
- Microbial ecology
- Reproductive biology
- Settlement substrates
- Systematics
- Transport modeling
- Other*

*Other: Five participants added the following "other" priorities:

- Local adaptation
- Predation
- Environmental requirements
- Recruits' survival rates
- Population genetic structure, rather than genetic diversity

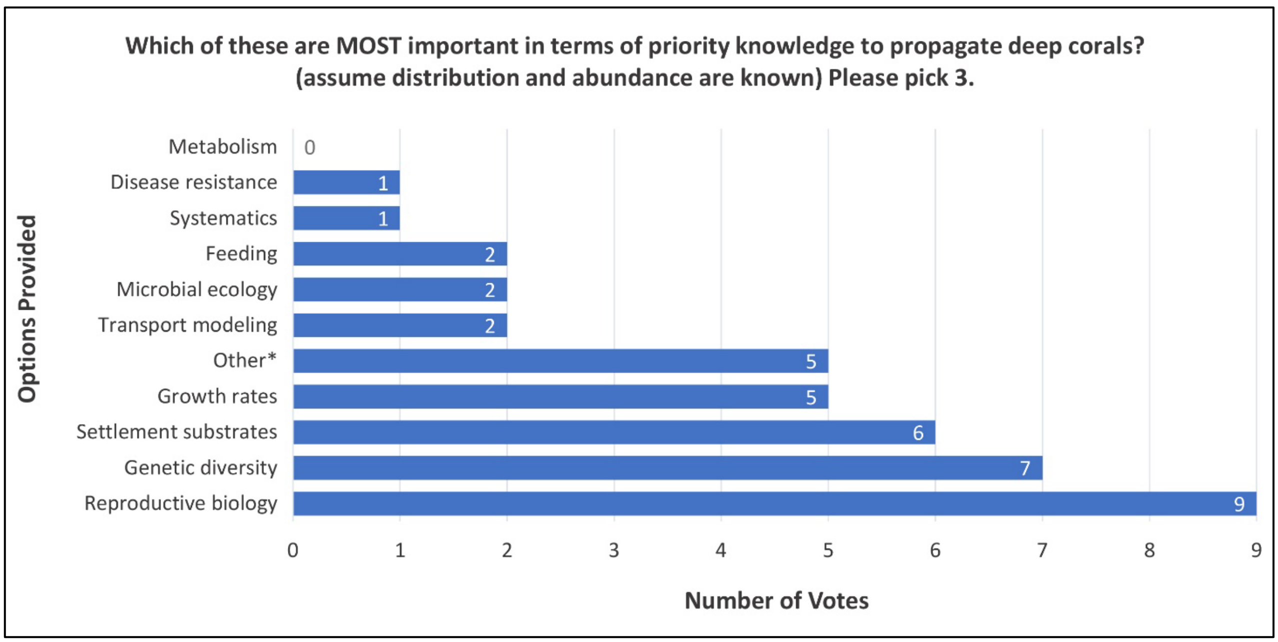


Figure E.17. Bar graph showing the number of votes participants gave to each of the options provided. A higher number of votes indicates participants ranked those options as most important for priority knowledge related to coral propagation.

**Question: Which of these are the LEAST important in terms of priority knowledge to propagate deep corals? Pick three. (Figure E.18)**

Options were:

- Disease resistance
- Feeding
- Genetic diversity
- Growth rates
- Metabolism
- Microbial ecology
- Reproductive biology
- Settlement substrates
- Systematics
- Transport modeling
- Other*

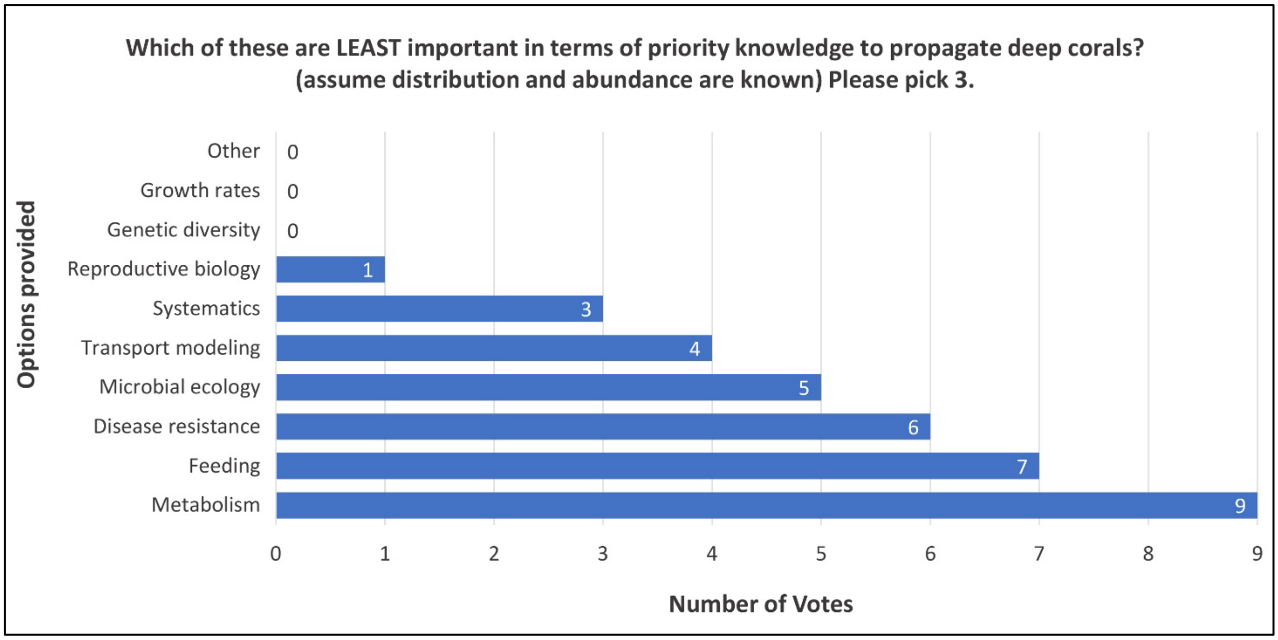


Figure E.18. Bar graph showing the number of votes participants gave to each of the options provided. A higher number of votes indicates participants ranked those options as least important for priority knowledge related to coral propagation.

### E.3.2. Action Priorities

**Question: Which of these actions are most promising in the SHORT TERM (2–3 years) for the DEEP SEA? Pick two. (Figure E.19)**

Each of the five options provided received votes. One participant included an "other" priority of monitoring of natural recovery/loss.

Options:

- Conduct studies of biology of the animals
- Deploy engineered substrates for enhanced recruitment
- Deploy natural substrates for passive recruitment
- Fragment corals in situ using tech divers and subs
- Generate fragments/genets for outplanting
- Other*

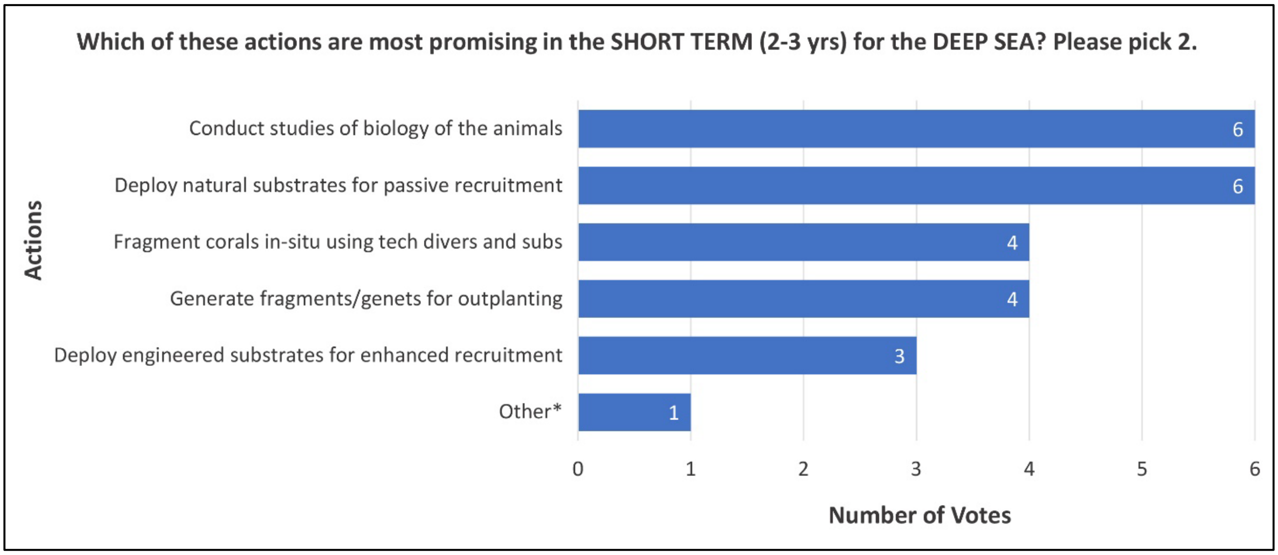


Figure E.19. Bar graph showing the number of votes participants gave to each of the actions provided. A higher number of votes indicates participants ranked those actions as most promising in the short-term for coral propagation in the deep sea.

**Question: Which of these actions are most promising in the SHORT TERM (2–3 years) for the MESOPHOTIC? Pick two. (Figure E.20)**

Options:

- Conduct studies of biology of the animals
- Deploy engineered substrates for enhanced recruitment
- Deploy natural substrates for passive recruitment
- Fragment corals in situ using tech divers and subs
- Generate fragments/genets for outplanting
- Other*

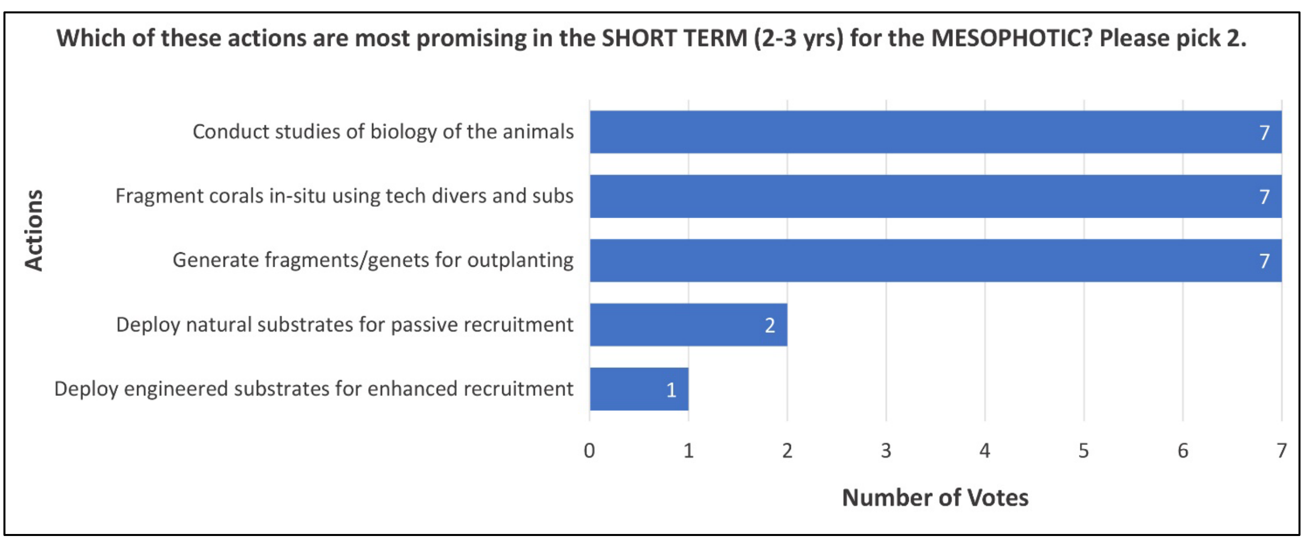


Figure E.20. Bar graph showing the number of votes participants gave to each of the actions provided. A higher number of votes indicates participants ranked those actions as most promising in the short-term for coral propagation in the mesophotic zone.

**Question: Which of these actions are most promising in the LONG TERM (5–7 years) for the DEEP SEA? Pick two (Figure E.21)**

Options:

- Conduct studies of biology of the animals
- Deploy engineered substrates for enhanced recruitment
- Deploy natural substrates for passive recruitment
- Fragment corals in situ using tech divers and subs
- Generate fragments/genets for outplanting

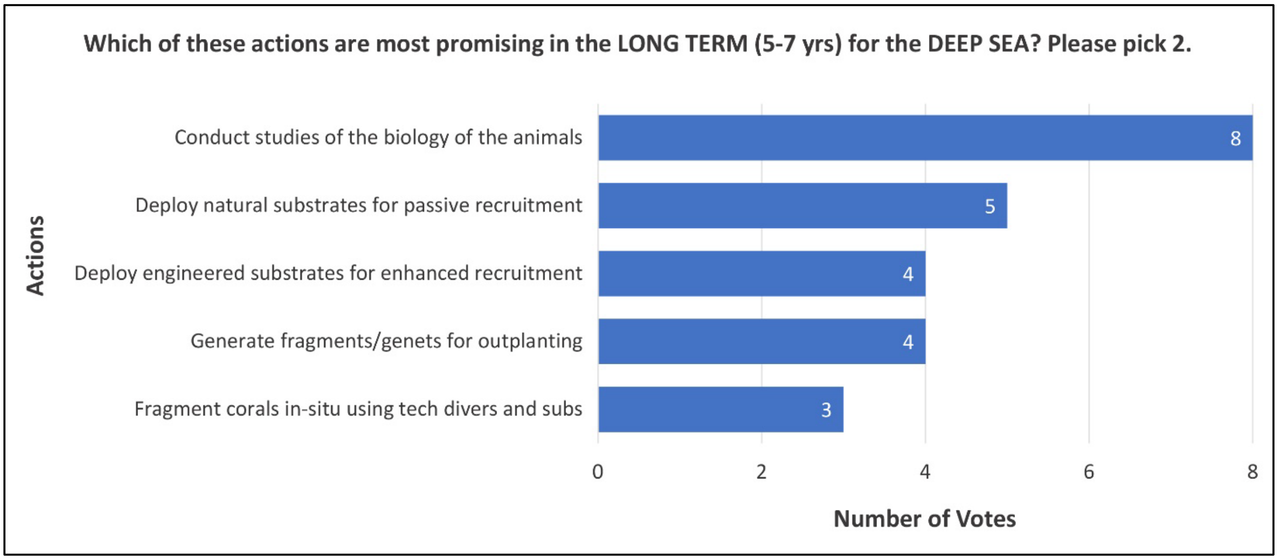


Figure E.21. Bar graph showing the number of votes participants gave to each of the actions provided. A higher number of votes indicates participants ranked those actions as most promising in the long-term for coral propagation in the deep sea.

**Question: Which of these actions are most promising in the LONG TERM (5–7 years) for the MESOPHOTIC? Pick two. (Figure E.22)**

Options:

- Conduct studies of biology of the animals
- Deploy engineered substrates for enhanced recruitment
- Deploy natural substrates for passive recruitment
- Fragment corals in situ using tech divers and subs
- Generate fragments/genets for outplanting

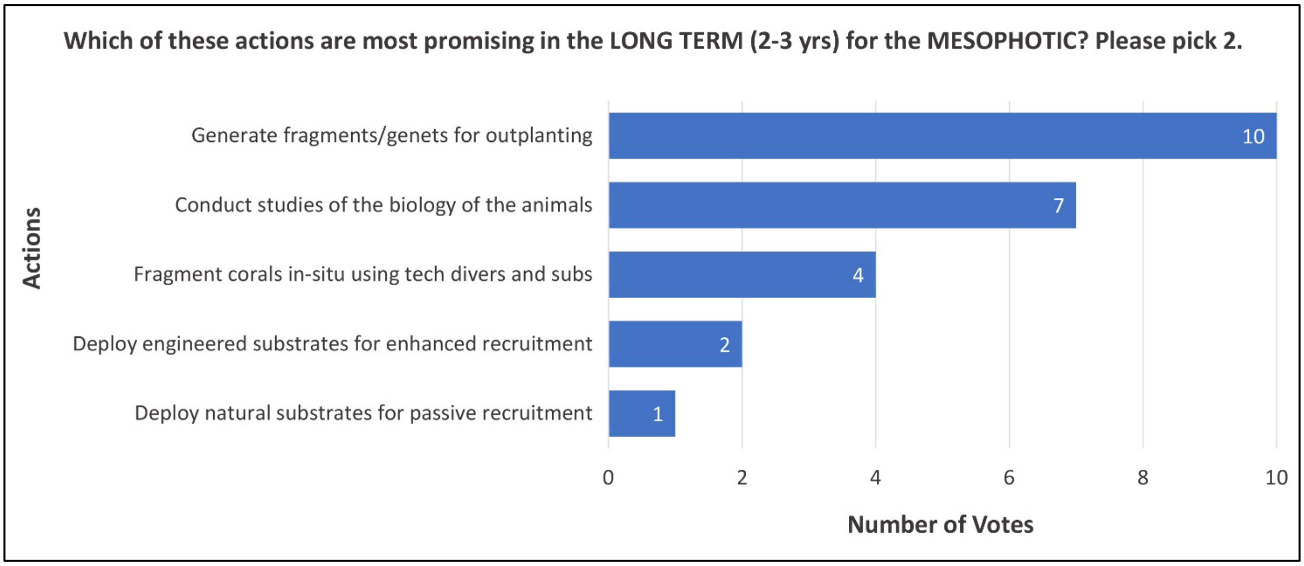


Figure E.22. Bar graph showing the number of votes participants gave to each of the actions provided. A higher number of votes indicates participants ranked those actions as most promising in the long-term for coral propagation in the mesophotic zone

## E.4. Additional Comments

The following list are additional comments from experts during the follow-up surveys.

- Biofilm characterization to improve settlement on natural/engineered substrates
- Local adaptation and a good understanding of the systematics of the species/genera being restored are critical for long-term (> 1 year) restoration success. By local adaptation, I mean we should match donor and transplanted sites habitat-wise as much as possible. My take is that bringing corals from different locations/habitats will decrease the long-term survival of the transplanted fragments.
- Many of these simply yes/no questions are not that simple. "Should we attempt propagation in the deep sea?" depends on the answers to most of the other questions. I still do not have enough information to answer that question.
- I think less engineered and less habitat manipulation is beast. I think the choice will be taxon specific for the best method. To predict and measure outcomes, we need more info on genetic diversity, biology, and environmental requirements for the target corals.
- RE: Reference sites adjacent to area of injury? (reference sites are places with high abundance of target species not injured by DWH). These should be sites that are likely sources of larvae for the impacted sites i.e. similar genetic pools
- Most of my opinions do not fit the dichotomous yes/no nature of the questions. In general, I am more cautious, especially regarding the deep sea, than my answers would suggest. Deep sea work will have to follow an adaptive approach in which multiple techniques are tested perhaps sequentially. I have no comments on the costs as I do not have a sense of the costs of operations relative to the available funds.

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