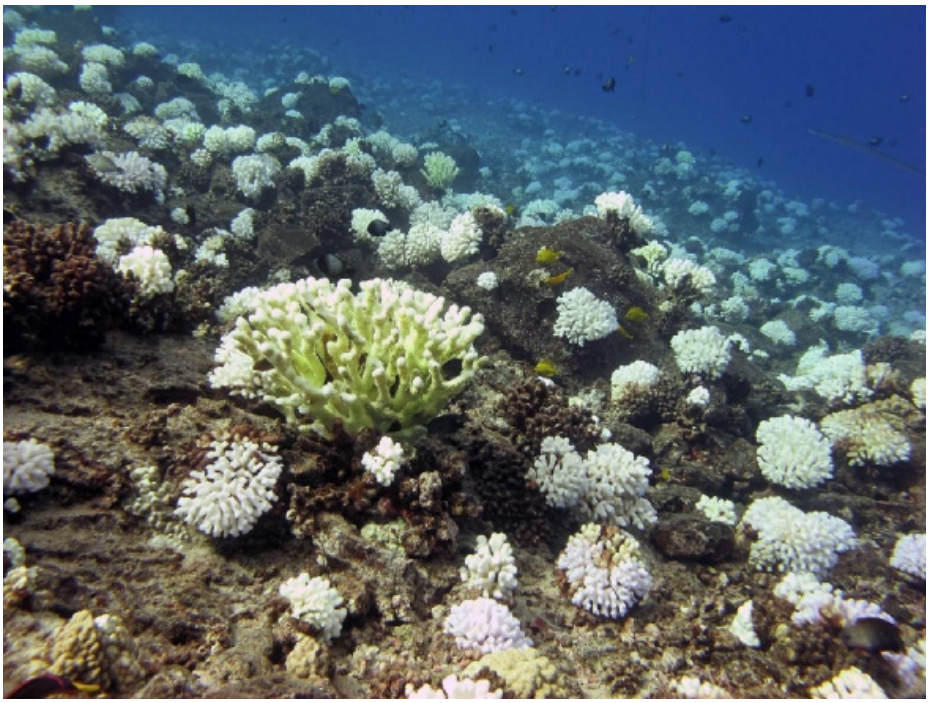
Hawaii Division of Aquatic Resources

Prioritized Management Strategies for Promoting Post-Bleaching Coral Recovery in Hawai'i: Survey Results



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NOAA CORAL REEF CONSERVATION PROGRAM

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Executive Summary

It is predicted that mass bleaching will occur annually in Hawaii by 2050. Despite this threat, consensus on management strategies to promote coral recovery following bleaching events is decidedly limited and there is an urgent need to expand the inventory of feasible and effective management actions to restore and promote the ability of coral reefs to recover from bleaching events.

In February 2016, the State of Hawaii Department of Land and Natural Resources, Division of Aquatic resources (DAR) launched an initiative to identify effective management actions to promote bleaching recovery and enhance the resilience of the state's coral reefs.

An online survey was created to solicit the input of a global group of coral reef scientists and managers with research and management experience relevant to coral bleaching and recovery. The survey consisted of 22 possible management actions to promote coral reef recovery and resilience following a bleaching event. The respondents were tasked to rate the ecological effectiveness of these actions. Survey takers rated each management action from 'very effective' to 'not effective' using a five point weighted Likert scale. Respondents were also asked to provide other management recommendations that would promote post-bleaching coral recovery and resilience.

The survey was sent to 176 coral bleaching experts from 20 countries around the world. The survey received 82 complete responses (47%). The vast majority of respondents were scientists (78%), with more than 10 publications in the field, and more than 10 years of experience.

Effectiveness scores were created for each of the 22 management strategies using the weighted answers. Survey respondents ranked reducing sediment stress and nutrient stress to coral reefs as the two most ecologically effective management interventions to accelerate coral recovery following a bleaching event. The third most-effective was increasing enforcement of state rules related to protecting coral reefs. The establishment of permanent, no-take Marine Protected Areas (MPAs) and areas specifically protecting herbivorous fishes, or Herbivore Fishery Management Areas (FMAs) were also among the top five strategies. Additional questions revealed that most respondents thought no-take MPAs should make up 21-30% of reef habitats and that FMAs should make up >30% of reef habitats. Related to protecting herbivores, coral bleaching experts felt that protecting parrotfishes (Scaridae) and surgeonfishes (Acanthuridae) would be most ecologically effective.

The least effective management actions were creating artificial reefs, eradicating Roi (Cephalopholis argus) and Crown-Of-Thorns-Starfish (Acanthaster planci), rotationally closed MPAs and a temporary moratorium on aquarium collecting.

Cover Photo: Darla White, DAR Maui

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Project Goals

The goal of this project was to research current and potential management responses to coral bleaching across various regions to inform the Hawaii Division of Aquatic Resources (DAR) on specific management actions to promote recovery of bleached coral reefs and to increase the resilience of Hawaii's reefs to future bleaching events.

Background

RECENT CORAL BLEACHING IN HAWAII

Hawaii's coral reefs suffered extensive coral bleaching in 2014 and 2015 due to dramatically elevated ocean temperatures. The 2014 event mainly affected areas of the Northwest Hawaiian Islands as well as the Main Hawaiian Islands of Kauai, Oahu, and Maui (Figure 1). Enclosed embayments such as Kaneohe Bay, Oahu were especially impacted.

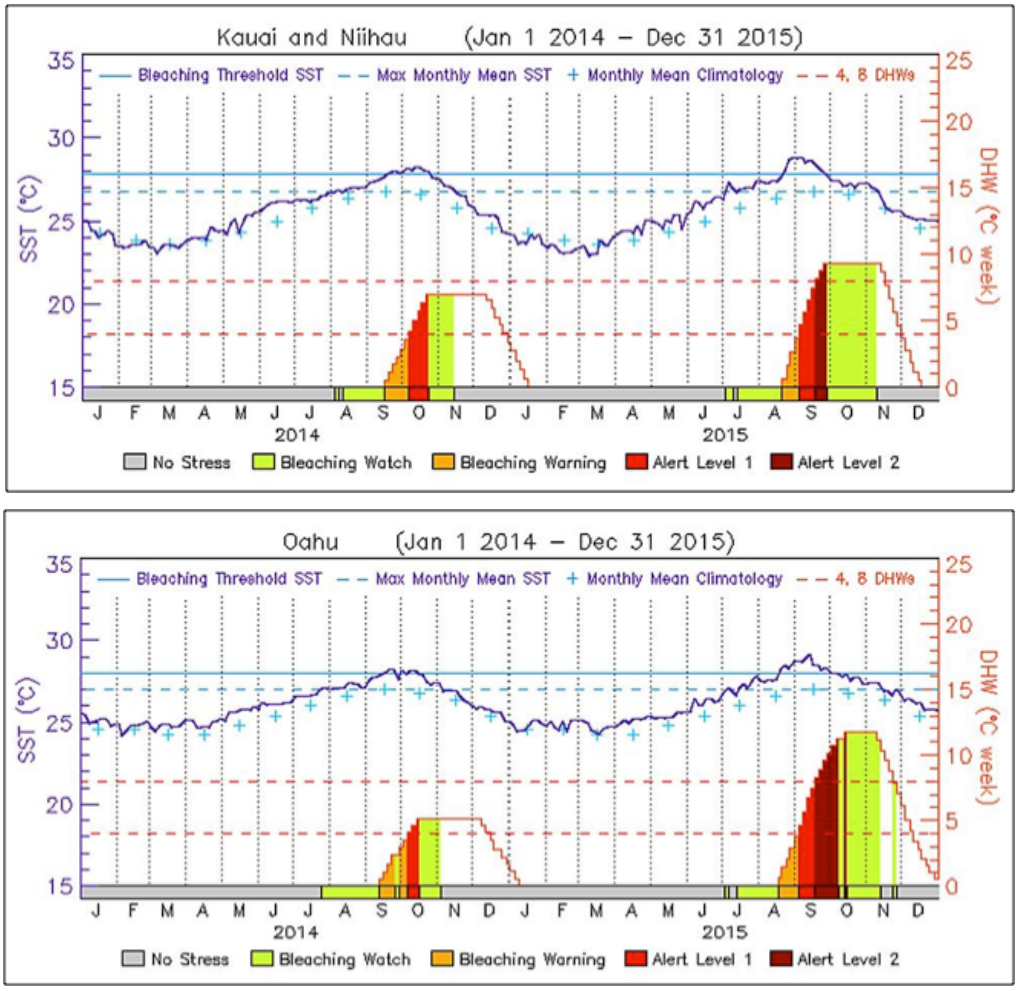


Figure 1. *NOAA Coral Reef Watch Program plot of Sea Surface Temperature (SST), Degree Heating Weeks. (DHW), and coral bleaching alerts for 2014 and 2015 in more northerly Main Hawaiian Islands.*

In 2015, a more intense temperature anomaly again resulted in coral bleaching particularly in the southern portions of the island chain, especially Maui and West Hawaii (Kona) (Figure 2).

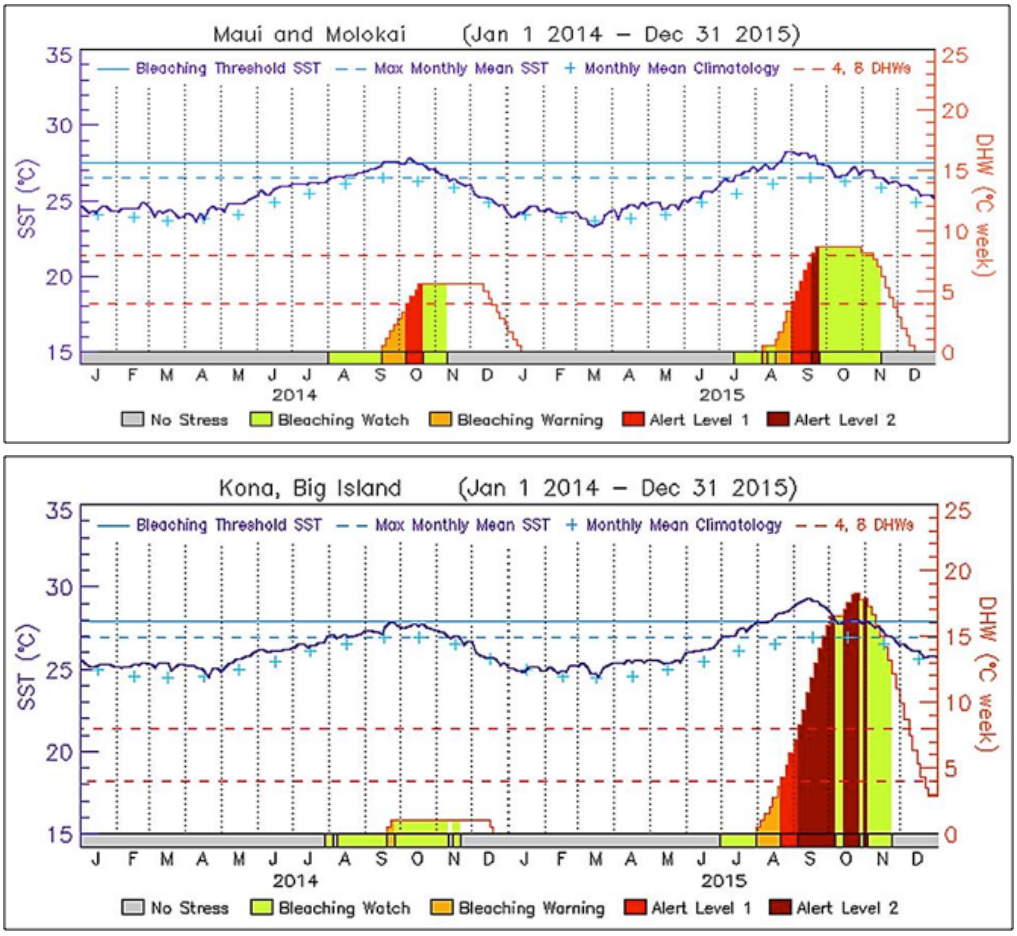


Figure 2. *NOAA Coral Reef Watch Program plot of Sea Surface Temperature (SST), degree Heating Weeks (DHW), and coral bleaching alerts for 2014 and 2015 for more southerly Main Hawaiian Islands.*

The stress exhibited on corals from the 2015 event peaked at 12 Degree Heating Weeks (DHW). The DHW depicts accumulated thermal stress during the most recent 12-week period. Significant coral bleaching typically occurs when DHW reaches 4 - °C-Weeks. If DHW values reach 8 -°C-Weeks, widespread bleaching is likely and significant coral mortality can be expected. At Bleaching Alert Level 1, significant bleaching is expected within a few weeks of the alert. At Bleaching Alert Level 2 and above, widespread bleaching and significant coral mortality are likely. Red dashed lines across the graphs indicate DHW threshold values of 4- and 8-degree Celsius-weeks (triggers for Bleaching Alert Level 1 and 2, respectively).

Methodology, Product Description, and Data Availability of NOAA Coral Reef Watch (CRW) Operational and Experimental Satellite Coral Bleaching Monitoring Products can be found at:

http://coralreefwatch.noaa.gov/satellite/methodology/methodology.php#dhw

In heavily affected areas in the 2015 event, bleaching mortality in some species such as Cauliflower Coral (*Pocillopora meandrina*) averaged over 70 percent (Figure 3).

PROJECT NEED

It is predicted that mass bleaching will occur more frequently in the coming years and will occur annually in Hawaii by 2050 (Hooidonk et al. 2013). Despite this threat, consensus on management strategies to promote coral recovery following bleaching events is decidedly limited (Aswani et al. 2015). There is currently an urgent need to expand the inventory of feasible and effective tactics to restore and promote the ability of coral reefs to recover from bleaching events.

In February 2016, the State of Hawaii Department of Land and Natural Resources, Division of Aquatic resources (DAR) launched an initiative to identify effective management actions to promote bleaching recovery and enhance the resilience of the state's coral reefs.

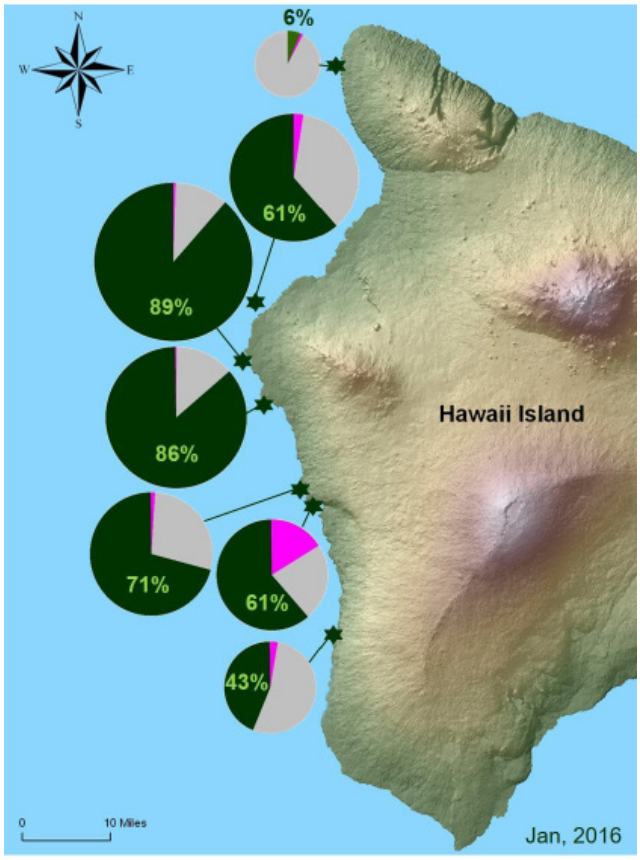


Figure 3. *Percent bleaching related mortality (dark green sections) in Pocillopora meandrina along the Kona coast (2014 -2016 comparison). Silver sections represent colonies partially affected by bleaching while dark pink ones are the proportion of colonies unaffected by bleaching (DAR data). The size of each chart is proportional to the number of colonies inspected ranging from 78 to 430.*

Methods

ASSEMBLING THE CORAL BLEACHING RECOVERY STEERING CREW

A steering crew (i.e.'committee') composed of ten Hawaii-based coral scientists and managers was assembled to help guide the process of ultimately developing management recommendations that DAR could pursue implement through the Hawaii Administrative Rulemaking process (Table 1). The steering crew compiled a list of survey respondents, developed possible management strategies for the survey, and structured survey questions.

Table 1. Members of the coral bleaching recovery steering crew

Name	Affiliation
Charles Birkeland	University of Hawaii at Mānoa, Department of Biology
Eric Conklin	The Nature Conservancy of Hawai'i (TNC)
Kelvin Goropse	NOAA Coral Reef Ecosystem Program (CREP)
Jamie Gove	NOAA Pacific Islands Fisheries Science Center
Tom Oliver	NOAA Coral Reef Ecosystem Program (CREP)
Linda Preskitt	DAR, former Eyes of the Reef Coordinator
Anne Rosinski	Hawaii Coral Reef Initiative, University of Hawaii at Mānoa
William Walsh	DAR, West Hawai'i
Darla White	DAR Maui
Ivor Williams	NOAA Coral Reef Ecosystem Program (CREP)

CREATING A LIST OF SURVEY RESPONDENTS

Survey respondents were compiled on an Excel spreadsheet contact list. Respondents on the contact list had to meet at least one out of the following criteria:

1. Lead author on a scientific paper or article dealing with an aspect of coral bleaching or other relevant topic (e.g. herbivory). Only the lead author was included on the contact list if the research was conducted outside of Hawaii.
2. All authors of a paper/article focused on Hawaii dealing with an aspect of coral bleaching or other relevant topic (e.g. herbivory).
3. Participant in a coral bleaching workshop.
4. Resource manager outside of Hawaii who has responded to bleaching events.

The contact list intentionally excluded resource managers based in Hawaii because their input will be incorporated in the next phase of the project focused on local application of the management recommendations. The contact list included 176 coral bleaching experts from 20 countries, a large percentage was based from the United States and Australia and other represented regions included Europe and Asia-Pacific. The list of contacts in provided in Appendix A.

DETERMINING MANAGEMENT STRATEGIES

The online survey consisted of 33 questions including five diagnostic questions about the survey taker and 28 questions on the ecological effectiveness of a selection of management actions to promote coral reef recovery and resilience following a bleaching event. The management strategies were divided into 7 categories:

1. Marine Protected Areas (MPAs)
2. Fisheries rules
3. Human in-water activity rules
4. Aquaculture techniques
5. Land-based strategies
6. Eradication techniques
7. Other strategies

The management strategies were derived from a review of the literature, suggestions from local experts, previously identified actions from a 2013 Hawaii coral bleaching response workshop of resource managers and scientists, restoration strategies that Hawaii DAR already engage in, and actions that had been suggested by stakeholders following the 2015 bleaching event (Table 2).

Table 2. Management strategies that were selected for the coral bleaching recovery survey

Category	Management Action
Marine Protected Areas	Establish a network of permanent, fully protected no-take MPAs
	Establish a network of temporary, rotationally closed, no-take MPAs
	Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores
Fisheries Rules	Prohibit all take (commercial and non-commercial) of sea urchins
	Prohibit only the commercial take of sea urchins
	Prohibit all take (commercial and non-commercial) of herbivorous fish
	Prohibit only the commercial take of herbivorous fish
	Prohibit all take (commercial and non-commercial) of parrotfishes
	Establish size limits to protect parrotfishes
	Establish bag limits to protect parrotfishes
Human in-water activity rules	Prohibit aquarium collecting of herbivorous fishes
	Establish a temporary moratorium on aquarium collecting
	Encourage the use of sunscreens that *do not* contain the ingredient Oxybenzone, which has been shown to be harmful to corals
	Close heavily bleaching-impacted reef areas to all human in-water activities
Aquaculture techniques	Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae
	Identify, collect, propagate and replant corals found to be resistant to bleaching
Land-based strategies	Work with authorized agencies to reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds
	Work with authorized agencies to reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds
Eradication techniques	Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus*
	Attempt to eradicate the Crown of Thorns Starfish, *Acanthaster planci*
Other strategies	Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection
	Create artificial reefs in heavily bleaching - impacted reef areas

ADMINISTERING THE SURVEY

The survey was shared with the coral bleaching expert contact list via email through surveymonkey.com and was open for 14 days. Experts were asked to share their recommendations by ranking a suite of management actions and their ecological effectiveness to promote the recovery and resilience of bleached coral reefs. Survey takers ranked each management action using a five point weighted Likert scale ranging from 'very effective' to 'not effective' (Figure 4). Responses were weighted, ranging from 2 for very effective, 1 for somewhat effective, 0 for undecided or unknown, -1 for somewhat ineffective, and -2 for not effective. Respondents did not consider political and socio-economic factors as these would be reviewed by DAR using the survey responses. A complete version of the survey is available in Appendix B.

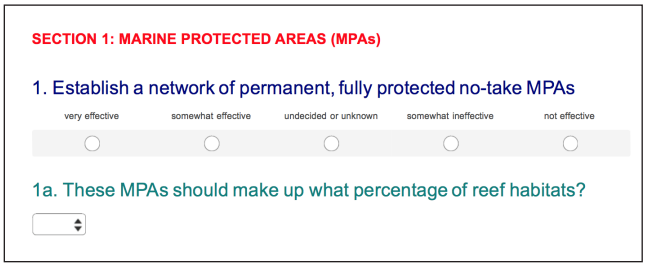


Figure 4. | *Example Likert scale question from the coral bleaching recovery survey*

Results

DEMOGRAPHICS AND RESEARCH EXPERTISE OF RESPONDENTS

The survey received 82 complete responses (47% response rate). Seven contacts opted out of the survey because they felt they did not have the expertise required to respond. There were two partial answers. Respondents were based in 12 countries; the majority were either American (n=62) or Australian (n=10) experts (Figure 5). Among American respondents, the majority (n=42) were based in Hawai'i. Other locations included California, Florida, and Washington, D.C.

The survey respondents were mostly scientists (78%). A portion (14%) identified as managers while others (8%) identified as "other." The majority (n=39, 52%) had more than 10 publications in the field and 48 respondents (72%) had more than 10 years of experience (Figure 6).

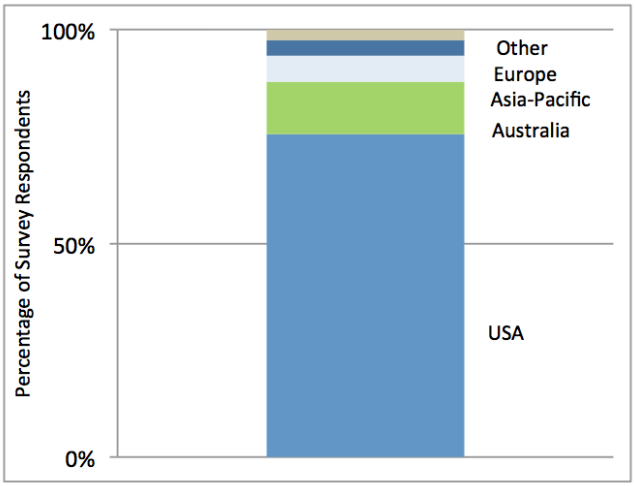
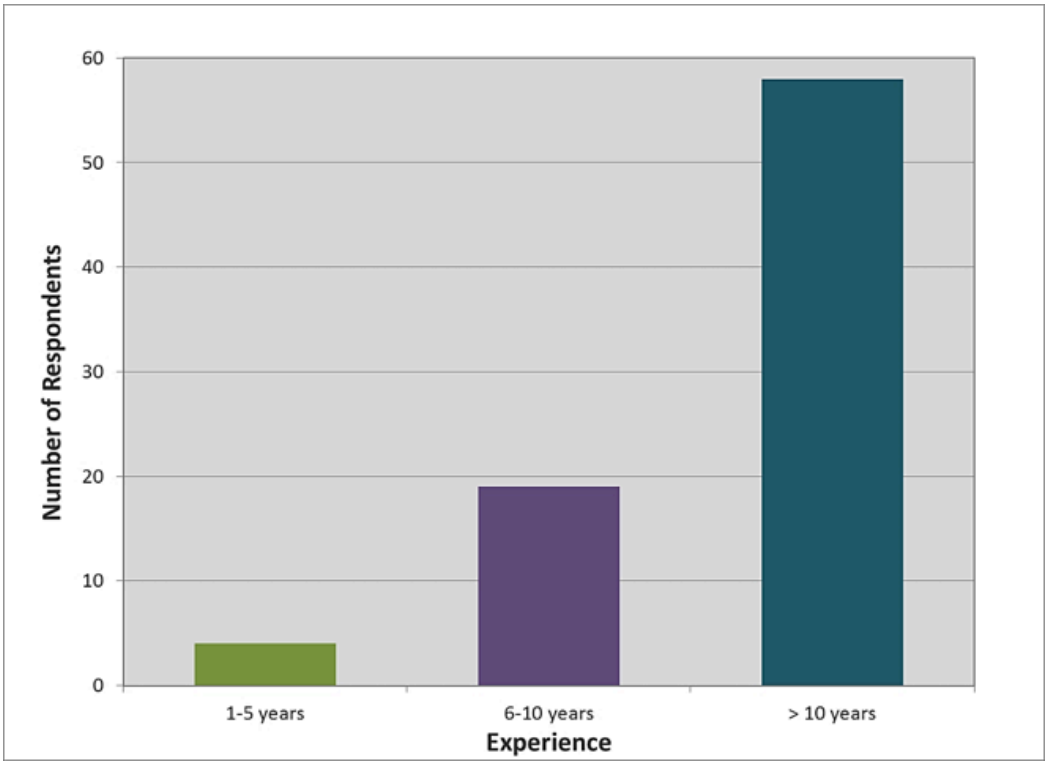


Figure 5. | *Geographic regions of survey respondents*



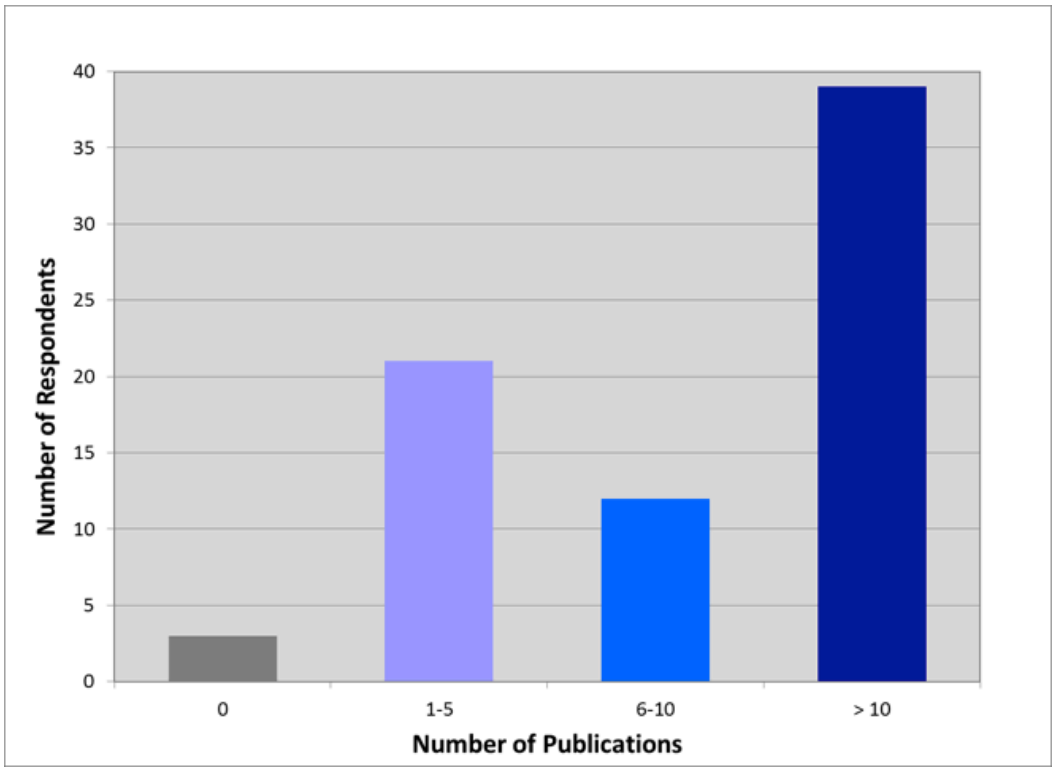


Figure 6. *Demographics of coral bleaching recovery survey respondents; number of years of experience related to coral bleaching (above) and number of relevant publications (below)*

MANAGEMENT STRATEGIES

Effectiveness scores were derived for each of the 22 management strategies using the weighted answers. The management strategy with the highest average effectiveness score (1.67) was "Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds" (Table 3). Also in the top five strategies were reducing nutrients, enhancing enforcement, creating permanent no-take areas, and creating a network of herbivore protection areas. The management strategy with the lowest score (-0.49) was "Create artificial reefs in heavily bleaching-impacted reef areas."

There was a fair amount of consensus, especially in the top five strategies, which had low rates of uncertainty and not effective ratings (Figure 7).

Table 3. Management strategies for promoting coral recovery following a bleaching event ranked by average score.

Management Strategy	Average Score
Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	1.67
Reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	1.62
Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection	1.50
Establish a network of permanent, fully protected no-take MPAs	1.32
Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores	1.11
Prohibit all take (commercial and non-commercial) of herbivorous fish	0.98
Prohibit all take (commercial and non-commercial) of parrotfishes	0.94
Establish size limits to protect parrotfishes	0.88
Establish bag limits to protect parrotfishes	0.53
Prohibit all take (commercial and non-commercial) of sea urchins	0.45
Prohibit only the commercial take of herbivorous fish	0.38
Close heavily bleaching-impacted reef areas to all human in-water activities	0.36
Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae	0.35
Prohibit aquarium collecting of herbivorous fishes	0.34
Identify, collect, propagate and replant corals found to be resistant to bleaching	0.30
Encourage the use of sunscreens that do not contain the ingredient Oxybenzone, which has been shown to be harmful to corals	0.26
Prohibit only the commercial take of sea urchins	0.22
Attempt to eradicate the Crown of Thorns Starfish, Acanthaster plancii	0.05
Establish a temporary moratorium on aquarium collecting	0.02
Establish a network of temporary, rotationally closed, no-take MPAs	-0.04
Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, Cephalopholis argus	-0.41
Create artificial reefs in heavily bleaching- impacted reef areas	-0.49

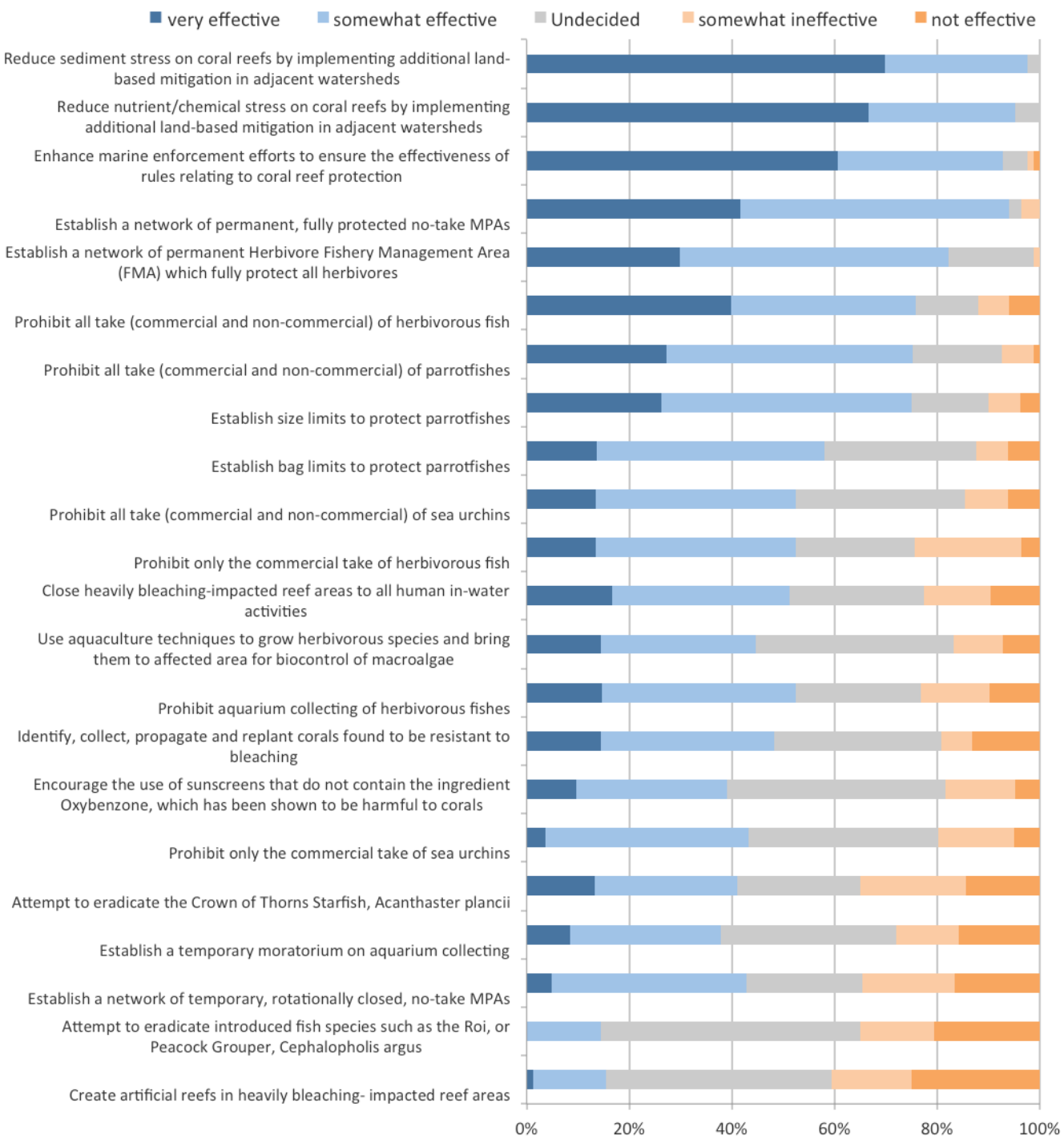
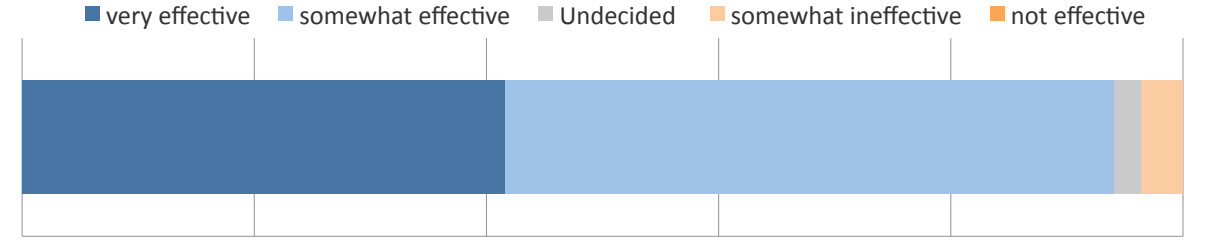


Figure 7. | *Management strategies ranked by ecological effectiveness, showing full extent of Likert scale responses*

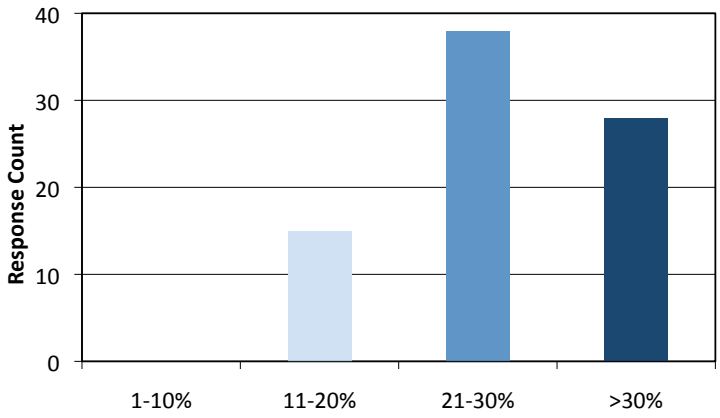
Additional Results by Management Strategy

CATEGORY: MARINE PROTECTED AREAS (MPAS)

Question Number	Question Text	Score	Rank out of 22
1	**Establish a network of permanent, fully protected no-take Marine Protected Areas (MPAs)**	1.32	4



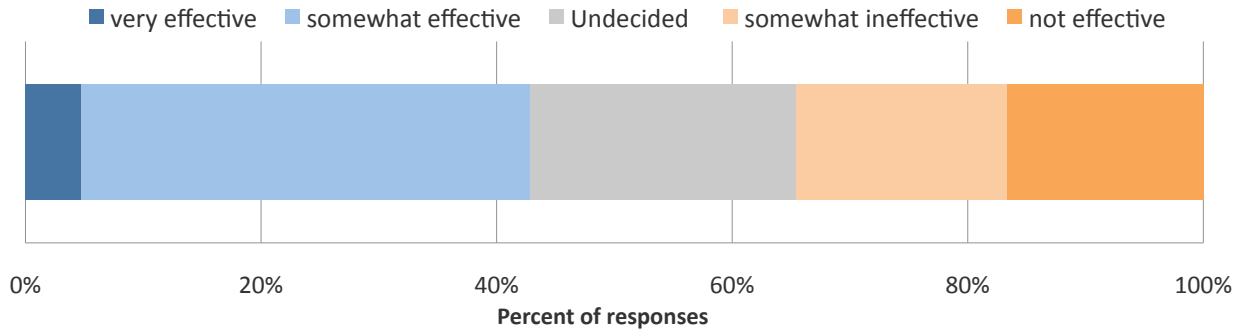
These MPAs should make up what percentage of reef habitats?



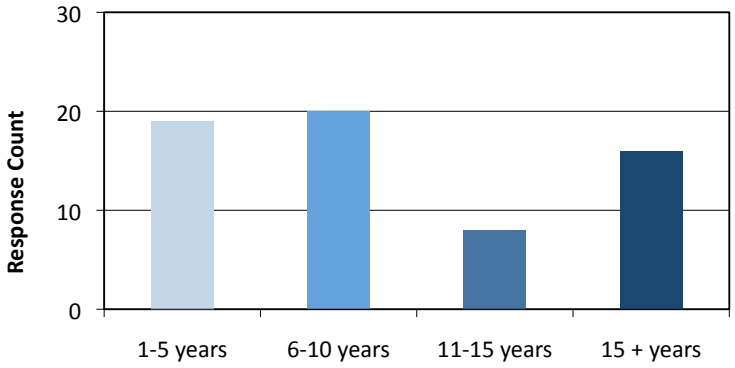
Additional comments:

Comment	Number of Comments
MPAs only part of the equation	13
Effective management and enforcement is key	12
MPAs not as effective directed at bleaching events	11
Must have 20-40% fully protected	5
Protect vulnerable areas	2
Protect resilient areas	2
Connectivity is key	2

Question Number	Question Text	Score	Rank out of 22
2	**Establish a network of <u>temporary, rotationally closed</u>, no-take MPAs**	-0.04	20



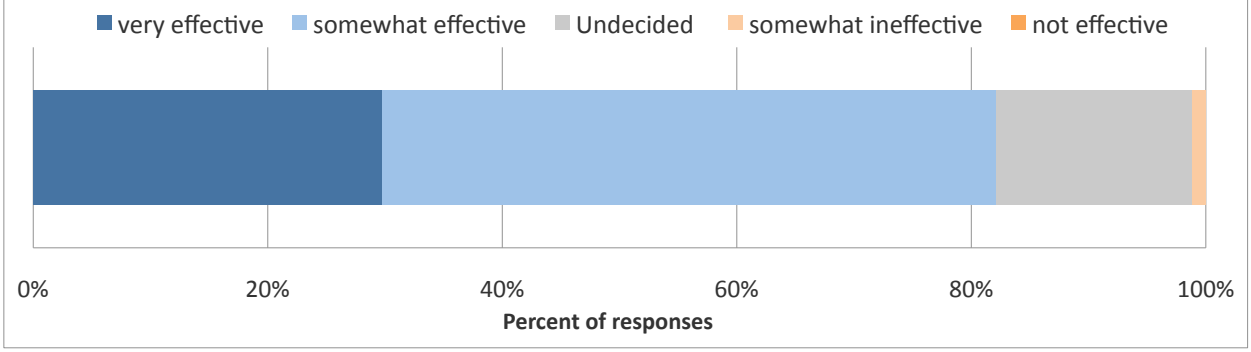
These temporary MPAs should be closed for what period of time?



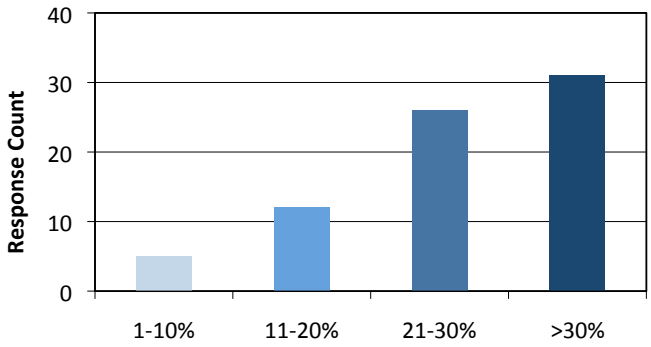
Additional Comments:

Comment	Number of Comments
Not effective	22
Longer closure is better	9
Only effective for certain systems	7
Use only as alternative to permanent MPA	6
Effective management and enforcement is key	2
May be effective specific to bleaching	2
More socially accepted	2
MPAs not as effective for bleaching events	2
more helpful for recovery rather than resilience	1
protect vulnerable areas	1
connectivity is key	1

Question Number	Question Text	Score	Rank out of 22
3	Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores	1.11	5



These FMAs should make up what percentage of reef habitats?

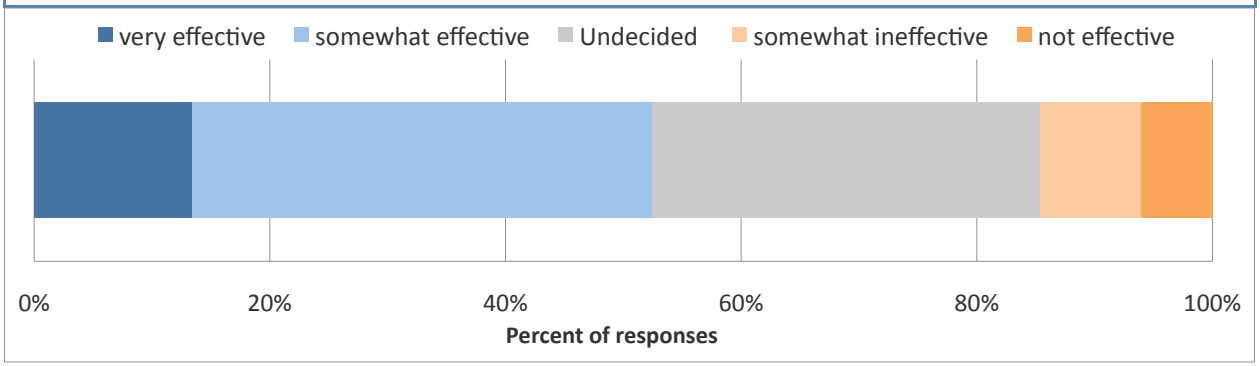


Additional Comments:

Comment	Number of Comments
Effective specific to bleaching	5
Look at success of local herbivore protection areas first	4
Use if there is a specific need to control algae	4
Use only as alternative to permanent MPA	4
Use if there is evidence of overexploitation	3
Effective management and enforcement is key	3
Socially accepted	3
Not effective	3
Use with permanent MPAs	2
Target bleaching affected areas	1
Need to protect all herbivores	1
Protect resilient areas	1
MPAs only part of the equation	1

CATEGORY: FISHERIES RULES

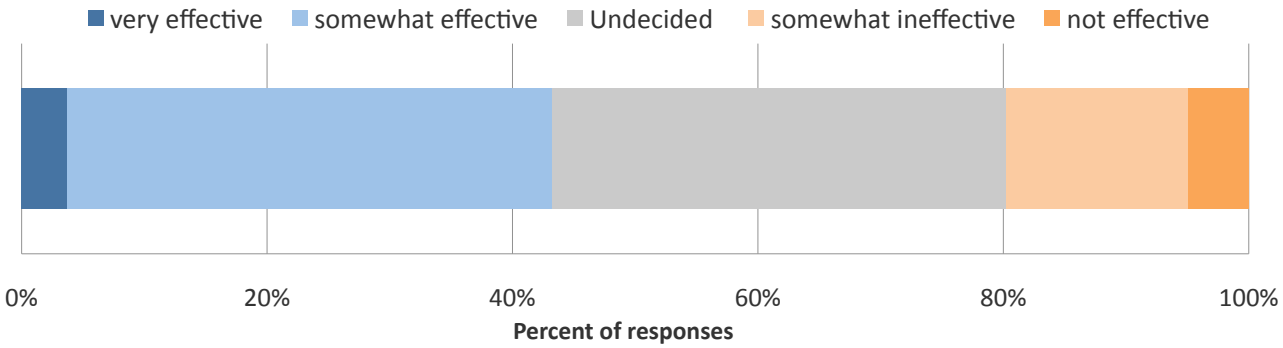
Question Number	Question Text	Score	Rank out of 22
4	**Prohibit <u>all take</u> (commercial and non-commercial) of sea urchins**	0.45	10



Additional comments:

Comments	Number of Comments
Not enough evidence that urchin herbivory is critical	7
Use if there is a specific need to control algae	6
This is important	5
Better to have partial closure	5
Use if there is evidence of overexploitation	5
Urchins not dominant herbivore	4
Possible to have overpopulation of urchins	3
Should target certain species	3
Use only as alternative to permanent MPA	3
Effective management and enforcement is key	2
Not as effective for bleaching events	2
Consider economic value of urchins	1
Look at success of local HFMAs first	1

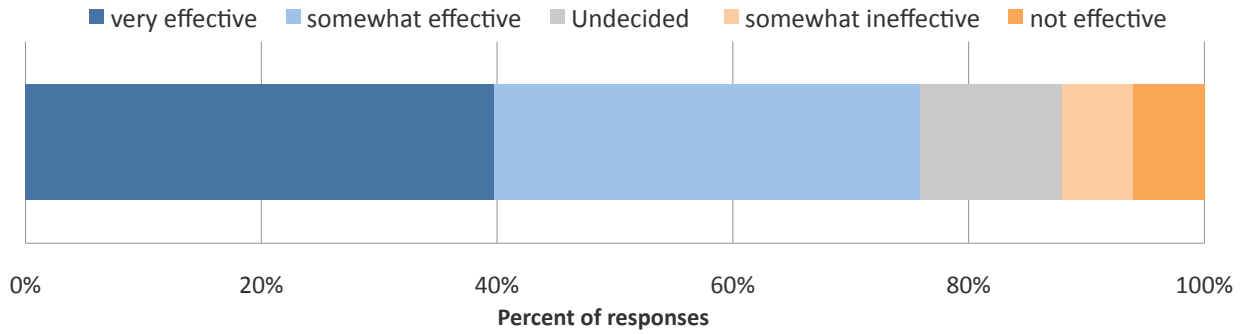
Question Number	Question Text	Score	Rank out of 22
5	**Prohibit only the commercial take of sea urchins**	0.22	17



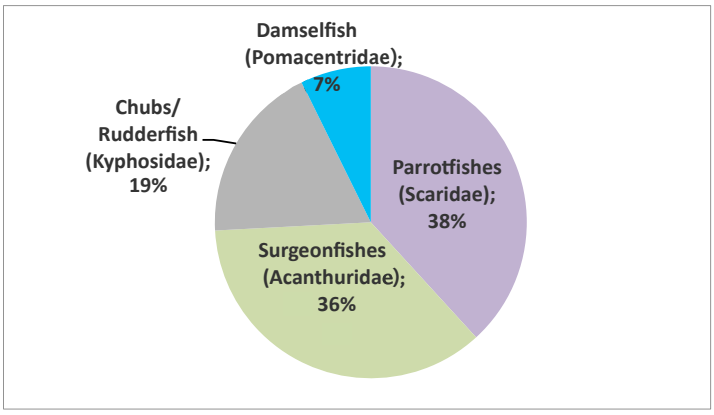
Additional Comments:

Comments	Number of Comments
Use if there is evidence of overexploitation	13
Not enough evidence that urchin herbivory is critical	4
Non-commercial take is more important	3
This is important	2
Better to have partial closure	1
Effective management and enforcement is key	1
Should target bleaching affected areas	1
Use if there is a specific need to control algae	1
Not as effective for bleaching events	1
Use only as alternative to permanent MPA	1

Question Number	Question Text	Score	Rank out of 22
6	**Prohibit <u>all take</u> (commercial and non-commercial) of herbivorous fish**	0.98	6



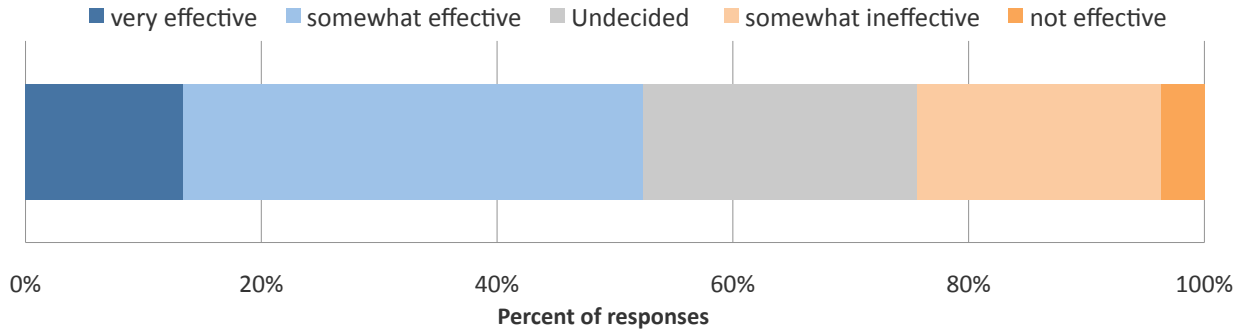
Which herbivorous fish families?



Additional Comments:

Comments	Number of Comments
Damselfish not effective	5
Need more research on individual species contributions	5
Not politically viable	4
Only part of the equation	4
Use only as alternative to permanent MPA	3
Better to target specific gear types	2
Important to allow fishing at low levels	2
Parrotfish are clearly at the top	2
Surgeonfish are clearly at the top	2
Effective management and enforcement is key	2
Parrotfish are important because they are effective and heavily targeted	1
This is important	1
Focus on grazing species	1
Use if there is a specific need to control algae	1
Use if there is evidence of overexploitation	1

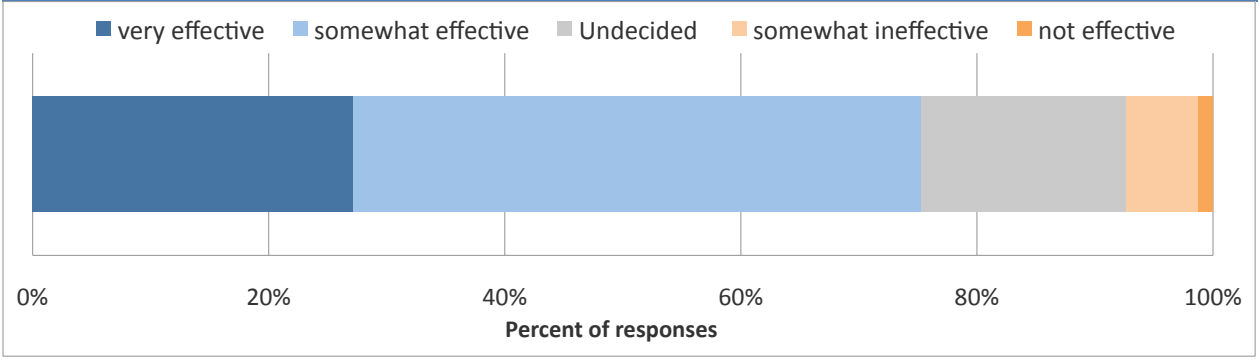
Question Number	Question Text	Score	Rank out of 22
7	**Prohibit only the commercial take of herbivorous fish**	0.38	11



Additional Comments:

Comments	Number of Comments
Non-commercial take is more important	15
Use if there is evidence of overexploitation	7
This is important	3
Important to ban commercial and non-commercial	3
Not politically viable	2
Important to allow fishing at low levels	2
Only part of the equation	1
Other trophic levels still important	1
Need more research on individual species contributions	1
Effective management and enforcement is key	1
Use only as alternative to permanent MPA	1

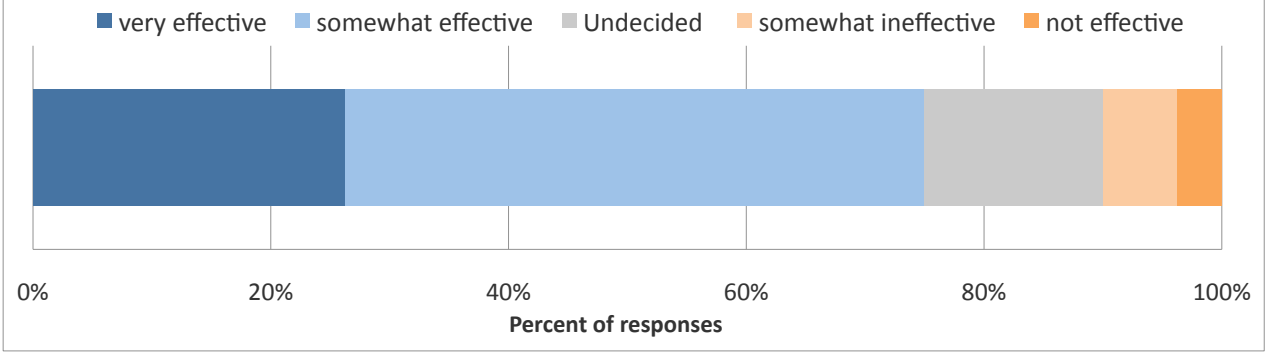
Question Number	Question Text	Score	Rank out of 22
8	**Prohibit <u>all take</u> (commercial and non-commercial) of parrotfishes**	0.94	7



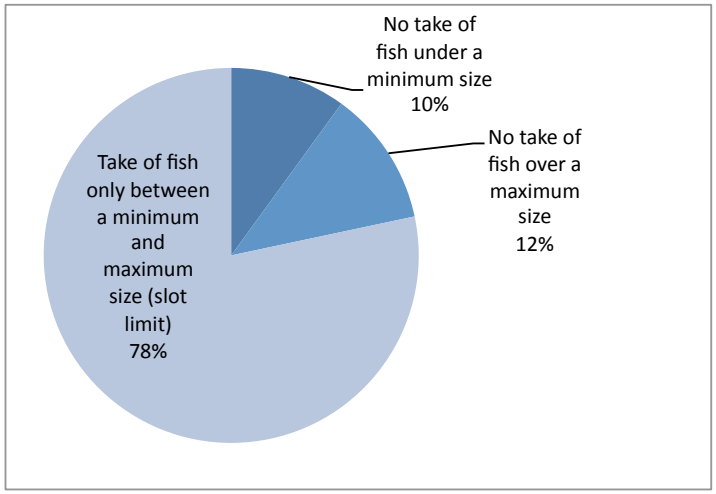
Additional Comments:

Comments	Number of Comments
This is important	5
Need more research on individual species contributions	3
Important to allow fishing at low levels	3
Not politically viable	2
Use if there is evidence of overexploitation	2
Effective management and enforcement is key	1
Only part of the equation	1
Use only as alternative to permanent MPA	1
Use if there is a specific need to control algae	1
Need to protect all herbivores	1

Question Number	Question Text	Score	Rank out of 22
9	**Establish size limits to protect parrotfishes**	**0.88**	**8**



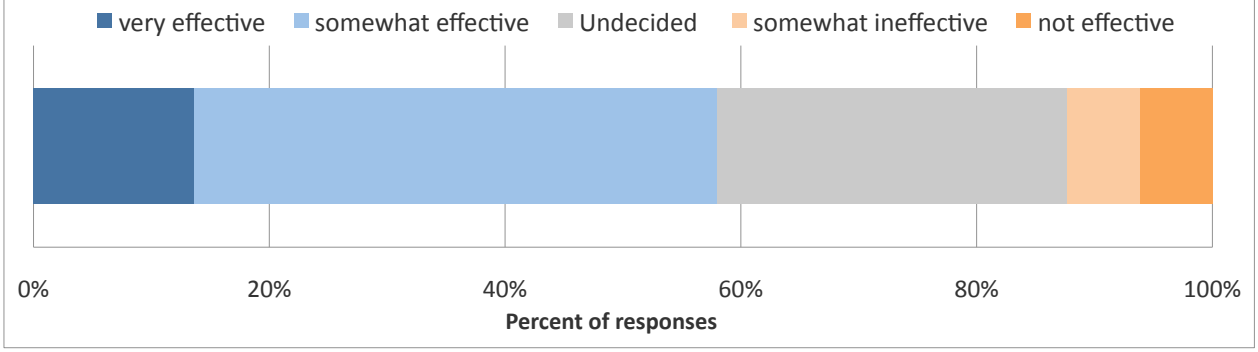
What type of size limit should be used?



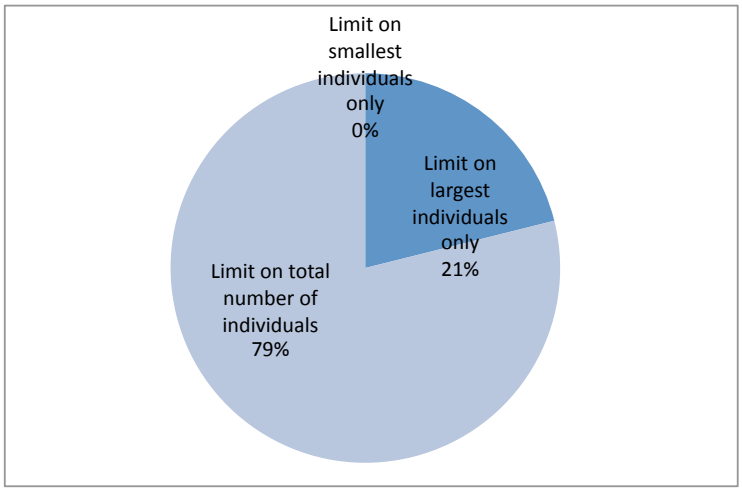
Additional Comments:

Comments	Number of Comments
This is important	3
Need more research on individual species contributions	3
Protecting females important	3
Effective management and enforcement is key	3
Implement bag and size limits together	2
Consider different ecological roles of age classes	2
Not politically viable	2
More research needed on spawning	1
Intermediate size best because of hermaphroditic quality	1
Should be across all sizes	1
Need to protect all herbivores	1

Question Number	Question Text	Score	Rank out of 22
10	Establish bag limits to protect parrotfishes	0.53	9



What type of bag limit should be used?

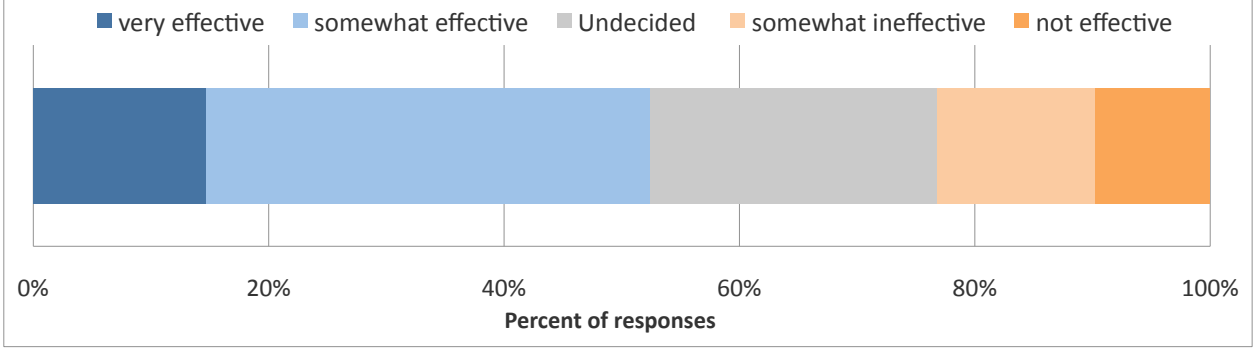


Additional Comments:

Comments	Number of Comments
Implement bag and size limits together	6
Create bag limit for large sizes	3
Effective management and enforcement is key	3
Not effective	1
This is important	1
Should be across all sizes	1
Use only as alternative to permanent MPA	1
Use with permanent MPAs	1

CATEGORY: HUMAN IN-WATER ACTIVITY RULES

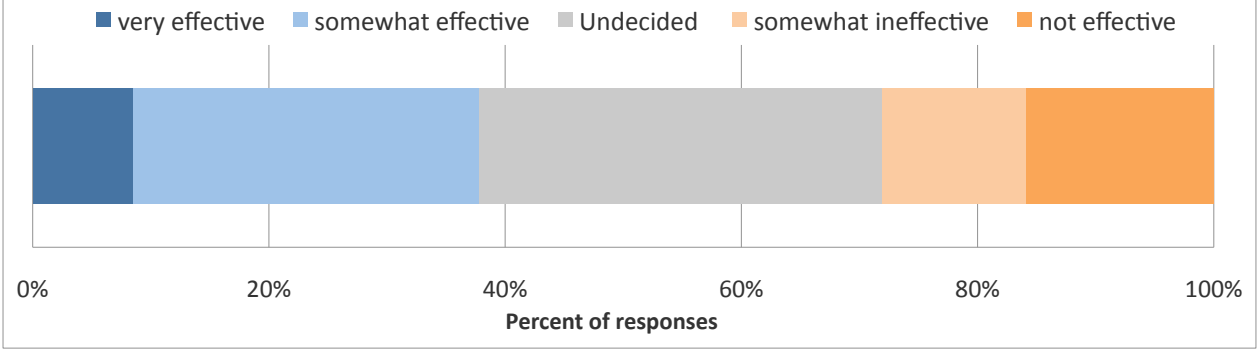
Question Number	Question Text	Score	Rank out of 22
11	**Prohibit aquarium collecting of herbivorous fishes**	0.35	14



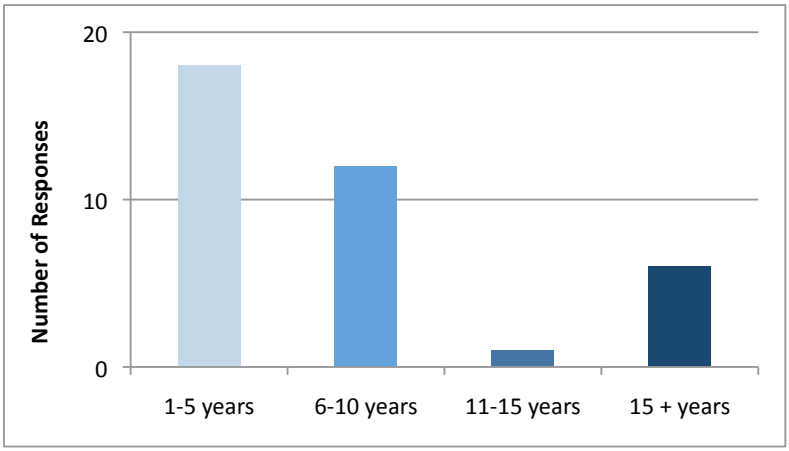
Additional Comments:

Comments	Number of Comments
Aquarium fishers not targeting species essential for recovery	9
Use if there is evidence of overexploitation	4
Shut down all aquarium collecting	3
Important to allow fishing at low levels	3
Not effective	2
Include aquarium collecting with commercial fishing	2
This is important	1
Existing regulations are enough	1
Important to ban commercial and non-commercial	1
Only part of the equation	1
Only effective for certain systems	1
Use with permanent MPAs	1

Question Number	Question Text	Score	Rank out of 22
12	Establish a temporary moratorium on aquarium collecting	0.02	19



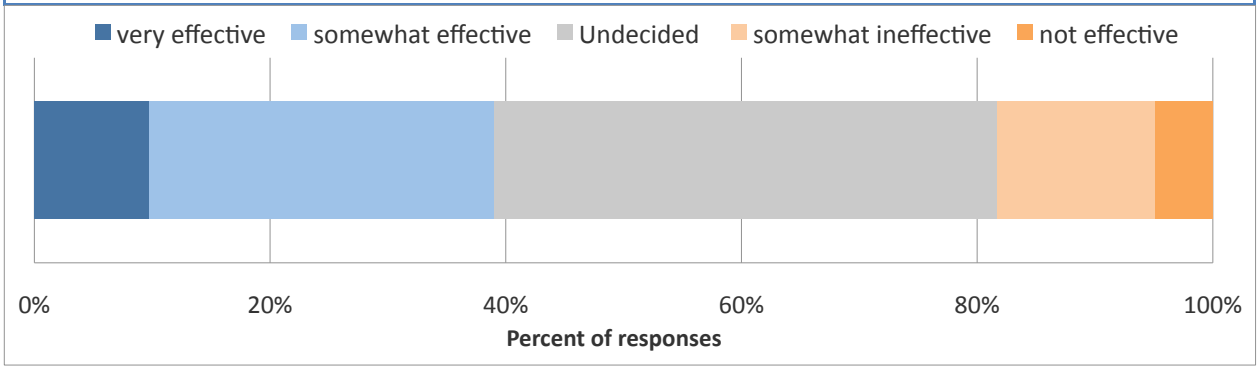
How long should the moratorium last?



Additional Comments:

Comments	Number of Comments
Account for life history of fish	5
Use if there is evidence of overexploitation	5
Not effective	3
Need more research on individual species contributions	3
Should establish a recovery target based on aquarium fish	2
Pursue a self-moratorium	1
Could have negative effect on industry	1
Shut down all aquarium collecting	1
Aquarium fishers not targeting species essential for recovery	1
Not as effective for bleaching events	1
Use with permanent MPAs	1

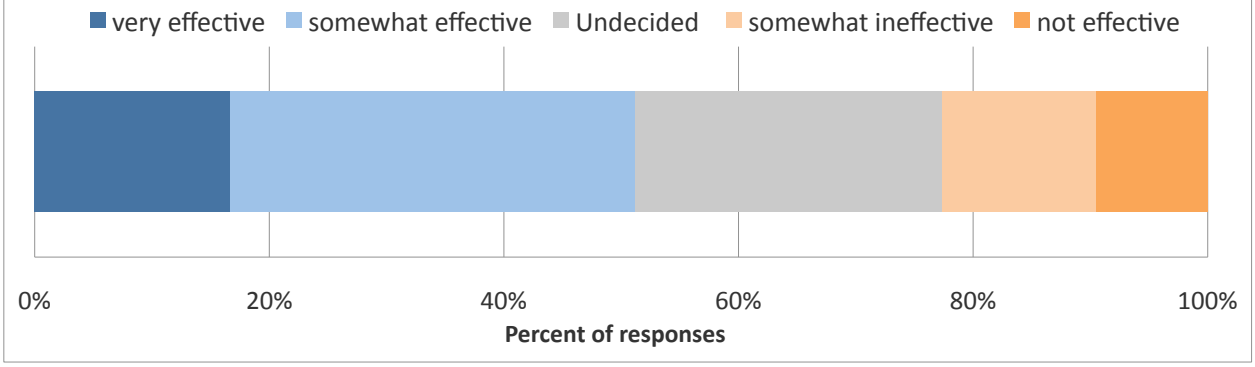
Question Number	Question Text	Score	Rank out of 22
13	Encourage the use of sunscreens that do not contain the ingredient Oxybenzone, which has been shown to be harmful to corals	0.26	16



Additional Comments:

Comments	Number of Comments
No evidence of actual effect on corals	16
Incompatible to scale of the problem	4
Target tourism areas	4
Create educational campaign	3
Only part of the equation	2
More important to target other toxins	1
Not effective	1
This is important	1

Question Number	Question Text	Score	Rank out of 22
14	Close heavily bleaching-impacted reef areas to all human in-water activities	0.02	19

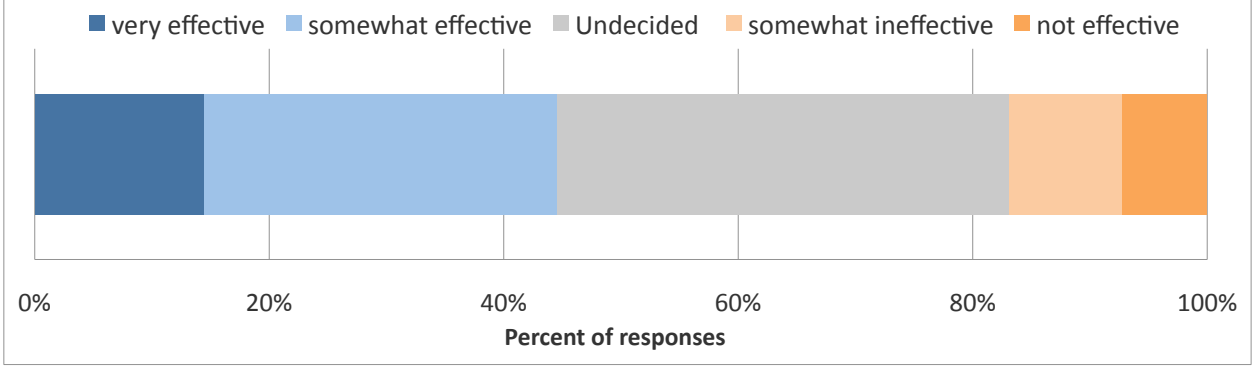


Additional Comments:

Comments	Number of Comments
No evidence of actual effect on corals	5
Not politically viable	4
This is important	3
Not effective	3
Effective management and enforcement is key	3
Proved effective in other places	2
Could make other regulations easier to enforce	2
Target tourism areas	2
Not as effective for bleaching events	2
Only part of the equation	2
Important to stop disease outbreaks	1
Better to focus on best practices	1
Complete closure not necessary	1
Effective if there are physical impacts to coral	1
Use if there is evidence of overexploitation	1
Should target bleaching affected areas	1

CATEGORY: AQUACULTURE TECHNIQUES

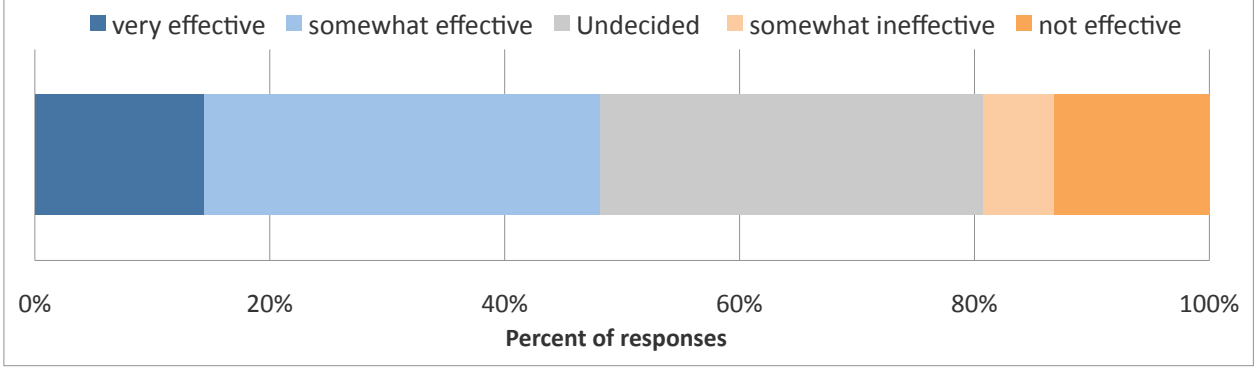
Question Number	Question Text	Score	Rank out of 22
15	Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae	0.35	13



Additional Comments:

Comments	Number of Comments
needs more research	10
This is important	9
Too expensive	8
Associated risks too high	5
Better to protect natural herbivores	3
Incompatible to scale of the problem	2
Be used with protection of herbivores	2
Use only as alternative to permanent MPA	1
No evidence of actual effect on corals	1
If sufficient number of herbivores can be produced	1

Question Number	Question Text	Score	Rank out of 22
16	Identify, collect, propagate and replant corals found to be resistant to bleaching	0.30	15

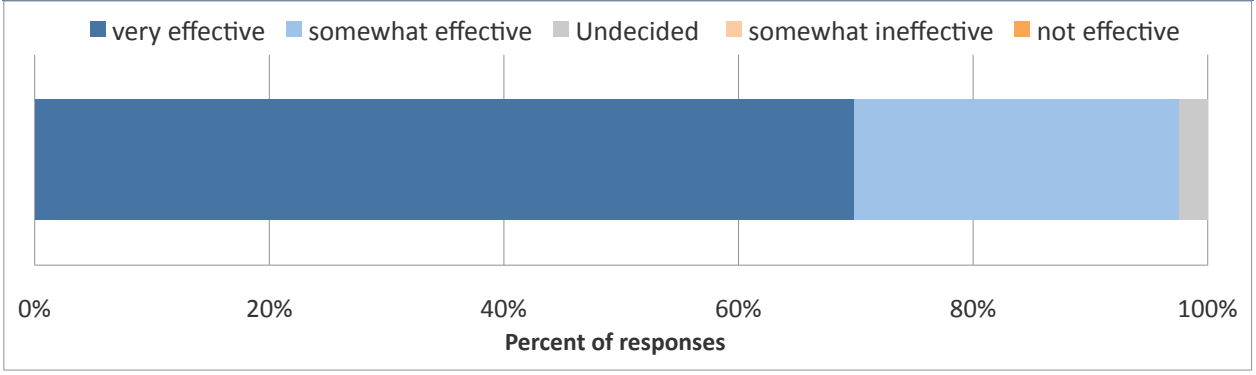


Additional Comments:

Comments	Number of Comments
Needs more research	14
Incompatible to scale of the problem	13
This is important	10
Too expensive	7
Only part of the equation	4
Not effective	4
Maintain genotypic diversity	3
Too slow	3
Use only as alternative to permanent MPA	1
Use with permanent MPAs	1
Target tourism areas	1
Important if transplants can reproduce	1

CATEGORY: LAND-BASED STRATEGIES

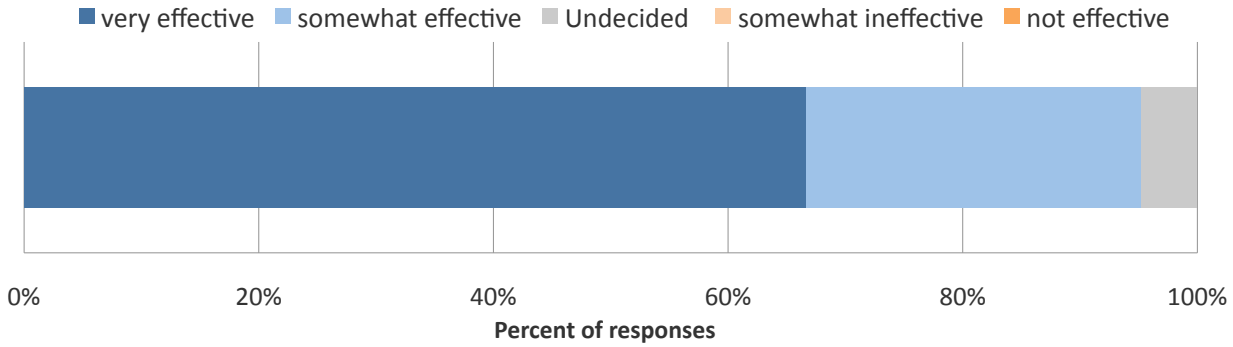
Question Number	Question Text	Score	Rank out of 22
17	Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	1.67	1



Additional comments:

Comments	Number of Comments
This is important	21
Very complicated to achieve	5
Only effective for certain systems	3
Only part of the equation	3
Important because of associated nutrients	3
In some cases, sediment inhibits bleaching	3
Not as effective for bleaching events	1
Effective management and enforcement is key	1

Question Number	Question Text	Score	Rank out of 22
18	Reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	1.62	2

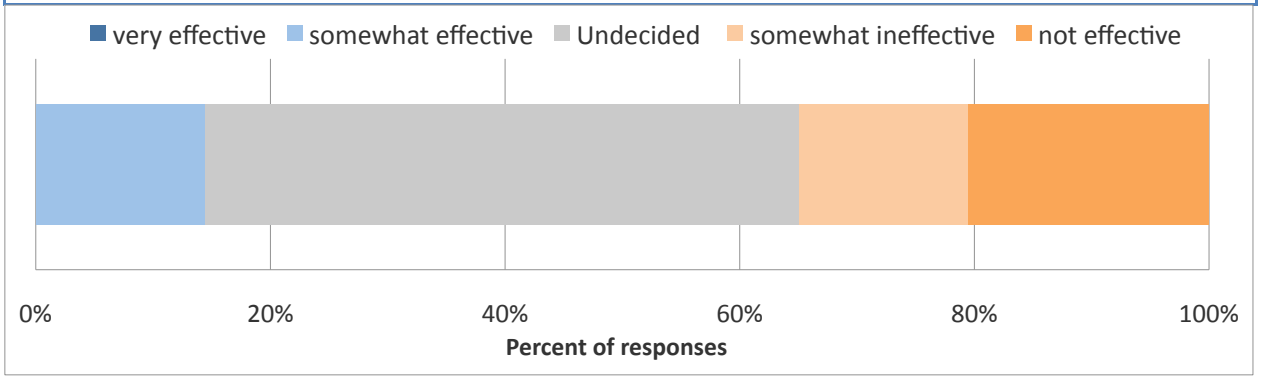


Additional Comments:

Comments	Number of Comments
This is important	18
no evidence of actual effect on corals	2
only effective for certain systems	1
not as effective for bleaching events	1
only part of the equation	1
effective management and enforcement is key	1
important because of associated nutrients	1

CATEGORY: ERADICATION TECHNIQUES

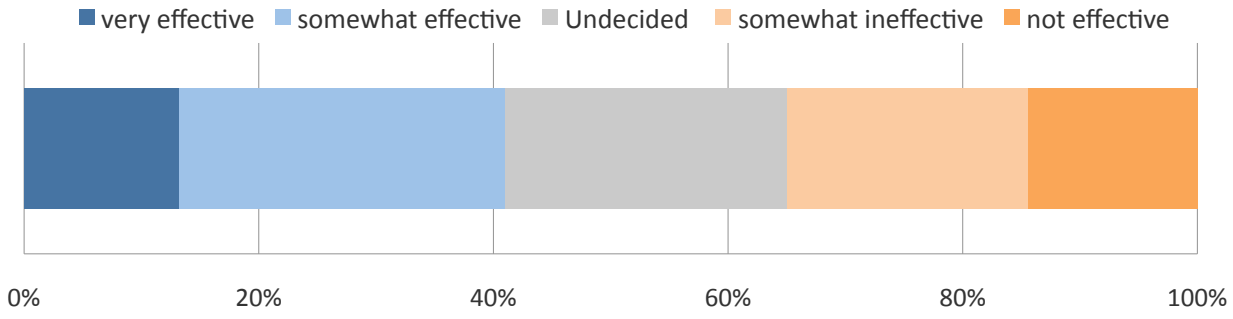
Question Number	Question Text	Score	Rank out of 22
19	**Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus***	-0.41	21



Additional Comments:

Comments	Number of Comments
Not effective	9
Very complicated to achieve	4
No evidence of actual effect on corals	3
Too expensive	3
Effective specific to bleaching	2
Only part of the equation	1
Incompatible to scale of the problem	1
Create educational campaign	1
Needs more research	1
This is important	1
Focus only on harmful invasives	1

Question Number	Question Text	Score	Rank out of 22
20	**Attempt to eradicate the Crown of Thorns Starfish, *Acanthaster planci***	0.05	18

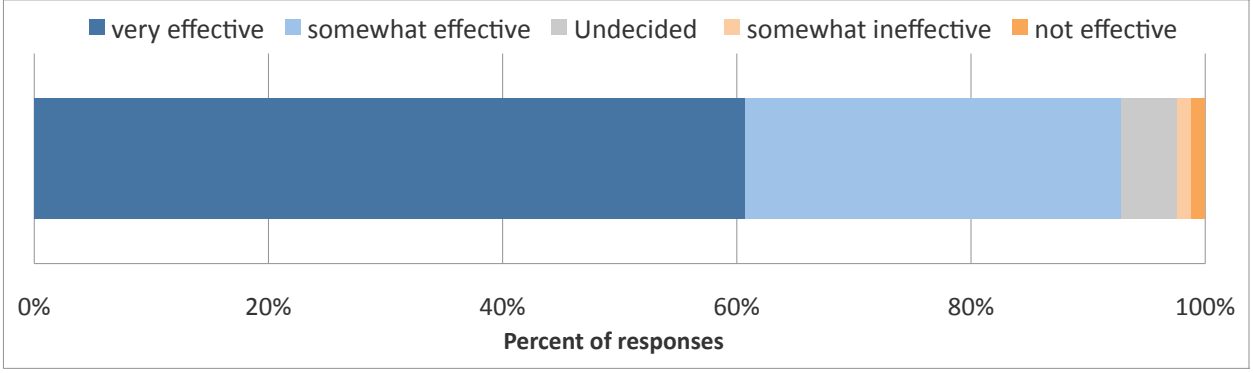


Additional Comments:

Comments	Total
Only target outbreaks	12
Very complicated to achieve	7
This is important	7
Not effective	4
Minor issue in Hawaii	4
Incompatible to scale of the problem	3
COTS are natural	3
Too expensive	2
Better to focus on underlying issues	2
Only part of the equation	1

CATEGORY: OTHER STRATEGIES

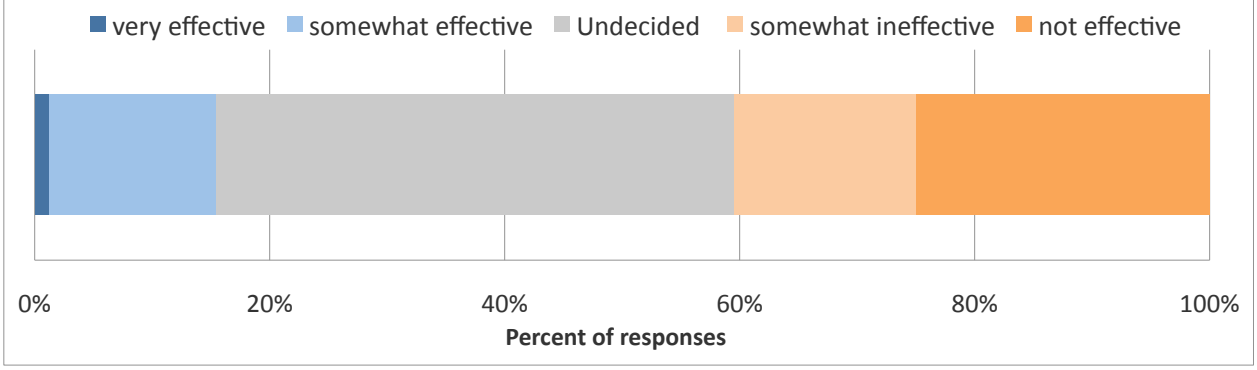
Question Number	Question Text	Score	Rank out of 22
21	Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection	1.50	3



Additional Comments:

Comments	Number of Comments
This is important	29
Enforce rules focused on reef recovery	8
Must be with community-based management	3
Not as effective for bleaching events	1
No evidence of actual effect on corals	1
Create educational campaign	1
Very complicated to achieve	1

Question Number	Question Text	Score	Rank out of 22
22	Create artificial reefs in heavily bleaching- impacted reef areas	-0.49	22



Additional Comments:

Comments	Number of Comments
Not effective	8
Only if there was loss of settlement substrate	6
Incompatible to scale of the problem	5
More effective for fish	4
Too expensive	4
Better to focus on underlying issues	4
This is important	3
Combine with transplanted corals	2
Use only as alternative to permanent MPA	1
No evidence of actual effect on corals	1
Too slow	1
Very complicated to achieve	1
Use in bleaching resilient areas	1
Will not promote recruitment	1

Additional Management Recommendations:

Comments	Number of Comments
Reduce all local stressors	15
Focus on education	15
Protect bleaching-resistant areas	11
Promote emission reduction	8
Bolster community managed areas	7
Continue to monitor reefs	6
Pursue steps towards active restoration	4
Need to protect all herbivores	3
Temporary access closures during bleaching season	3
Regulate coastal construction	3
Increase enforcement manpower	3
Focus on increasing all fish populations	3
Research algae species in post-bleached areas	2
Reduce stressors that trigger coral disease	2
More research on bleaching mitigation and aiding recovery	2
Effective management and enforcement is key	1
Use with permanent MPAs	1
Research evolution of thermally resistant corals	1
Allow only subsistence use of inshore resources	1
Streamline research permitting process	1
Protect spawning fish	1
Integrate effects of ocean acidification	1
Lessen physical impact from permitted activities	1

References

Aswani S, Mumby PJ, Baker AC, Christie P, McCook LJ, Steneck RS and Richmond RH. (2015). Scientific frontiers in the management of coral reefs. Front. Mar. Sci. 2:50. doi: 10.3389/fmars.2015.00050.

Hooidonk, RV, Maynard JA, Manzello, D and Planes S. (2014). Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology. 20: 103-112, doi: 10.111/gcb.12394doi: 10.1111/gcb.12394.

Appendix A: Coral Bleaching Survey Contact List

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Thomas	Oliver	Coral Reef Ecosystems Program, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI USA
Jamie	Oliver	International Center for Living Aquatic Resources Management, Penang, Malaysia
Ling	Ong	SWCA Environmental Consultants, Honolulu, HI USA
Stephen	Palumbi	Hopkins Marine Lab, Stanford University, CA USA

John	Pandolfi	School of Biological Sciences and the Australian Research Council Centre of Excellence for Coral Reef Studies, University of Queensland
Britt	Parker	NOAA Office for Coastal Management Coral Reef Conservation Program, Washington DC USA
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Douglas	Rasher	Darling Marine Center, Walpole, Maine, USA
Robert	Richmond	Kewalo Marine Laboratory, University of Hawaii at Mānoa, Honolulu, HI USA
Ku'ulei	Rodgers	Hawaii Institute of Marine Biology, University of Hawaii at Mānoa, Honolulu, HI USA
George	Roff	Marine Spatial Ecology Lab, School of Biological Sciences, University of Queensland, Brisbane, Australia
Nedeljka	Rosic	School of Biological Sciences, The University of Queensland, Brisbane, Australia
Megan	Ross	Hawaii Institute of Marine Biology, University of Hawaii at Mānoa, Honolulu, HI USA
Gary	Russ	College of Marin and Environmental Sciences, James Cook University, Townsville, Australia
Rod	Salm	Asia Pacific Coastal Marine Program, The Nature Conservancy, Honolulu, HI USA
Stuart	Sandin	Center for Marine Biodiversity and Conservation, Scripps Institute of Oceanography, University of CA, San Diego USA
Helmut	Schuhmacher	Universität Duisburg-Essen, Institut für Ökologie, Abtlg. Hydrobiologie, Essen, Germany
Heidi	Schuttenberg	United States Agency for International Development Forestry and Biodiversity, Washington DC USA
Elizabeth	Selig	Science + Knowledge Division, Conservation International, Arlington, VA USA
Nachshon	Siboni	Australian Institute of Marine Science, Townsville, Australia
Nyssa	Silbiger	University of California-Irvine, CA USA
Celia	Smith	Botany Department, University of Hawaii at Mānoa, Honolulu, HI USA
Lance	Smith	Protected Resources Division, NOAA Pacific Islands Regional Office, Honolulu, HI USA
Jennifer	Smith	Scripps Institution of Oceanography, University of CA, San Diego, USA
Tyler	Smith	Center for Marine and Environmental Studies, University of the Virgin Islands
Michael	Stat	Department of Environment & Agriculture, Curtin University, Perth, Australia
Curt	Storlazzi	U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA USA
Robert	Streit	College of Marine and Environmental Sciences, James Cook University, Townsville, Australia
Mareike	Sudek	Benthic Ecologist, American Samoa Department of Marine and Wildlife Resources, Pago Pago, American Samoa
Misaki	Takabayashi	University of Hawaii Hilo, HI USA
Lida	Teneva	Conservation International, Honolulu, HI USA
Angus	Thompson	Australian Institute of Marine Science, Townsville, Australia
Brian	Tissot	Marine Laboratory, Humboldt State University, Arcata, CA USA
Susie	Tomson	Earth to Ocean Hampshire, UK

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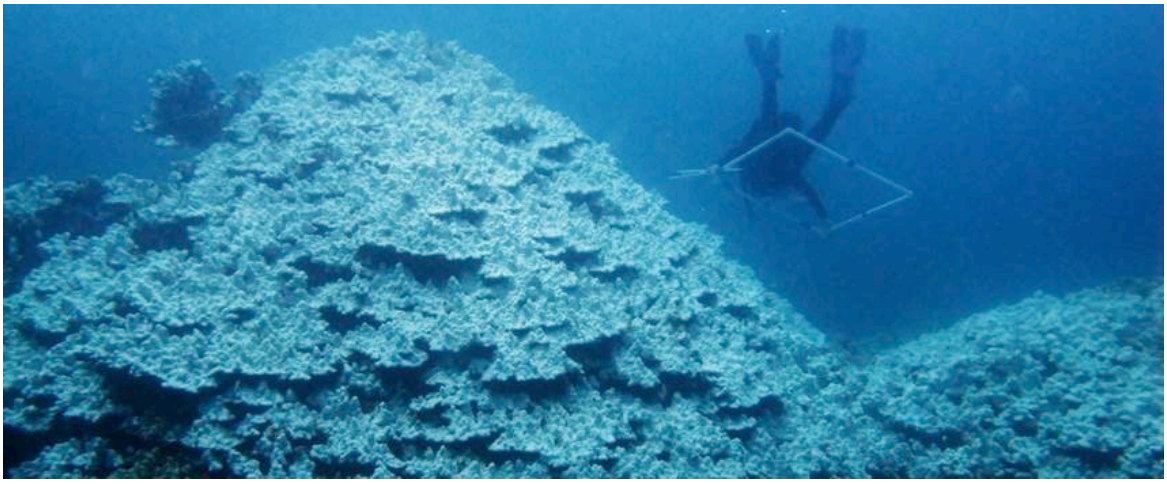
Jordan	West	ORD/NCEA/Global Change Research Program, U.S. Environmental Protection Agency, Washington, D.C., USA
Chad	Wiggins	Hawai'i Island Marine Program, The Nature Conservancy of Hawaii, Kailua Kona, HI USA
Gareth	Williams	School of Ocean Sciences, Bangor University, UK
Ivor	Williams	Coral Reef Ecosystems Program, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI USA
Dana	Williams	Protected Resources Division/Benthic Ecosystem Assessment and Research, NOAA Southeast Science Fisheries Center, Miami, FL USA
Scott	Wooldridge	Australian Institute of Marine Science, Townsville, Australia
Hussein	Zahir	Ministry of Housing and Environment, Male', Maldives.
Zhenlin	Zhang	School of Earth and Environment, The University of Western Australia, Perth, Australia

Appendix B: Coral Bleaching Recovery Survey

Hawai'i DAR Division of Aquatic Resources

Coral Bleaching Recovery Survey



In the following questions, please click the appropriate buttons regarding the **ecological effectiveness of each management strategy to promote coral reef recovery and resilience**. Some questions have a follow-up question. Also feel free to provide additional comments after each question. In total, this survey should take you approximately 20-30 minutes to complete.

SECTION 1: MARINE PROTECTED AREAS (MPAs)

1. Establish a network of permanent, fully protected no-take MPAs

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

1a. These MPAs should make up what percentage of reef habitats?

1b. Additional Comments

2. Establish a network of temporary, rotationally closed, no-take MPAs

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

2a. These temporary MPAs should be closed for what period of time?

2b. Additional Comments

3. Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

3a. These FMAs should make up what percentage of reef habitats?

3b. Additional Comments

SECTION 2: FISHERIES RULES

4. Prohibit **all take** (commercial and non-commercial) of sea urchins

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

4a. Additional Comments

5. Prohibit only the **commercial take** of sea urchins

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

5a. Additional Comments

6. Prohibit **all take** (commercial and non-commercial) of herbivorous fish

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

6a. Which herbivorous fish families? (*check all that apply*)

- ☐ Parrotfishes (*Scaridae*)
- ☐ Surgeonfishes (*Acanthuridae*)
- ☐ Chubs/Rudderfish (*Kyphosidae*)
- ☐ Damselfish (*Pomacentridae*)

6b. Additional Comments

7. Prohibit only the **commercial take** of herbivorous fish

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

7a. Additional Comments

8. Prohibit **all take** (commercial and non-commercial) of parrotfishes

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

8a. Additional Comments

9. Establish size limits to protect parrotfishes

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

9a. What type of size limit should be used?

9b. Additional Comments

10. Establish bag limits to protect parrotfishes

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

10a. What type of bag limit should be used?

10b. Additional Comments

SECTION 3: HUMAN IN-WATER ACTIVITIES RULES

11. Prohibit aquarium collecting of herbivorous fishes

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

11a. Additional Comments

12. Establish a temporary moratorium on aquarium collecting

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

12a. How long should the moratorium last?

12b. Additional Comments

13. Encourage the use of sunscreens that *do not* contain the ingredient Oxybenzone, which has been shown to be harmful to corals

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

13a. Additional Comments

14. Close heavily bleaching-impacted reef areas to all human in-water activities

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

14a. Additional Comments

SECTION 4: AQUACULTURE TECHNIQUES

15. Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

15a. Additional Comments

16. Identify, collect, propagate and replant corals found to be resistant to bleaching

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

16a. Additional Comments

SECTION 5: LAND-BASED STRATEGIES

17. Work with authorized agencies to reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

17a. Additional Comments

18. Work with authorized agencies to reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

18a. Additional Comments

SECTION 6: ERADICATION TECHNIQUES

19. Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus*

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

19a. Additional Comments

20. Attempt to eradicate the Crown of Thorns Starfish, *Acanthaster plancii*

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

20a. Additional Comments

SECTION 7: OTHER STRATEGIES

21. Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

21a. Additional Comments

22. Create artificial reefs in heavily bleaching- impacted reef areas

very effective	somewhat effective	undecided or unknown	somewhat ineffective	not effective
○	○	○	○	○

22a. Additional Comments

Coral Bleaching Recovery Survey

Please provide any other management recommendations that you think would be effective to promote post-bleaching coral reef recovery and resilience.

1.
2.
3.
4.
5.

Almost done...

Coral Bleaching Recovery Survey

Hawai'i DAR Division of Aquatic Resources

Which of the following best describes you in your current role? (*check all that apply*)

- [ ] Scientist
- [ ] Manager
- [ ] Other (please specify)

If you checked scientist, how many relevant publications do you have on this subject?

- ◯ 0
- ◯ 1-5
- ◯ 6-10
- ◯ > 10

How many years of experience do you have that are relevant to this issue?

- ◯ 1-5 years
- ◯ 6-10 years
- ◯ > 10 years

Would you like to receive a summary of the results of this survey?

- ◯ Yes
- ◯ No

Would you prefer to have your survey responses remain confidential?

- ◯ Yes
- ◯ No

Mahalo!