## EXECUTIVE SUMMARY

On October 20, 2009, the Center for Biological Diversity petitioned the National Marine Fisheries Service (NMFS) to list 83 coral species as threatened or endangered under the U.S. Endangered Species Act. The petition was based on a predicted decline in available habitat for the species, citing anthropogenic climate change and ocean acidification as the lead factors among the various stressors responsible for the potential decline. The NMFS identified 82 of the corals as candidate species, finding that the petition provided substantive information for a potential listing of these species. The NMFS established a Biological Review Team (BRT) to prepare this Status Review Report that examines the status of these 82 candidate coral species and evaluates extinction risk for each of them. This document makes no recommendations for listing, as that is a separate evaluation to be conducted by the NMFS.

The BRT considered two major factors in conducting this review. The first factor was the interaction of natural phenomena and anthropogenic stressors that could potentially contribute to coral extinction. After extensive review of available scientific information, the BRT considers ocean warming, disease, and ocean acidification to be the most influential threats in posing extinction risks to the 82 candidate coral species between now and the year 2100. Threats of local origin but having widespread impact, such as sedimentation, nutrient enrichment, and fishing, were considered of medium importance in determining extinction risks. It is acknowledged that many other threats (e.g., physical damage from storms or ship groundings, invasive species or predator outbreaks, collection and trade) also negatively affect corals, often acutely and dramatically, but generally at relatively small local scales. These local threats were considered to be of limited scope and not deemed to contribute appreciably to the risk of species extinction, except in those special cases where species have restricted geographic or habitat ranges or species have already undergone precipitous population declines such that these local threats further contribute to depensatory processes that can magnify extinction risks (e.g., feedback-loops whereby individual survival decreases with smaller population size). The BRT acknowledges that local and global threats operate on different time scales and, though there is high confidence in the general progression of some key global threats, such as ocean warming and ocean acidification, there is much less certainty in the timing and spatial patterns of these threats. There is also substantial uncertainty in the abilities of the 82 candidate coral species to tolerate or adapt to each of the threats examined, as well as uncertainty in the dynamics of multiple simultaneous stresses. The BRT specifically identified increasing human population levels and the intensity of their collective human consumption as the root drivers of almost all global and local threats to coral species. In evaluating future threat impacts, the BRT attempted to project current trends, without assumptions of future policy changes or technological advances that could potentially alter the projections used in this analysis.

The second major factor was the fundamental ecological character of each candidate coral species—particularly life history, taxonomy, and abundance. Corals have complex life cycles and a taxonomy based on variable skeletal morphologies. Both of these complicate assessment of species status and extinction risk. Planktonic larval phases, cryptic settlement, long post-settlement periods with high mortality, and external fertilization are characteristics of many coral species. A lack of adequate data on many aspects of life history makes it difficult to determine the population dynamics of corals throughout their ranges with confidence. In addition, the increasing availability of genetic analyses of coral populations in many cases calls into question the morphology-based classifications traditionally used to separate nominal coral species. Even if species are assumed to be identifiable in the field, it is often difficult to distinguish separate colonies, and there is no way to distinguish genetic individuals in the field (i.e., many colonies may be genetically identical clones). These limitations make it challenging to assess accurate population demographics for most species. Coral reef monitoring data offer some insights, but are often reported at the genus level or are not optimized for relatively rare species. As a result of these demographic and monitoring limitations, species-level abundance and trend data were virtually non-existent for most of the 82 candidate coral species under consideration.

In the absence of species-specific abundance and trend information, BRT members relied heavily upon the best available information on the spatial extent of the species ranges and on their understanding of the likely impacts of the suite of threats on each of the individual coral populations over the period until 2100. The lack of adequate information on complex coral ecology and interactions between threats made the assessment of extinction risk for each of the 82 nominal coral species extremely challenging and uncertain.

The BRT chose to evaluate extinction risk as the likelihood of a species status falling below a Critical Risk Threshold by the year 2100, a time frame over which climate projections are readily available and have been sufficiently vetted through extensive scientific peer review to be deemed to have reasonable reliability. The Critical Risk Threshold

describes a condition where the species is of such low abundance, or so spatially fragmented, or at such reduced genetic and/or genotypic diversity that extinction is extremely likely. Assessment of the Critical Risk Threshold took into consideration depensatory processes, environmental stochasticity, and catastrophic events. Following extensive discussion about each candidate coral species, the likelihood of the status of the species falling below the Critical Risk Threshold by 2100 was anonymously estimated by each BRT member assigning ten points to eight "risk likelihood categories" linked to probabilities; points were summed across the seven BRT members for each risk likelihood category. After further discussion and a second round of anonymous voting for each of the 82 candidate coral species, the likelihood of the species status falling below the Critical Risk Threshold was expressed as a histogram of the percentage of likelihood points for each risk category and an estimate of the mean likelihood was calculated (Fig. ES-1). After completing at least two rounds of separate voting for each of the 82 candidate coral species, the BRT discussed the relative rankings of the species in a comparative sense to identify potential outliers that needed further consideration and an additional closed vote was taken when warranted by this analysis or discovery of new information.

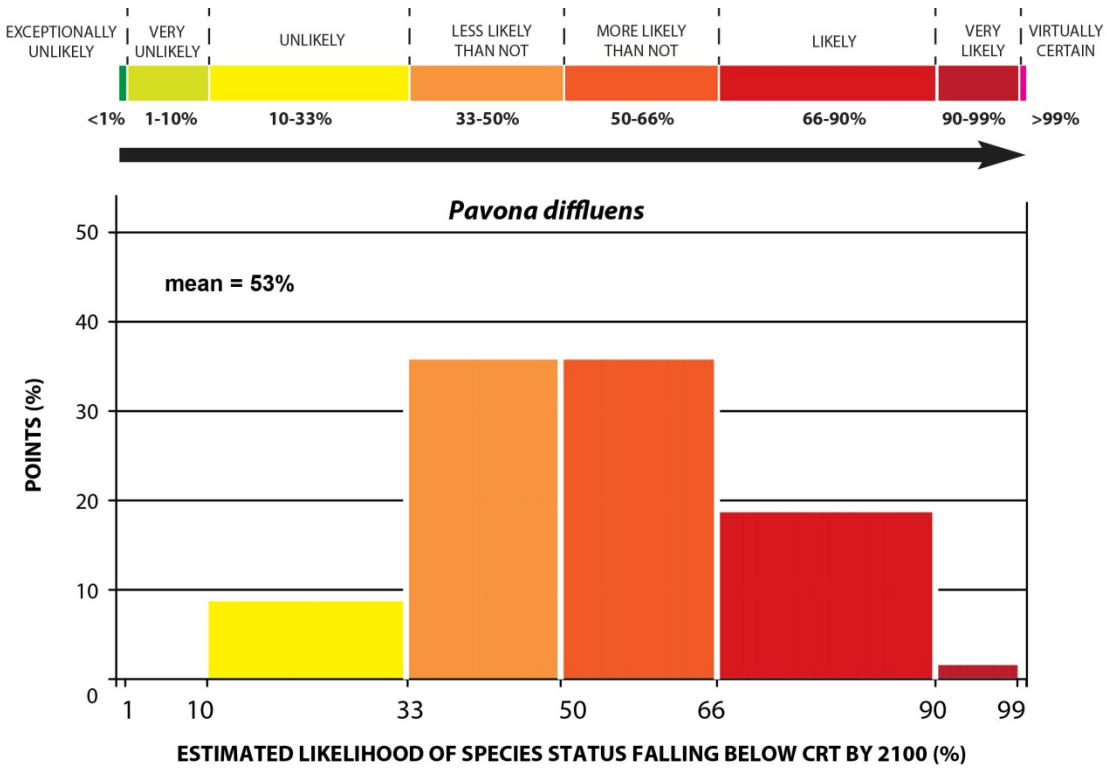


Figure ES-1. Example histogram showing the distribution of points to estimate the likelihood that the status of *Pavona diffluens* will fall below the Critical Risk Threshold (the species is of such low abundance, or so spatially fragmented, or at such reduced diversity that extinction is extremely likely) by 2100.

This process yielded a list of the 82 candidate coral species ranked by the mean likelihood of falling below the Critical Risk Threshold by 2100 (Fig. ES-2, Table ES-1). Given the myriad uncertainties described above, this list must be understood as a qualitative ranking, not supporting fine parsing among species whose mean scores differ by only a few points. While the mean likelihood of a species status falling below the Critical Risk Threshold by 2100 is an important indicator of the extinction risk, the broad distribution of points in these histograms highlights the high level of uncertainty in these estimates of Critical Risk Threshold likelihood by the BRT members. Both the mean likelihood scores and the uncertainty should be considered in the application of these estimates.

That said, certain patterns in the Critical Risk Threshold likelihood estimates are notable. Caribbean species were estimated to have relatively high likelihoods of falling below their Critical Risk Thresholds by 2100, with five of the seven candidate species from that region ranked in the top seven overall. This reflects the relatively small and restricted geographic extent of these species, pervasive and demonstrated impacts of both local and global threats, and the significant, well-documented declines of corals throughout the Caribbean region. Other candidate species determined by

Figure ES-2. Summary of votes tallied across Critical Risk Threshold likelihood categories for all 82 candidate coral species ranked by mean likelihood. The x-axis indicates the percent likelihood of a species status falling below the Critical Risk Threshold. Darkness of color scales to the proportion of votes in each risk category for each species. Red text is used for Caribbean species names and black text is used for Indo-Pacific species names. See the Individual Species Accounts (chapters 6 and 7) for the distribution of votes in each likelihood category.

Table ES-1. Summary of votes tallied in each risk likelihood category (colored columns), mean (and standard error, SE) likelihood of falling below the Critical Risk Threshold by 2100, and mean likelihood range for each of the 82 candidate coral species ranked by mean likelihood as determined by the BRT. The SE was calculated by taking the standard deviation of the seven mean voting scores of the BRT members. Mean likelihood range is the mean range of the likelihood estimates of the seven BRT voters. For example, an individual voter spreading votes in categories between "unlikely" and "more likely than not" would have an individual range of 56%. Three voters with a 33% range, one with a 56% range, and three with a 66% range would produce an average likelihood range of 50.4%. Red text is used for Caribbean species names and black text is used for Indo-Pacific species names. Species listed in parentheses were not petitioned per se, but were incorporated based on best available taxonomic information (see Sections 7.3.2, 7.8, 7.10.4 for discussions of taxonomic issues within Pocillopora, Montipora, and Porites respectively).

| SPECIES | # OF VOTES IN EACH RISK LIKELIHOOD CATEGORY | | | | | | | | MEAN LIKELI-HOOD (%) | SE OF BRT MEANS (%) | MEAN LIKELIHOOD RANGE (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <1 | 1-10 | 10-33 | 33-50 | 50-66 | 66-90 | 90-99 | >99 | | | |
| *Montastraea annularis* | 0 | 0 | 0 | 0 | 19 | 29 | 22 | 0 | 78 | 6.9 | 45.4 |
| *Montastraea faveolata* | 0 | 0 | 0 | 0 | 19 | 29 | 22 | 0 | 78 | 6.9 | 45.4 |
| *Acropora lokani* | 0 | 0 | 0 | 1 | 17 | 34 | 18 | 0 | 77 | 8.1 | 50.1 |
| *Acropora jacquelineae* | 0 | 0 | 0 | 1 | 17 | 37 | 15 | 0 | 76 | 7.3 | 50.1 |
| *Dendrogyra cylindrus* | 0 | 0 | 0 | 1 | 22 | 33 | 14 | 0 | 74 | 6.6 | 48.9 |
| *Montastraea franksi* | 0 | 0 | 0 | 3 | 25 | 24 | 18 | 0 | 74 | 9 | 47.9 |
| *Mycetophyllia ferox* | 0 | 0 | 0 | 5 | 26 | 30 | 9 | 0 | 70 | 8.2 | 50 |
| *Acropora rudis* | 0 | 0 | 0 | 9 | 19 | 34 | 8 | 0 | 70 | 11.2 | 49 |
| *Acropora dendrum* | 0 | 0 | 0 | 4 | 30 | 29 | 7 | 0 | 69 | 5.6 | 55 |
| *Pocillopora elegans* (E Pacific) | 0 | 0 | 3 | 7 | 25 | 26 | 9 | 0 | 67 | 13 | 53.4 |
| *Montipora patula (verrilli)* | 0 | 0 | 0 | 11 | 28 | 24 | 7 | 0 | 66 | 9.9 | 50.1 |
| *Acropora donei* | 0 | 0 | 0 | 13 | 28 | 26 | 3 | 0 | 64 | 8.2 | 52.6 |
| *Acropora pharaonis* | 0 | 0 | 0 | 15 | 27 | 23 | 5 | 0 | 64 | 8.9 | 55 |
| *Euphyllia paradivisa* | 0 | 0 | 0 | 15 | 28 | 22 | 5 | 0 | 63 | 9.6 | 50.3 |
| *Millepora foveolata* | 0 | 0 | 0 | 16 | 26 | 25 | 3 | 0 | 63 | 9.8 | 50.3 |
| *Millepora tuberosa* | 0 | 0 | 0 | 17 | 25 | 25 | 3 | 0 | 63 | 10.1 | 50.3 |
| *Euphyllia paraancora* | 0 | 0 | 0 | 17 | 27 | 21 | 5 | 0 | 63 | 10.4 | 50.3 |
| *Isopora cuneata* | 0 | 0 | 0 | 15 | 29 | 24 | 2 | 0 | 62 | 8.5 | 51.3 |
| *Euphyllia cristata* | 0 | 0 | 0 | 19 | 26 | 21 | 4 | 0 | 62 | 10.5 | 50.3 |
| *Montipora dilatata/flabellata (turgescens)* | 0 | 0 | 0 | 17 | 30 | 20 | 3 | 0 | 61 | 7.3 | 56.1 |
| *Agaricia lamarcki* | 0 | 0 | 0 | 17 | 29 | 23 | 1 | 0 | 61 | 6.3 | 54.9 |
| *Anacropora spinosa* | 0 | 0 | 0 | 22 | 27 | 19 | 2 | 0 | 59 | 7.5 | 54.9 |
| *Dichocoenia stokesi* | 0 | 0 | 0 | 19 | 33 | 17 | 1 | 0 | 59 | 5.1 | 58.3 |
| *Acropora microclados* | 0 | 0 | 3 | 19 | 27 | 19 | 2 | 0 | 58 | 11 | 60.3 |
| *Montipora lobulata* | 0 | 0 | 3 | 23 | 22 | 18 | 4 | 0 | 58 | 11.9 | 57.1 |
| *Acropora striata* | 0 | 0 | 2 | 21 | 27 | 19 | 1 | 0 | 58 | 8.4 | 58.1 |
| *Acropora listeri* | 0 | 0 | 3 | 18 | 31 | 17 | 1 | 0 | 58 | 6.7 | 64.9 |
| *Acropora globiceps* | 0 | 0 | 2 | 21 | 29 | 17 | 1 | 0 | 57 | 8.1 | 58.1 |
| *Pachyseris rugosa* | 0 | 0 | 3 | 23 | 24 | 18 | 2 | 0 | 57 | 10.8 | 57.1 |
| *Alveopora fenestrata* | 0 | 0 | 0 | 28 | 23 | 18 | 1 | 0 | 57 | 8.5 | 52.6 |
| *Alveopora allingi* | 0 | 0 | 0 | 27 | 25 | 17 | 1 | 0 | 57 | 8.7 | 52.6 |
| *Montipora australiensis* | 0 | 0 | 3 | 25 | 22 | 17 | 3 | 0 | 57 | 12 | 53.7 |
| *Anacropora puertogalerae* | 0 | 0 | 2 | 24 | 26 | 16 | 2 | 0 | 57 | 8.1 | 60.1 |
| *Acropora tenella* | 0 | 0 | 2 | 22 | 28 | 18 | 0 | 0 | 57 | 7.7 | 58.1 |
| *Montipora angulata* | 0 | 0 | 3 | 26 | 21 | 17 | 3 | 0 | 57 | 11.9 | 53.7 |
| *Isopora crateriformis* | 0 | 1 | 4 | 20 | 24 | 20 | 1 | 0 | 57 | 14.2 | 51.3 |
| *Montipora caliculata* | 0 | 0 | 3 | 25 | 23 | 16 | 3 | 0 | 57 | 11.6 | 53.7 |
| *Alveopora verrilliana* | 0 | 0 | 0 | 29 | 24 | 16 | 1 | 0 | 56 | 9 | 49.1 |
| *Montipora calcarea* | 0 | 0 | 3 | 26 | 23 | 15 | 3 | 0 | 56 | 11.6 | 53.7 |
| *Caulastrea echinulata* | 0 | 0 | 5 | 21 | 28 | 13 | 3 | 0 | 56 | 9.6 | 62.6 |
| *Seriatopora aculeata* | 0 | 0 | 4 | 25 | 25 | 15 | 1 | 0 | 55 | 10.3 | 59.1 |

| SPECIES | # OF VOTES IN EACH RISK LIKELIHOOD CATEGORY | | | | | | | | MEAN LIKELI-HOOD (%) | SE OF BRT MEANS (%) | MEAN LIKELIHOOD RANGE (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <1 | 1-10 | 10-33 | 33-50 | 50-66 | 66-90 | 90-99 | >99 | | | |
| *Acropora speciosa* | 0 | 0 | 4 | 25 | 25 | 16 | 0 | 0 | 55 | 10.1 | 54.4 |
| *Acropora verweyi* | 0 | 0 | 7 | 21 | 25 | 16 | 1 | 0 | 54 | 11.5 | 59.1 |
| *Acropora retusa* | 0 | 0 | 6 | 25 | 22 | 15 | 2 | 0 | 54 | 13.2 | 55.7 |
| *Pocillopora danae* | 0 | 0 | 8 | 20 | 28 | 11 | 3 | 0 | 54 | 13.7 | 52.3 |
| *Pavona diffluens* | 0 | 0 | 6 | 25 | 25 | 13 | 1 | 0 | 53 | 12 | 61.4 |
| *Acropora paniculata* | 0 | 0 | 5 | 26 | 26 | 12 | 1 | 0 | 53 | 9.4 | 49.9 |
| *Acropora polystoma* | 0 | 0 | 6 | 26 | 25 | 12 | 1 | 0 | 53 | 9.9 | 61.3 |
| *Acropora vaughani* | 0 | 0 | 8 | 24 | 24 | 13 | 1 | 0 | 52 | 11.2 | 61.3 |
| *Astreopora cucullata* | 0 | 0 | 8 | 25 | 24 | 11 | 2 | 0 | 52 | 9.2 | 59 |
| *Barabattoia laddi* | 0 | 0 | 4 | 28 | 29 | 8 | 1 | 0 | 52 | 12.6 | 51.1 |
| *Acropora palmerae* | 0 | 0 | 7 | 24 | 28 | 11 | 0 | 0 | 52 | 8.8 | 60 |
| *Acropora horrida* | 0 | 0 | 5 | 27 | 29 | 9 | 0 | 0 | 52 | 6.8 | 56.7 |
| *Physogyra lichtensteini* | 0 | 0 | 10 | 25 | 22 | 12 | 1 | 0 | 51 | 11.4 | 62.3 |
| *Porites horizontalata* | 0 | 0 | 10 | 25 | 22 | 12 | 1 | 0 | 51 | 11.7 | 62.3 |
| *Pocillopora elegans* (W Pacific) | 0 | 2 | 9 | 23 | 23 | 12 | 1 | 0 | 50 | 14.6 | 56.9 |
| *Porites napopora* | 0 | 0 | 8 | 27 | 27 | 8 | 0 | 0 | 50 | 9.1 | 57.7 |
| *Acanthastrea brevis* | 0 | 0 | 8 | 28 | 26 | 7 | 1 | 0 | 50 | 9.1 | 57.7 |
| *Acanthastrea hemprichii* | 0 | 0 | 8 | 28 | 26 | 7 | 1 | 0 | 50 | 9.1 | 57.7 |
| *Acanthastrea ishigakiensis* | 0 | 0 | 8 | 28 | 26 | 7 | 1 | 0 | 50 | 7 | 59.9 |
| *Porites nigrescens* | 0 | 0 | 8 | 29 | 25 | 7 | 1 | 0 | 50 | 8.9 | 57.7 |
| *Acropora acuminata* | 0 | 0 | 9 | 25 | 30 | 6 | 0 | 0 | 49 | 8.5 | 56.6 |
| *Acropora aculeus* | 0 | 0 | 11 | 22 | 30 | 7 | 0 | 0 | 49 | 11.8 | 51 |
| *Pectinia alcicornis* | 0 | 0 | 16 | 22 | 20 | 10 | 2 | 0 | 48 | 15.6 | 58.9 |
| *Acropora aspera* | 0 | 1 | 9 | 24 | 31 | 5 | 0 | 0 | 48 | 9.3 | 57.9 |
| *Pavona bipartita* | 0 | 0 | 10 | 28 | 26 | 6 | 0 | 0 | 48 | 10.9 | 47.4 |
| *Acanthastrea regularis* | 0 | 3 | 8 | 26 | 25 | 8 | 0 | 0 | 48 | 15 | 46.6 |
| *Pavona cactus* | 0 | 0 | 12 | 27 | 24 | 7 | 0 | 0 | 47 | 10.7 | 47.4 |
| *Pavona decussata* | 0 | 0 | 11 | 28 | 25 | 6 | 0 | 0 | 47 | 10.7 | 50.7 |
| *Pavona venosa* | 0 | 0 | 11 | 28 | 25 | 6 | 0 | 0 | 47 | 12 | 48.3 |
| *Cyphastrea agassizi* | 0 | 0 | 15 | 22 | 25 | 8 | 0 | 0 | 47 | 13.8 | 51.7 |
| *Cyphastrea ocellina* | 0 | 0 | 15 | 23 | 24 | 8 | 0 | 0 | 47 | 13.7 | 51.7 |
| *Turbinaria stellulata* | 0 | 0 | 8 | 33 | 29 | 0 | 0 | 0 | 46 | 5.9 | 40.6 |
| *Galaxea astreata* | 0 | 1 | 9 | 34 | 24 | 2 | 0 | 0 | 45 | 7.5 | 51.9 |
| *Psammacora stellata* | 0 | 2 | 18 | 30 | 18 | 2 | 0 | 0 | 41 | 9.2 | 58.4 |
| *Leptoseris incrustans* | 0 | 6 | 17 | 27 | 17 | 3 | 0 | 0 | 39 | 10.3 | 61.1 |
| *Leptoseris yabei* | 0 | 6 | 18 | 25 | 19 | 2 | 0 | 0 | 39 | 11.1 | 57.7 |
| *Turbinaria mesenterina* | 0 | 3 | 19 | 36 | 12 | 0 | 0 | 0 | 37 | 9.5 | 45.1 |
| *Turbinaria peltata* | 0 | 3 | 19 | 36 | 12 | 0 | 0 | 0 | 37 | 9.5 | 45.1 |
| *Turbinaria reniformis* | 0 | 3 | 19 | 36 | 12 | 0 | 0 | 0 | 37 | 9.5 | 45.1 |
| *Heliopora coerulea* | 0 | 4 | 24 | 28 | 11 | 3 | 0 | 0 | 37 | 11.1 | 54.1 |
| *Porites* (Clade 1 forma *pukoensis**) | 0 | 30 | 25 | 14 | 1 | 0 | 0 | 0 | 19 | 8.3 | 43.1 |
| all votes summed | 0 | 65 | 494 | 1750 | 1981 | 1209 | 241 | 0 | | | |
| frequency of species per likelihood bin | 0 | 13 | 57 | 80 | 82 | 77 | 57 | 0 | | | |
| percentage of species per likelihood bin (%) | 0 | 16 | 70 | 98 | 100 | 94 | 70 | 0 | | | |
| mean likelihood score frequency | 0 | 0 | 1 | 25 | 46 | 10 | 0 | 0 | | | |

* see species account *Porites pukoensis* for details

the BRT to have relatively high extinction risk also tended to have highly restricted geographic ranges, documented declines in abundance or low population sizes, and/or were extremely vulnerable to one or more threats. In contrast, lower risk candidate coral species tended to have wide geographic and habitat distributions, tolerance to marginal environmental conditions, and/or known tolerance of important threats. Among the 82 candidate coral species, the mean estimated likelihood of a species status falling below the Critical Risk Threshold by 2100 ranged from 78% ("likely" to fall below the Critical Risk Threshold by 2100) to 19% ("unlikely" to fall below the Critical Risk Threshold by 2100). The overall mean likelihood of falling below the Critical Risk Threshold by 2100 was 55% across all 82 candidate coral species, thereby falling into the "more likely than not (50%–66%)" risk likelihood category (the mode was also in this category). The distribution of mean likelihood scores across the 8 risk likelihood categoies for all 82 candidate coral species (Fig. ES-3) shows that the mean likelihood scores for 26 of the 82 species were in the 'less likely than not' (25) or 'unlikely' (1) risk likelihood categories and 56 of the 82 species were in the 'more likely than not' (46) and 'likely' (10) risk likelihood categories. The overall uncertainty was high with the mean range of votes for all 82 of the candidate coral species spanning 53.75% (SD 12.73) of the total likelihood range. In simplified terms, the BRT concluded, albeit with high uncertainty, that the status of most of the 82 candidate coral species are "more likely than not" to fall below the Critical Risk Threshold by 2100 under the assumption of status quo policies and technologies.

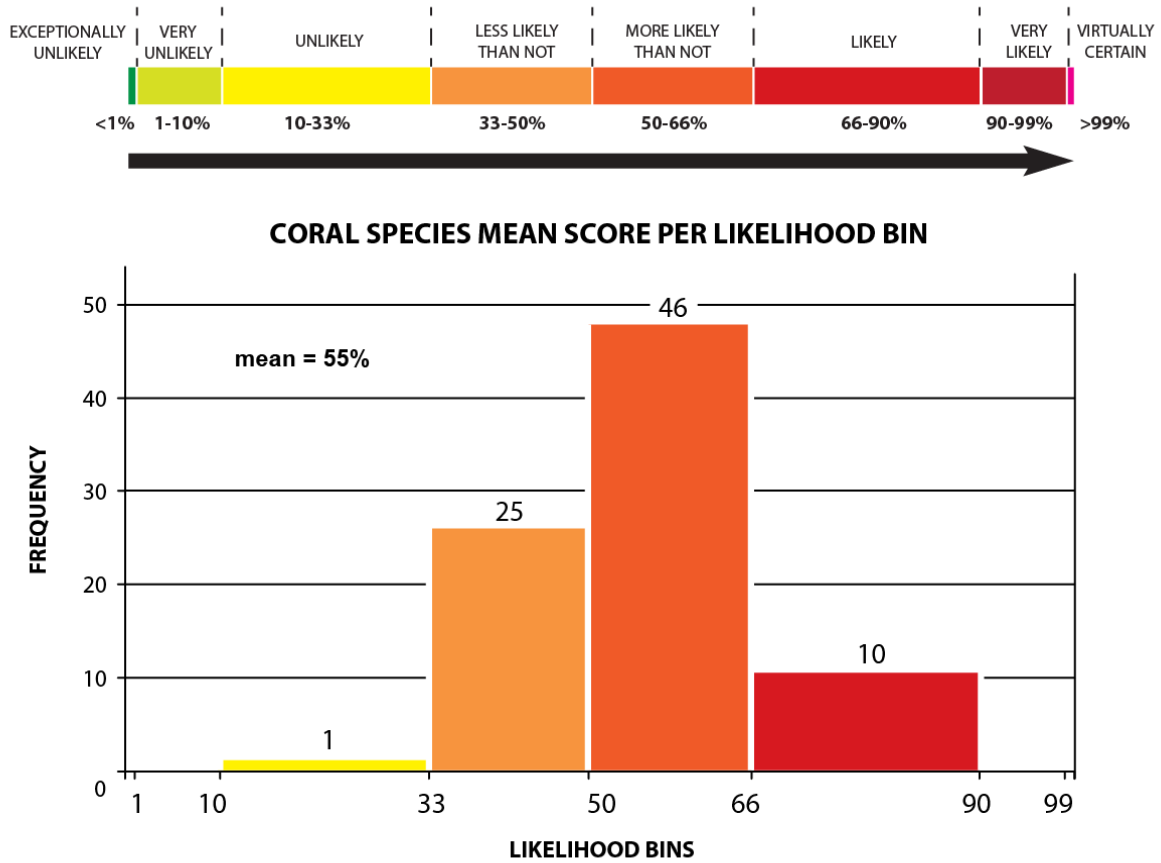


Figure ES-3. Number of coral species mean with likelihood scores (total = 82 scores) in each risk likelihood category. The overall mean of the mean likelihood scores of all 82 species is 55%.