Pocillopora meandrina:
Status Review Report

Pocillopora meandrina (left) and *P. eydouxi* (right), Philippines (Doug Fenner).

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Executive Summary

On March 14, 2018, the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity to list the Indo-Pacific reef-building coral *Pocillopora meandrina* (sometimes called cauliflower coral or rose coral) under the Endangered Species Act (ESA). On September 20, 2018, NMFS published a positive 90-day finding announcing that the petition and other readily available information indicated that *P. meandrina* may warrant listing (83 FR 47592), initiating the requirement to conduct a Status Review of the species. The Status Review consists of two documents: (1) The Indo-Pacific Reef-building Corals General Status Assessment (Smith 2019), which provides contextual information on the status and trends of the coral reef ecosystems that *P. meandrina* is part of; and (2) this species-specific Status Review Report, which describes the biology, habitat, demographic risk factors, threats evaluation, and extinction risk assessment for *P. meandrina*. The information in the Status Review provides the basis for the determination of whether *P. meandrina* should be proposed for listing or not.

Colonies of *P. meandrina* are small upright bushes commonly 20-40 cm (8-16 in) in diameter, with branches radiating from the initial point of growth. Coloration is typically light brown or cream, but may also be green or pink. While there is uncertainty about the taxonomic classification and field identification of *P. meandrina*, genetic studies support the conclusion that *P. meandrina* is a valid species, and Indo-Pacific coral species experts are confident in their abilities to consistently identify the species. *Pocillopora meandrina* is considered a competitive species, based on its capacity to successfully compete for space with other reef-building corals, especially following disturbances when it is often one of the first coral species to colonize denuded substrates. The species prefers high energy habitats with strong currents and constant wave action, and is often abundant on reef crests and upper reef slopes throughout its range. However, its habitat breadth includes most other reef-building coral habitats, including deeper reef slopes, back-reef areas, lava, boulders, and artificial substrates.

In order to help determine the extinction risk of species being considered for ESA listing, NMFS uses a risk analysis framework that considers the four demographic factors of distribution, abundance, productivity, and diversity.

The geographic distribution of *P. meandrina* includes 95 of the 133 Indo-Pacific coral reef ecoregions, giving it a very large range. While *P. meandrina* is most commonly found in shallow, high-energy habitats such as reef crests and shallow forereefs, its depth distribution extends from the surface to at least 34 m (112 ft). There is no evidence of any reduction in its historic range. Thus, *P. meandrina*'s distribution is very large and stable (Table 1).

Abundance of *P. meandrina* is described in terms of relative abundances, absolute abundances, and abundance trends in ecoregions for which information is available. In the 65 ecoregions for which relative abundance information is available, it is dominant in seven, common in 18, uncommon in 36, and rare in four ecoregions. It is a nearly ubiquitous species in many of the *Pocillopora*-dominated reef coral communities of the central Pacific. Absolute abundance information is available for U.S. waters (four entire ecoregions and portions of four others, which together make up ≈1% of the species' range), where the total population in 2012-2018 was estimated at 1.48 billion colonies. In the 10 ecoregions for which abundance trend information is available, *P. meandrina* appears to be decreasing in five ecoregions, and stable in five ecoregions. Because we only have abundance trend information from 10 of the 95 ecoregions, the trend in *P. meandrina*'s overall abundance is unknown. Thus, *P. meandrina*'s overall abundance is very high, but its overall abundance trend is unknown (Table 1).

The high reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability of *P. meandrina* are all characteristics of high productivity, i.e., they all positively affect population growth rate. These life history characteristics all buffer the species against threats such as warming-induced bleaching by providing the potential for rapid recovery from die-offs, as documented in some of its 95 ecoregions. Thus, *P. meandrina*'s productivity appears to be both high and stable (Table 1).

Genetic studies show high genotypic diversity in *P. meandrina* on small geographic scales (e.g., one island), and genotypic diversity is likely even higher within individual ecoregions, let alone across the 95 ecoregions that make up the range of the species. Studies of the responses of *P. meandrina* to elevated seawater temperatures show high phenotypic diversity in multiple locations. Furthermore, the species' distribution has not been reduced. Thus, *P. meandrina*'s diversity appears to be both high and stable (Table 1).

Table 1. Conclusions on status and trends of *P. meandrina*'s demographic factors.

Demographic Factor	Status	Trends
Distribution	Broad geographic (95 ecoregions) and depth (34 m, 112 ft) ranges: <u>Very large distribution</u>.	Current range = historic range: <u>Stable distribution</u>.
Abundance	Dominant or common in ≈⅓ of range; Population in U.S. waters (≈1% of range) = 1.48 billion colonies: <u>Very high overall abundance</u>.	Of 10 ecoregions with abundance trend information, 5 decreasing, 5 stable, 0 increasing. No info for 85/95 ecoregions: <u>Unknown overall abundance trend</u>.
Productivity	High reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability: <u>High overall productivity</u>.	Recent recoveries from disturbances at many locations throughout its range indicate continued high productivity: <u>Stable productivity</u>.
Diversity	High genetic diversity within a single ecoregion; large range and very high habitat heterogeneity: <u>High diversity</u>.	Large and stable distribution; high overall abundance, and stable abundance trends in most ecoregions w/ trend information: <u>Stable diversity</u>.

In addition to the demographic factors, the extinction risk analysis framework also considers the threats to the species. The vulnerability of *P. meandrina* to each threat is a function of its susceptibility and exposure, considered at the spatial scale of the 95 ecoregions that make up the current range of *P. meandrina*, and the temporal scale of now through the foreseeable future (i.e., the year 2100). Based on these vulnerability ratings, the six worst threats to *P. meandrina* currently are ocean warming (high), ocean acidification (high), predation (moderate), fishing (low to moderate), land-based sources of pollution (low to moderate), and collection and trade (low to moderate). The interactions of threats may also represent a major threat, but there is not enough information available to determine *P. meandrina*'s vulnerability to it. Vulnerabilities to all threats are expected to increase in the foreseeable future (Table 2). While the inadequacy of existing regulatory mechanisms does not constitute a direct physical or biological threat to *P. meandrina*, it is a problem that either causes or exacerbates the other threats to the species.

Table 2. Current susceptibilities, exposures, and vulnerabilities (a function of susceptibility and exposure) of *P. meandrina* to the threats. The expected trends in vulnerabilities in the foreseeable future are also shown.

Threat	Current Susceptibility	Current Exposure	Current Vulnerability	Future Vulnerability*
Ocean Warming	Moderate to High	High	High	↑
Ocean Acidification	High	Variable	High	↑
Sea-level Rise	Low	Variable	Low	↑
Fishing	Moderate	Low	Low to Moderate	↑
LBSP	Moderate	Low	Low to Moderate	↑
Coral Disease	Low	Variable	Low	↑
Predation	Moderate	Variable	Moderate	↑
Collection & Trade	Moderate	Low	Low to Moderate	↑
Other Threats (global)	Low	Variable	Low	↑
Other Threats (local)	Low	Very Low	Very Low to Low	↑
Interactions of Threats	Unknown	Unknown	Unknown	↑

*   ↑ = a negative upward trend

An extinction risk assessment (ERA) was carried out by a 7-member ERA Team, which included assessments of *P. meandrina*'s demographic risk, threats, and overall extinction risk, based on the information in the General Status Assessment of Indo-Pacific Reef-building Corals (Smith 2019) and this Status Review Report, and following NMFS internal ERA and climate change guidance. The ERA was conducted for the time period from now through the year 2100 (the foreseeable future), assuming continuation of climate change scenario RCP8.5 as the status quo. With regard to demographic risks, the ERA Team concluded that most of *P. meandrina*'s demographic factors are indicative of a robust and resilient species, but that abundance poses a moderate risk, based on declining abundance in five of the 10 ecoregions for which abundance trend data and information are available. The ERA Team also concluded that the worst threats to *P. meandrina* are those caused by global climate change (ocean warming, ocean acidification, interactions of these two threats with one another and other threats), which are projected to greatly worsen in the foreseeable future (now through 2100) under RCP8.5, exacerbated by the inadequacy of regulatory mechanisms, especially for greenhouse gas emissions management.

With regard to extinction risk, the ERA Team's draft ratings resulted in the Low, Moderate, and High extinction risk categories receiving 48%, 38%, and 14% of the likelihood points, respectively. After holding a Team meeting to discuss the available information (i.e., the General Status Assessment and this Status Review Report) and the climate change guidance (i.e., assumption of RCP8.5 from now to 2100), the ERA Team completed its final ratings, resulting in the Low, Moderate, and High extinction risk categories receiving 35%, 56%, and 9% of the likelihood points, respectively. The draft and final ratings were based on the same written information and guidance.

In conclusion, the information in the GSA (Smith 2019), this Status Review Report, and the ERA Team's results lead to the following conclusions regarding *P. meandrina*'s extinction risk currently and in the foreseeable future (now to 2100): (1) the species is currently at low risk of extinction throughout its range, despite current threats, because of its strong demographic factors; and (2) as threats worsen in the foreseeable future, the species is expected to face a low to moderate risk of extinction throughout its range, moderated by its strong demographic factors. We conclude that *P. meandrina* is currently at low risk of extinction throughout its range, and that it will be at low to moderate risk of extinction throughout its range in the foreseeable future (now to 2100).

1. Introduction

On March 14, 2018, the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity (CBD 2018) to list the Indo-Pacific reef-building coral *Pocillopora meandrina* (sometimes called cauliflower coral or rose coral) in Hawaiʻi as an endangered or threatened species under the Endangered Species Act (ESA). The petition requested that the Hawaiʻi population of *P. meandrina* be considered a significant portion of the range of the species, and that the species be listed because of its status in Hawaiʻi. Our policy on the interpretation of the phrase "Significant Portion of Its Range" (SPR) under the ESA states that, before undergoing an SPR analysis, we must first find that the species is neither endangered nor threatened throughout all of its range (79 FR 37577, July 1, 2014). Therefore, we interpreted the petition as a request to consider the status of *P. meandrina* throughout its range first. On September 20, 2018, we published a positive 90-day finding announcing that the petition and other readily available information indicated that *P. meandrina* may warrant listing as a threatened species or an endangered species throughout its range, and that a range-wide Status Review of *P. meandrina* would be conducted (83 FR 47592). We noted that if this Status Review led to a determination that *P. meandrina* is not warranted for listing throughout its range, we would then determine if Hawaiʻi constitutes an SPR, and proceed accordingly.

The range-wide Status Review of *P. meandrina* consists of two documents: (1) The Indo-Pacific Reef-building Corals General Status Assessment (GSA)(Smith 2019); and (2) this species-specific *P. meandrina* Status Review Report (SRR). The Status Review was organized in this way because the approximately 760 known species of Indo-Pacific reef-building corals (Corals of the World website, http://www.coralsoftheworld.org, accessed February 2019) share common characteristics (biology, habitat), they are threatened primarily by the same suite of global climate change threats (Brainard et al. 2011), and there is typically much more general information available than species-specific information. The GSA provides contextual information on the status and trends of Indo-Pacific reef-building corals, and the SRR reports the status and trends of *P. meandrina*, both based on the best available scientific information. The conclusions in this Status Review are subject to revision should important new information arise in the future. Where available, we provide literature citations to review articles that provide even more extensive citations for each topic. Data and information were reviewed through February 2019 for the GSA, and May 2019 for the SRR.

The GSA and SRR are organized as shown in Table 1 below. The information in this Status Review (i.e., the GSA and SRR together) was used to develop the Extinction Risk Assessment (ERA) in Section 5 below by an ERA Team consisting of six Federal employees and one State of Hawaiʻi employee (listed above in Acknowledgements). The ERA is based on a 3-step assessment process conducted by the ERA Team: (1) An assessment of the four demographic risk factors for *P. meandrina* described in Section 3 of the SRR, within the context of key trends in Indo-Pacific reef-building coral communities described in Section 3 of the GSA; (2) an assessment of the threat vulnerabilities of *P. meandrina* described in Section 4 of the SRR, within the context of the threats to Indo-Pacific reef-building corals described in Section 4 of the GSA; and (3) the overall extinction risk of *P. meandrina* in light of the information considered in Steps 1 and 2. The ERA process is described in more detail in Section 5 of the SRR below.

Table 1. Organization of general and species-specific information in the General Status Assessment (GSA) and *P. meandrina* Status Review Report (SRR), which together make up the *P. meandrina* Status Review.

Section	Information	GSA	SRR
1	Introduction	Describe purpose (provide general, contextual information)	Describe purpose (provide species-specific information)
2	Biology and Habitat	Characteristics of the biology and habitat common to Indo-Pacific reef-building corals	Species-specific biology and habitat of *P. meandrina*
3	Key information for assessing extinction risk	Descriptions and trends of Indo-Pacific reef-building coral communities	Descriptions and trends of demographic risk factors for *P. meandrina*
4	Threats Evaluation	Descriptions and trends of the threats affecting Indo-Pacific reef-building corals	Descriptions and trends of the vulnerabilities of *P. meandrina* to the threats
5	Extinction Risk Assessment	N/A	ERA for *P. meandrina*, based on info in the GSA and SRR

2. Biology and Habitat

The general biology and habitats of Indo-Pacific reef-building corals are described in Section 2 of the GSA (Smith 2019), which provides the context for the following species-specific descriptions of the biology and habitat of *P. meandrina*. That is, the GSA describes characteristics of the biology and habitats common to Indo-Pacific reef-building corals, while the sections below summarize the nomenclature, morphology, taxonomic and species identification uncertainty, life history, and habitat breadth of *P. meandrina*.

2.1. Nomenclature and Morphology

Pocillopora meandrina was described by James Dana from specimens collected in Hawai'i (Dana 1846a, b), thus the formal scientific name is "*Pocillopora meandrina*, Dana 1846". Veron and Pichon (1976) considered *P. meandrina* a heterotypic synonym (a described species that has been reduced in status to part of a different taxon) of *P. verrucosa,* but later agreed with other Indo-Pacific reef-building coral taxonomists (Randall and Myers 1983, Nemenzo 1986) in considering them as two valid species (Veron 1986, Corals of the World website http://www.coralsoftheworld.org, accessed February 2019). The World List of Scleractinia provides detailed lists of synonyms and associated references for both *P. meandrina* and *P. verrucosa* (http://www.marinespecies.org, accessed March 2019). However, as described in the taxonomic uncertainty section below, additional research is needed to fully understand the taxonomic complexity within the genus *Pocillopora*, including the relationships of *P. meandrina* to the other *Pocillopora* corals.

Morphologically, *P. meandrina* colonies are small upright bushes, with branches radiating from the initial point of growth. Adult colonies are commonly 20-40 cm (8-16 in) in diameter. Coloration is typically light brown or cream, but may also be green or pink. Branches are usually oval in cross section, and about 2-5 cm (1-2 in) thick. The ends of branches often appear flattened and curved (Fig. 1A-1C). There is a wide range in the extent to which branches are flattened, from very wide and flat to nearly round. Branches are usually about 1-2.5 cm (⅜-1 in) apart. The branches are covered with small bumps called verrucae about 3 mm (⅛ in) in diameter. The surface of the branches and verrucae are covered with tiny (1 mm, 1/16 in) pits in the skeleton (corallites, Fig. 1D) where the polyps are located (Fenner 2005, Corals of the World website http://www.coralsoftheworld.org, accessed February 2019).
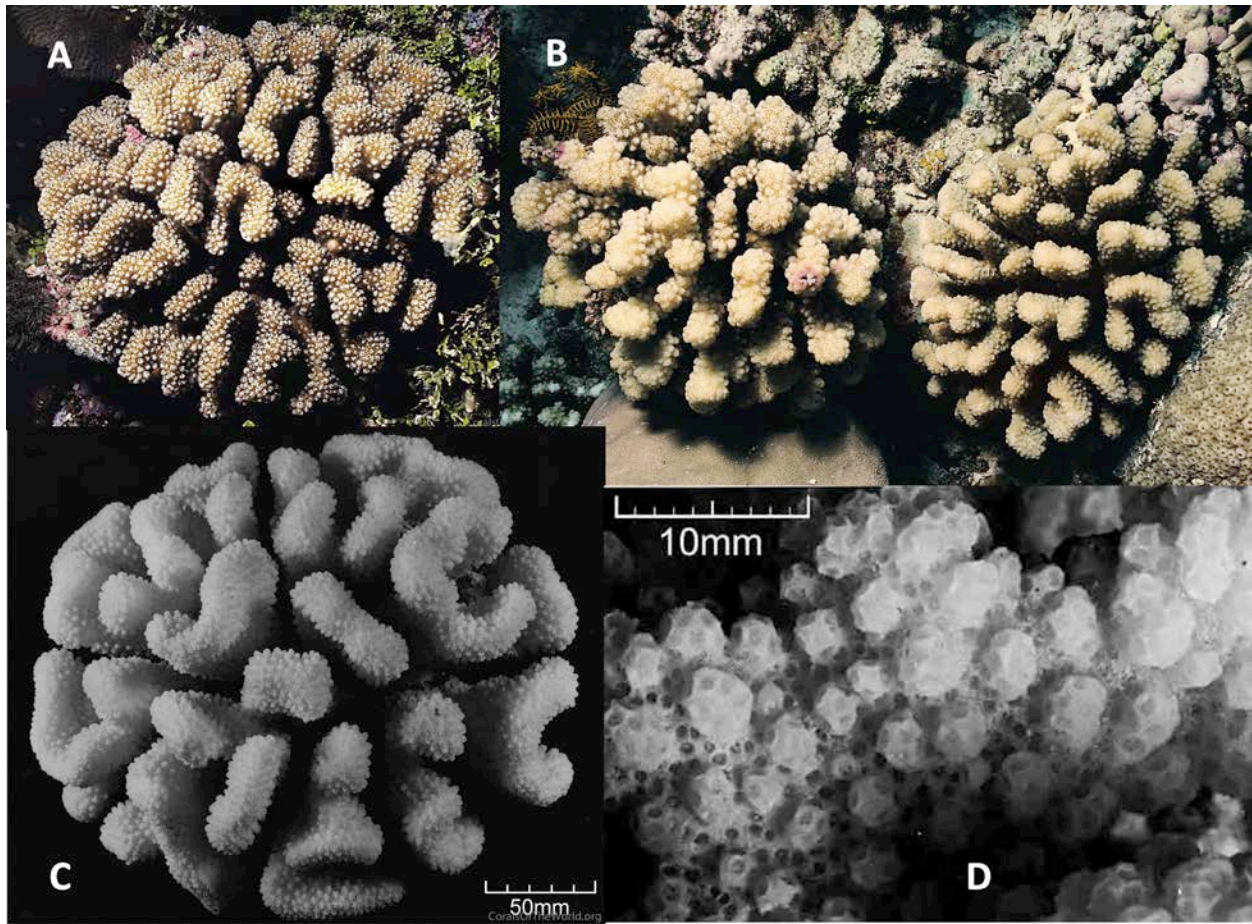
Figure 1. Photos of *P. meandrina*: (A) Common colony shape on an upper reef slope, Papua New Guinea (photo by Charlie Veron); (B) *Pocillopora verrucosa* (left) with *P. meandrina* (right) on a reef slope, Papua New Guinea (photo by Charlie Veron); (C) whole colony skeleton, collected from Hawaiʻi (photo by Jim Maragos); and (D) verrucae skeleton, collected from Great Barrier Reef (photo by Charlie Veron; Corals of the World website http://www.coralsoftheworld.org, accessed February 2019).

2.2. Taxonomic and Species Identification Uncertainty

Taxonomic uncertainty refers to how a species should be scientifically classified. The morphology-based taxonomy of the genus *Pocillopora*, including *P. meandrina*, has been called into question by several genetics papers over the last few years. A range-wide phylogeographic survey that included most currently recognized pocilloporid species found that reliance on colony morphology is broadly unreliable for species identification, and that several genetic groups have highly limited geographic distributions. The study concluded that "a taxonomic revision informed foremost by genetic evidence is needed for the entire genus" (Pinzón et al. 2013). Similarly, a phylogeographic survey of several currently recognized pocilloporid species representing a range of atypical morphologies thought to be rare or endemic to remote locations throughout the Indo- Pacific found that (1) the current taxonomy of *Pocillopora* based on colony morphology shows little correspondence with genetic groups; (2) colony morphology is far more variable than previously thought; and (3) there are numerous cryptic lineages (i.e., two or more

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distinct lineages that are classified as one due to morphological similarities). The study concluded that "the genus *Pocillopora* is in need of taxonomic revision using a combination of genetic, microscopic characters, and reproductive data to accurately delineate species" (Marti-Puig et al. 2014). Likewise, a study of several currently recognized pocilloporid species sampled from across the Indo-Pacific found that genetic groups do not correspond to colony morphology, and exhibit a wide range of morphological variation (Forsman et al. 2013). In short, more research is needed before the taxonomic uncertainty can hope to be resolved for the genus.

Although the genetics results for *Pocillopora* to date raise more taxonomic questions than answers, taxonomic uncertainty appears to be lower for *P. meandrina* than some other *Pocillopora* species and available information supports the conclusion that *P. meandrina* is a valid species. A combined genetics and morphology study of several *Pocillopora* species, including *P. meandrina*, did not propose any taxonomic changes to *P. meandrina*. The study found that, in contrast to morphological similarities, *P. verrucosa* and *P. meandrina* are distinct genetically, and *P. meandrina* is genetically more closely related to *P. eydouxi* than to *P. verrucosa* (Schmidt-Roach et al. 2014). In addition, a genomic study found that *Pocillopora* species are genetically distinct from one another, and that there is a lack of introgressive hybridization among species (Johnston et al. 2017).

We do not believe that species identification uncertainty for *P. meandrina* affects the quality of the information used in this report. Whereas taxonomic uncertainty refers to how a species should be scientifically classified, species identification uncertainty refers to how a species should be identified in the field. Both types of uncertainty apply to most Indo-Pacific reef-building corals (Fenner 2014). Although taxonomic uncertainty is relatively low for *P. meandrina*, species identification uncertainty can be greater because of similarity to other species in the genus (Fenner 2005, Veron 1986), as well as intraspecific morphological plasticity in response to different environmental conditions (Paz-García et al. 2015a,b). For example, genetic studies of Hawaiian *Pocillopora* species found that morphology-based identifications often led to *P. ligulata* being mistaken for *P. meandrina* in the Northwestern Hawaiian Islands (NWHI), especially in the three most northern islands (Kure, Midway, Pearl and Hermes), where the genetic testing showed that all samples were *P. ligulata*. The authors hypothesized that *P. meandrina* may have a northern range limit to the south of Pearl and Hermes, while *P. ligulata* may be better adapted to the northern edges of the subtropics typified by Kure, Midway, Pearl and Hermes (Johnston et al. 2018). However, coral scientists with decades of field experience in the NWHI point out that the field sample collection for this study was not done by coral experts, and that key details about the sampled locations were not recorded (e.g., habitat type and depth), raising concerns about the results (Jean Kenyon, Pers. Comm., March 2019). Thus, corroborating studies are needed before the hypothesis put forward by Johnston et al. (2018) can be accepted.

That said, while *P. meandrina* is similar in appearance to *P. elegans*, *P. verrucosa* and other *Pocillopora* species, experienced coral species field workers do not consider typical *P. meandrina* colonies difficult to distinguish from these similar species. In a series of surveys conducted between 1994 and 2016 in 31 of the Indo-Pacific's most species-rich ecoregions (i.e., Coral Triangle and surrounding areas), the distributions and abundances of 672 Indo-Pacific reef-building corals were recorded by the same team (DeVantier and Turak 2017). Of the 672 species, the team noted that 33 species had "various taxonomic or identification issues," but *P. meandrina* was not one of them (DeVantier and Turak 2017, Table S1). Elsewhere in the species' range, coral species experts acknowledge the similarities between *P. meandrina* and some other *Pocillopora* species, but expressed confidence in their abilities to consistently

distinguish these species from one another, including in the main Hawaiian Islands (Kuʻulei Rodgers and Eric Brown, Pers. Comm., March 2019), the Northwestern Hawaiian Islands (Jean Kenyon, Pers. Comm., March 2019), the Samoan Islands (Doug Fenner, Pers. Comm., February 2019), the Marshall Islands (Doug Fenner and Steve Kolinski, Pers. Comm., March 2019), and the Mariana Islands (Dave Burdick and Peter Houk, Pers. Comm., March 2019).

2.3. Life History

An organism's life history is a broad term referring to traits and events related to a species' survival and reproduction. The life history of *P. meandrina* shares many life history traits with most other Indo-Pacific reef-building corals: Occurrence as modular, colonial, and sessile individuals; symbiosis with zooxanthellae; skeletal plasticity; utilization of a combination of sexual and asexual reproduction; occurrence as many populations across a very large range, and other features, as described in Section 2 of the GSA (Smith 2019). There are approximately 760 species of Indo-Pacific reef-building corals (Corals of the World website, http://www.coralsoftheworld.org, accessed February 2019), and while these species share many similarities, there is also a great deal of life history diversity among species. Darling et al. (2012) performed a biological trait-based analysis to categorize the world's reef-building coral species into four life history strategies: generalist, weedy, competitive, and stress-tolerant. The classifications were primarily separated by colony morphology, growth rate, and reproductive mode. *Pocillopora meandrina* was classified as a competitive species, based on its broadcast spawning, rapid skeletal growth, and branching colony morphology, which allow it to recruit quickly to available substrate and successfully compete for space (Darling et al. 2012).

Characteristics of *P. meandrina*'s life history that are particularly relevant to its extinction risk are described in more detail in Section 3 below, including distribution (Section 3.1), abundance (Section 3.2), productivity (Section 3.3), and diversity (3.4). Vulnerabilities of *P. meandrina* to the threats are described in the Threats Evaluation below (Section 4).

2.4. Habitat Breadth

Habitat breadth refers to the diversity of habitats occupied by a species (Karlson 2002). This section describes the habitats occupied by *P. meandrina*, in terms of both its preferred habitat (i.e., the type of habitat where it is most abundant), as well as the other habitats where it is known to occur. As described in the GSA (Smith 2019, Section 2.2), in the Indo-Pacific, shallow coral reefs occur from the surface to 30-40 m (98-131 ft) of depth in various forms (i.e., fringing reefs, barrier reefs, atolls, and platform or patch reefs), most of which are made up of a reef slope, a reef crest, and a back-reef flat that each provide distinctive habitats for reef-building corals. In some areas, physical factors such as cool seawater temperatures and high wave energy stunt reef formation, creating simpler shallow coral reefs consisting of a bench and slope that lack a well-defined reef crest and flat (e.g., parts of Hawaiʻi). In addition to shallow coral reefs, non-reef habitats are areas where environmental conditions prevent reef accretion and formation by reef-building corals (e.g., lava bedrock or boulders), but may provide habitat for some reef-building coral species (Smith 2019).

Pocillopora meandrina prefers high energy habitats with strong currents and constant wave action, and is often abundant on reef crests and upper reef slopes throughout its range (Fenner 2005, Veron 2000). In Hawaiʻi where there are relatively few other coral species to compete with, *P. meandrina* dominates such high energy habitat to the extent that it has been termed the "*P. meandrina* zone" (Dollar 1982). The species is abundant in other types of high energy habitats, including non-reef habitats like lava bedrock in many volcanic archipelagos such as the northern Mariana Islands (Smith and Marx 2016), the Revillagigedo Islands (Reyes-

Bonilla 2003), and the Marquesas Islands (Salvat et al. 2016), as well as unconsolidated rocks and boulders along coastlines with poorly-developed coral reefs such as in Baja California (Reyes-Bonilla 2003) and parts of Hawaiʻi (Goodell and Friedlander 2018).

While the above describes *P. meandrina*'s preferred habitats, it also occurs in lower abundances in most other habitats where reef-building corals are found. These include middle and lower reef slopes (Stephen Smith, Pers. Comm., March 2019), back-reef areas such as reef flats (Zoe Richards, Pers. Comm., March 2019) and patch reefs (David Benavente, Pers. Comm., April 2019), and atoll lagoons (Doug Fenner, Pers. Comm., March 2019). In a study of intertidal habitat in the Bonaparte Archipelago on the Kimberley Coast of Australia, *P. meandrina* was found at several sites, including sites with several meters of tidal range where the coral community is sometimes exposed to air for several hours at a time (Richards et al. 2015). In addition, *P. meandrina* can be one of the most common corals found on artificial substrates, such as concrete structures and metal buoys (Dave Burdick and Stephen Smith, Pers. Comm., March 2019). In summary, the habitat breadth of *P. meandrina* includes shallow high energy habitats where it most abundant, but also includes most other reef-building coral habitats, including artificial substrates, between the surface and >30 m (>98 ft) of depth. The depth range of *P. meandrina* is described in Section 3.1.2 of the Distribution section below.

3. Demographic Risk Factors

In order to determine the extinction risk of species being considered for ESA listing, NMFS uses a demographic risk analysis framework based on the Viable Salmonid Population (VSP) approach of McElhany et al. (2000). The framework considers the four demographic factors of *distribution, abundance, productivity*, and *diversity*, as defined below.

1. *Distribution*: Maintaining connectivity between genetic groups supports proper metapopulation function. Ensuring that populations are well represented across diverse habitats helps to maintain and enhance genetic variability and population resilience. Additionally, ensuring wide geographic distribution across diverse climate and geographic regions helps to minimize risk from catastrophes (e.g., droughts, floods, hurricanes, etc.).

2. *Abundance*: Small populations face a host of risks intrinsic to their low abundance; conversely, large populations exhibit a greater degree of resilience. A large part of the science of conservation biology involves understanding and predicting the effects of population size. All else being equal, small populations are at greater risk of extinction than large populations primarily because several processes that affect population dynamics operate differently in small populations than they do in large populations. These processes are deterministic density effects, environmental variation, genetic processes, demographic stochasticity, ecological feedback and catastrophes.

3. *Productivity*: Population growth rate (productivity) and factors that affect population growth rate provide information on how well a population is "performing." These parameters, and related trends in abundance, reflect conditions that drive a population's dynamics and thus determine its abundance. Changes in environmental conditions, including ecological interactions, can influence a population's intrinsic productivity or the environment's capacity to support a population, or both. Such changes may result from random environmental variation over a wide range of temporal scales (environmental stochasticity). A population growth rate that is unstable or declining over a long period of time indicates poor resiliency to future environmental change.

4. *Diversity*: A robust population should maintain both genotypic and phenotypic diversity and have distributions that are spatially and temporally diverse. For example, diversity in reproductive strategies and timing, age structure, size, morphology, behavior, and genetics may protect a population from small-scale, catastrophic threats. Of these traits, some (such as DNA or protein sequence variation) are completely genetically based, whereas others (such as nearly all morphological, behavioral, and life-history traits) usually vary as a result of a combination of genetic and environmental factors). Phenotypic diversity can be maintained by spatial and temporal variation in habitat characteristics.

Each demographic risk factor is described for *P. meandrina* below. The demographic risk analysis framework is described in more detail in the NMFS Guidance on Responding to Petitions and Conducting Status Reviews under the Endangered Species Act (NMFS 2017a).

3.1. Distribution
The first demographic factor is distribution, as defined in the introduction to Section 3 above. *Pocillopora meandrina* is found on most coral reefs of the Indo-Pacific and eastern Pacific, with its range encompassing >230° longitude from the western Indian Ocean to the eastern Pacific Ocean, and ≈60° latitude from the northern Ryukyu Islands to central western Australia in the western Pacific, and the Gulf of California to Easter Island in the eastern Pacific (http://www.coralsoftheworld.org, accessed February 2019). Distribution of *P. meandrina* is described below in terms of geographic distribution across the Indo-Pacific area, as well as depth distribution.

3.1.1.   The 95 Ecoregions
The Corals of the World website (http://www.coralsoftheworld.org) provides comprehensive range information for all 758 currently known Indo-Pacific reef-building corals, based on presence/absence in 133 Indo-Pacific ecoregions. As of February 2019, the website shows *P. meandrina* as present in 91 of the 133 ecoregions. In addition, we found information confirming *P. meandrina* in four ecoregions in the southeastern and eastern Pacific; the Austral Islands (Mayfield et al. 2015), the Tuamotu Archipelago (Faure and Laboute 1984), the Marquesas Islands (Salvat et al. 2016), and Clipperton Atoll (Carricart-Ganivet and Reyes-Bonilla 1999). Therefore, these 95 ecoregions are considered to be the current, known range of *P. meandrina* (Fig. 2, Table 2).

In a series of surveys conducted between 1994 and 2016 of 672 Indo-Pacific reef-building corals in the Coral Triangle and adjacent areas, *P. meandrina* had the 195th largest range of the 672 species, which was smaller than 29%, larger than 68%, and the same range as 3% of the other 671 species (DeVantier and Turak 2017). The abundances of *P. meandrina* in the ecoregions surveyed by DeVantier and Turak (2017) are included in the Demographic section below, along with abundance information for the species from other sources and other ecoregions. Abundance information was found for 65 of the 95 ecoregions. There is no evidence of any reduction in its range due to human impacts, thus we consider its historic and current ranges to be the same.
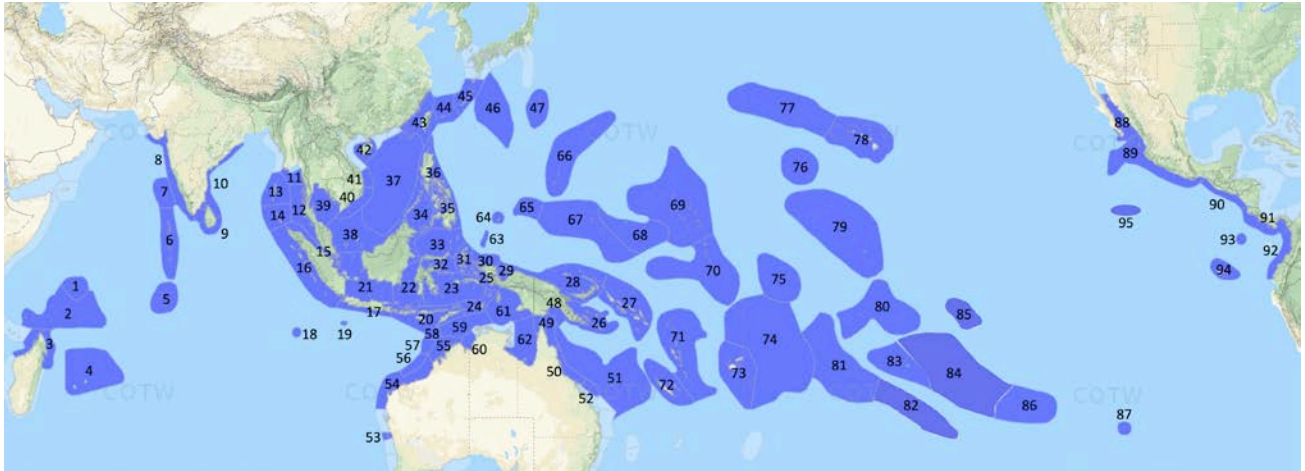
Figure 2. The 95 ecoregions that make up the known range of *P. meandrina* including the 91 shown on the Corals of the World range map (http://www.coralsoftheworld.org, February 2019), plus four additional ecoregions (#82, 84, 85, 95).

Table 2. Ecoregion key for Figure 2 above.

#	Name	#	Name
1	Seychelles north	49	GBR far north and Torres Strait
2	Seychelles south	50	GBR north-central
3	Madagascar north	51	Coral Sea
4	Mascarene Islands	52	GBR southeast, Pompey and Swains Reefs
5	Chagos Archipelago	53	Houtman Abrolhos Islands, west Australia
6	Maldives	54	Ningaloo Reef and coastal northwest Australia
7	Lakshadweep Islands	55	Kimberley Coast, northwest Australia
8	India west and south	56	Rowley Shoals, west Australia
9	Sri Lanka south	57	Scott Reef, west Australia
10	Sri Lanka north and India east	58	Ashmore Reef, northwest Australia
11	Myanmar, Gulf of Martaban	59	Timor Sea
12	Andaman Sea	60	Joseph Bonaparte Gulf, northwest Australia
13	Andaman Islands	61	Arafura Sea
14	Nicobar Islands	62	Gulf of Carpentaria, northeast Australia
15	Malacca Strait	63	Helen Reef, Palau
16	Sumatra west	64	Palau
17	Java south	65	Yap Islands, Micronesia
18	Cocos Keeling Atolls	66	Mariana Islands
19	Christmas Island, Indian Ocean	67	Caroline Islands, Micronesia
20	Lesser Sunda Islands and Savu Sea	68	Pohnpei and Kosrae, Micronesia
21	Java Sea	69	Marshall Islands
22	Makassar Strait	70	Kiribati West (Gilbert Islands)
23	Banda Sea and Moluccas	71	Vanuatu
24	Arafura Sea Islands north	72	New Caledonia
25	Papua, coastal southwest	73	Fiji
26	Milne Bay, Papua New Guinea	74	Samoa-Tuvalu-Tonga
27	Solomon Islands and Bougainville	75	Kiribati Central (Phoenix Islands)
28	Bismarck Sea, New Guinea	76	Johnston Atoll
29	Cenderawasih Bay, Papua	77	Northwestern Hawaiian Islands/NWHI
30	Raja Ampat, Papua	78	Main Hawaiian Islands/MHI
31	Halmahera	79	Kiribati Northeast (northern Line Islands)
32	Gulf of Tomini, Sulawesi	80	Kiribati Southeast (southern Line Islands)
33	Celebes Sea	81	Cook Islands
34	Sulu Sea	82	Austral Islands
35	Philippines southeast	83	Society Islands
36	Philippines north	84	Tuamotu Archipelago
37	South China Sea	85	Marquesas Islands
38	Sunda Shelf	86	Pitcairn Islands
39	Gulf of Thailand	87	Easter Island
40	Vietnam south	88	Gulf of California
41	Vietnam central	89	Mexico West (inc. Revillagigedo Islands)
42	Hainan, south China	90	Guatemala, El Salvador, Nicaragua
43	Taiwan and coastal China	91	Costa Rica and Panama
44	Ryukyu Islands south	92	Columbia and Ecuador
45	Ryukyu Islands south	93	Cocos Island
46	Ogasawara Islands, Japan	94	Galapagos Islands
47	Okinotorishima, Japan	95	Clipperton Atoll
48	Gulf of Papua, Papua New Guinea		

3.1.2.   Depth Range

In addition to geographic range, another key aspect of distribution is depth range. As described in the Habitat Breadth section above, *P. meandrina* is typically more abundant in very shallow (<5 m, 16 ft), high energy habitats than elsewhere. For example, the Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP) monitored percentage cover of coral species annually from 1999 to 2018 throughout the main Hawaiian Islands at 68 sites, most of which are pairs of adjacent shallow (3 m, 10 ft) and deep (10 m, 33 ft) sites. Mean % cover of *P. meandrina* was higher at the shallow stations than at the deep stations in 19 out of the 20 years (Eric Brown, Pers. Comm., April 2019). Information from elsewhere within the species range confirms this abundance gradient with depth. For example, in Fagatele Bay, American Samoa, a monitoring program conducted sporadically between 1985 and 2018 at multiple depths from 1 m (3 ft) to 12 m (39 ft) usually found higher mean abundances of *P. meandrina* at the shallower transects than the deep transects (Chuck Birkeland, Pers. Comm., March 2019). The CRAMP and Fagatele Bay monitoring results are described in more detail below in Section 3.2.3.

Although *P. meandrina* is more common at depths of <5 m (16 ft) than in deeper areas, its habitat breadth encompasses most habitats found on coral reefs and non-reef habitat between the surface and >30 m (98 ft) of depth. For example, in a transect from 8 m (26 ft) to 36 m (118 ft) depth on Fanning Island in Kiribati surveyed in the early 1970s, colonies of *P. meandrina* were recorded at 31 m (102 ft) and 34 m (112 ft), the deepest record of the species. Maximum cover of *P. meandrina* on the transect was at 10 m (33 ft), where it made up 25% of live coral cover (Maragos 1974a). The cover of *P. meandrina* may have been even greater at depths shallower than the transect (maximum depth = 8 m, 26 ft), but the shallower areas were not surveyed. Observations of *P. meandrina* elsewhere also indicate that the species sometimes occurs at 30 m (98 ft) or deeper. For example, *P. meandrina* colonies have been recorded at approximately 30 m (98 ft) in Farallon de Medinilla in the Mariana Islands, and at >30 m near the mouth of Pearl Harbor on Oahu (Stephen Smith, Pers. Comm., March and June 2019). Based on this information, we consider the depth range of *P. meandrina* to be from the surface to at least 34 m (112 ft).

3.1.3.   Distribution Summary

In summary, the geographic distribution of *P. meandrina* encompasses >230° longitude and ≈60° latitude, and includes 95 of the 133 Indo-Pacific ecoregions (Fig. 2), giving it a larger range than about two-thirds of Indo-Pacific reef-building coral species (DeVantier and Turak 2017). Its range includes a large number of very remote areas with small or no human populations, including Cocos Keeling Atoll, Christmas Island, and most of the Maldives in the Indian Ocean, and parts of eastern Indonesia, the northern GBR, the Northwestern Hawaiian Islands, the Northern Mariana Islands, the Tuamotu Archipelago, and Clipperton Atoll in the Pacific Ocean, in addition to many others (Fig. 2). Although *P. meandrina* is more common at depths of <5 m (16 ft) than in deeper areas, its depth range is from the surface to at least 34 m (112 ft). There is no evidence of any reduction in its range due to human impacts, thus we consider its historic and current ranges to be the same. Therefore, based on the best available information provided above, we consider *P. meandrina*'s distribution to be very large and stable.

3.2. Abundance

The second demographic factor is abundance, as defined in the introduction to Section 3 above. Three types of abundance information are described below for *P. meandrina* from some of its 95 ecoregions: (1) Relative abundances from 65 ecoregions; (2) absolute abundances from 8 ecoregions; and (3) abundance trends from 10 ecoregions. In addition, the following

information describes how the abundance of *P. meandrina* compares to that of other Indo-Pacific reef-building coral species: In a series of surveys conducted between 1994 and 2016 of 672 Indo-Pacific reef-building corals in the Coral Triangle and adjacent areas, *P. meandrina* had the 214th highest overall abundance of the 672 species, which was lower than 32% and higher than 68% of the other 671 species (DeVantier and Turak 2017). In a study of 323 Indo-Pacific reef-building corals in Indonesia, Papua New Guinea, Solomon Islands, Samoa, and French Polynesia, *P. meandrina* had the 18th highest coral cover, which was lower than 5% and higher than 95% of the other 322 species (Hughes et al. 2014).

3.2.1.   Relative Abundances – 65/95 Ecoregions

Relative abundance refers to how common *P. meandrina* is relative to other reef-building corals in an ecoregion. Information on the relative abundances of *P. meandrina* is available for 65 of the 95 ecoregions from many different sources. In some cases, quantitative results are available (e.g., DeVantier and Turak 2017, Fenner 2019, Richards et al. 2009), while in others only qualitative information is available (e.g., Veron 1990a, Veron 1992, Glynn et al. 2018). For each ecoregion, results from all sources are considered together to rate the relative abundance of *P. meandrina* in that ecoregion as Rare, Uncommon, Common, or Dominant.

DeVantier and Turak (2017) used Overall Abundance to characterize relative abundances of each reef-building coral species they surveyed in 31 Indo-Pacific ecoregions. To allow for comparison with results from other sources for each ecoregion, we simplified their categories as follows: <1.0 = Rare; 1.0–<50.0 = Uncommon; 50.0– <100.0 = Common; ≥100.0 = Dominant), and incorporated into the following abundance definitions.

In order to synthesize qualitative and quantitative relative abundance results from different sources that used different methodologies, the following definitions are used:

- Rare:
    - Qualitative: One of the least common corals in the ecoregion. Occurs at a few sites in small numbers, or at many sites in very small numbers.
    - Quantitative: An overall abundance score of <1.0, based on methods from (DeVantier and Turak 2017).
- Uncommon:
    - Qualitative: Occurs at a few sites in moderate to large numbers, or at many sites in small numbers.
    - Quantitative: An overall abundance score of 1.0–<50.0, based on methods from (DeVantier and Turak 2017).
- Common:
    - Qualitative: Occurs at some sites in large numbers, or at most or all sites in moderate numbers, but not one of the most common corals in the ecoregion.
    - Quantitative: An overall abundance score of 50.0–<100.0, based on methods from (DeVantier and Turak 2017).
- Dominant:
    - Qualitative: One of the most common corals in the ecoregion. Occurs at most sites in moderate to large numbers.
    - Quantitative: An overall abundance score of ≥100.0, based on methods from (DeVantier and Turak 2017).
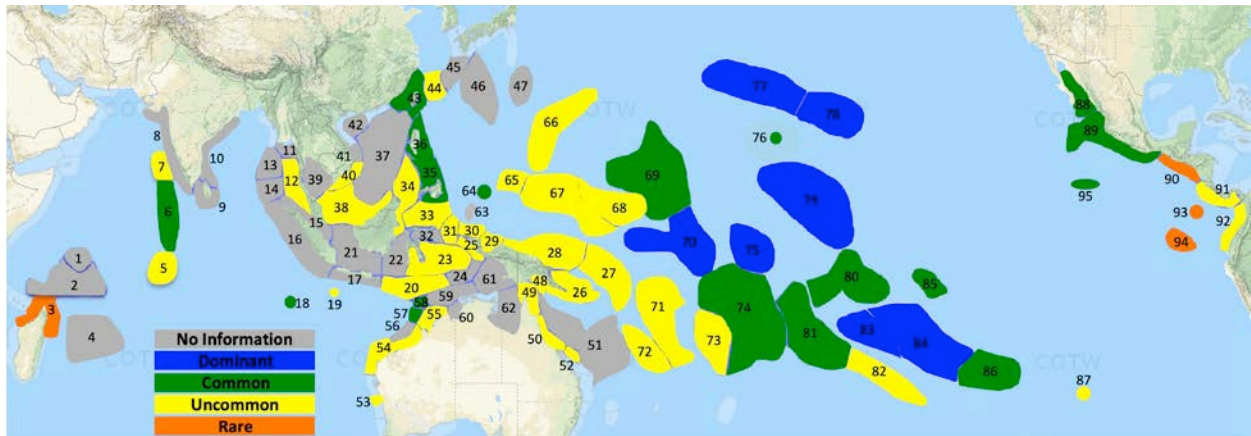
Figure 3. Relative abundances of *P. meandrina* in 65 of its 95 ecoregions.

Relative abundance information was found for 65 of the 95 ecoregions within *P. meandrina*'s range (Fig. 3), based on surveys conducted between 1970 and 2018, as described below (numbers in parentheses refer to ecoregion # on maps in Figures 2 and 3, and in Table 2). All references to the Corals of the World website in this section refer to http://www.coralsoftheworld.org as of February 2019. The ecoregion-specific relative abundance information is listed below for the 95 ecoregions:

1. Seychelles North Ecoregion: No abundance information.
2. Seychelles South Ecoregion: No abundance information.
3. Madagascar North Ecoregion: Although *P. meandrina* is reported to occur in this ecoregion (Corals of the World website), a coral survey of 36 sites there in 2003 did not find it (DeVantier and Turak 2017). Thus, we rate the abundance of *P. meandrina* as rare in this ecoregion (Fig. 3).
4. The Mascarene Islands Ecoregion: No abundance information.
5. Chagos Archipelago Ecoregion: Based on a survey of 39 sites in 2015, *P. meandrina* had an overall abundance score of 31.0 (Fenner 2019), thus we rate it as uncommon in this ecoregion (Fig. 3).
6. Maldives Ecoregion: In a study conducted at 10 sites distributed over an approximately 500 km^2 area on Ari Atoll, *P. meandrina* was reported as a common species (Muir et al. 2017), thus we rate it as common in this ecoregion (Fig. 3).
7. Lakshadweep Islands Ecoregion: Based on a survey of 14 sites in 2000, *P. meandrina* had an overall abundance score of 21.43 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
8. India West and South Ecoregion: No abundance information.
9. Sri Lanka South Ecoregion: No abundance information.
10. Sri Lanka north and India East Ecoregion: No abundance information.
11. Myanmar, Gulf of Martaban Ecoregion: No abundance information.
12. Andaman Sea Ecoregion: Based on a survey of 54 sites in 2005, *P. meandrina* had an overall abundance score of 1.85 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
13. Andaman Islands Ecoregion: No abundance information.
14. Nicobar Islands Ecoregion: No abundance information.
15. Malacca Strait Ecoregion: No abundance information.

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16. Sumatra West Ecoregion: No abundance information.
17. Java South Ecoregion: No abundance information.
18. Cocos Keeling Atolls Ecoregion: In a survey of 16 sites, *P. meandrina* was reported as common on most upper reef slopes (Veron 1990a). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).
19. Christmas Island, Indian Ocean Ecoregion: In a survey of nine sites in 2013, *P. meandrina* was present at five sites and absent at four sites. At the five sites where *P. meandrina* was present, its abundance was rated as rare (three sites) and infrequent (two sites; Richards and Hobbs 2014). Since it occurred at the majority of sites in small numbers, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).
20. Lesser Sunda Islands and Savu Sea Ecoregion: Based on surveys of 248 sites conducted during six years (1995, 2006, 2008, 2011–2012, 2016), *P. meandrina* had an overall abundance score of 11.29 (DeVantier and Turak 2017), and thus was rate it as uncommon in this ecoregion (Fig. 3).
21. Java Sea Ecoregion: No abundance information.
22. Makassar Strait Ecoregion: No abundance information.
23. Banda Sea and Moluccas Ecoregion: Based on a survey of 86 sites in 2003–2004, *P. meandrina* had an overall abundance score of 6.98 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
24. Arafura Sea Islands North Ecoregion: No abundance information.
25. Papua Coastal Southwest Ecoregion: Based on a survey of 68 sites in 2006, *P. meandrina* had an overall abundance score of 30.88 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
26. The Milne Bay, Papua New Guinea Ecoregion: Based on surveys of 85 sites in 2000 and 2007, *P. meandrina* had an overall abundance score of 29.41 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
27. Solomon Islands and Bougainville Ecoregion: Based on a survey of 114 sites in 2005 and 2007, *P. meandrina* had an overall abundance score of 40.85 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
28. Bismarck Sea, New Guinea Ecoregion: Based on surveys of 155 sites in 2002, 2004, and 2006, *P. meandrina* had an overall abundance score of 20.65 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
29. Cenderawasih Bay, Papua Ecoregion: Based on a survey of 66 sites in 2006, *P. meandrina* had an overall abundance score of 18.18 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
30. Raja Ampat, Papua Ecoregion: Based on a survey of 94 sites in 2002, *P. meandrina* had an overall abundance score of 17.14 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
31. Halmahera Ecoregion: Based on surveys of 89 sites in 1997 and 2006, *P. meandrina* had an overall abundance score of 39.74 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
32. Gulf of Tomini, Sulawesi Ecoregion: No abundance information.
33. Celebes Sea Ecoregion: Based on surveys of 160 sites in 2000 and 2004–2005, *P. meandrina* had an overall abundance score of 11.88 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).

34. The Sulu Sea Ecoregion: Based on surveys of 149 sites in 2004 and 2009, *P. meandrina* had an overall abundance score of 16.11 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
35. Philippines Southeast Ecoregion: Based on surveys of two sites in this ecoregion, and reviews of information from previous surveys of many sites throughout the ecoregion, *P. meandrina* was reported as common on some reef slopes (Veron and Hodgson 1989). As of 2018, *P. meandrina* was abundant in some parts of the central Visayas portion of the ecoregion (Gregor Hodgson, Pers. Comm., April 2019). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).
36. Philippines North Ecoregion: Based on a survey of 16 sites in 2007, *P. meandrina* had an overall abundance score of 50.00 (DeVantier and Turak 2017). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).
37. South China Sea Ecoregion: No abundance information.
38. Sunda Shelf Ecoregion: Based on surveys of 103 sites in 2008–2009, 2012, and 2014, *P. meandrina* had an overall abundance score of 28.16 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
39. Gulf of Thailand Ecoregion: No abundance information.
40. Vietnam South Ecoregion: Based on surveys of 97 sites in 2003–2005, *P. meandrina* had an overall abundance score of 8.25 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
41. Vietnam Central Ecoregion: No abundance information.
42. Hainan, South China Ecoregion: No abundance information.
43. Taiwan and Coastal China Ecoregion: A comprehensive review of Taiwan's reef corals states that *P. meandrina* occurs in all reef areas around Taiwan and its offshore islands, and that it is especially common in shallow exposed reef areas (Dai and Horng 1989). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).
44. Ryukyu Islands South Ecoregion: In a review of coral distribution and abundance at Ishigaki Island in the southern Ryukyus, *P. meandrina*'s abundance was rated as uncommon (Fujioka 1998), thus we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).
45. Ryukyu Islands North Ecoregion: No abundance information.
46. Okinotorishima, Japan Ecoregion: No abundance information.
47. Ogasawara Islands, Japan Ecoregion: No abundance information.
48. Gulf of Papua, Papua New Guinea Ecoregion: Based on surveys of 32 sites in 2001 and 2011, *P. meandrina* had an overall abundance score of 12.50 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
49. GBR Far North and Torres Strait: Based on surveys of 32 sites in 2001 and 2011, *P. meandrina* had an overall abundance score of 12.50 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
50. GBR North-central Ecoregion: Based on surveys of 582 sites in 1994–1997, 2001–2002, and 2011, *P. meandrina* had an overall abundance score of 2.92 (DeVantier and Turak 2017), thus we rate it as uncommon in this ecoregion (Fig. 3).
51. Coral Sea Ecoregion: No abundance information.
52. GBR Southeast, Pompey and Swains Reefs Ecoregion: A survey of three sites in this ecoregion did not find *P. meandrina* (DeVantier and Turak 2017). However, it is reported

from the entire length of the GBR (Andrew Baird, Pers. Comm., March 2019), thus we rate it as uncommon in this ecoregion (Fig. 3).

53. Houtman Abrolhos Islands, West Australia Ecoregion: Surveys of many sites at 17 locations throughout Western Australia in the 1970s and 1980s found *P. meandrina* at four locations, including the Houtman Abrolhos Islands, and its overall abundance in Western Australia was rated as uncommon (Veron and Marsh 1988). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

54. Ningaloo Reef and Coastal Northwest Australia Ecoregion: Surveys of many sites at 17 locations throughout Western Australia in the 1970s and 1980s found *P. meandrina* at four locations, including at Ningaloo Reef and the Dampier Zone within this ecoregion, and its overall abundance in Western Australia was rated as uncommon (Veron and Marsh 1988). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

55. Kimberley Coast, Northwest Australia Ecoregion: In a study at 23 sites on three islands in the Bonaparte Archipelago, *P. meandrina* was recorded at four of the sites (Richards et al. 2015). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

56. Rowley Shoals, West Australia Ecoregion: No abundance information.

57. Scott Reef, West Australia Ecoregion: In surveys of nine reef slope and three lagoon transects in 2015, *P. meandrina* was found on all reef slope transects and two of the three lagoon transects (Zoe Richards, Pers. Comm., July 2019). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

58. Ashmore Reef, Northwest Australia Ecoregion: A survey of eight sites (six at Ashmore, two at Cartier) in 2009 found that *P. meandrina* was one of 35 "key species" there, defined as those species with at least 75 percent the abundance the most abundant reef coral species (*Seriatopora hystrix*), of which 1,003 colonies were recorded on transects (Richards et al. 2009). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

59. Timor Sea Ecoregion: No abundance information.

60. Joseph Bonaparte Gulf, Northwest Australia: No abundance information.

61. Arafura Sea Ecoregion: No abundance information.

62. Gulf of Carpentaria, Northeast Australia Ecoregion: No abundance information.

63. Helen Reef, Palau Ecoregion: No abundance information.

64. Palau Ecoregion: Based on a survey of 51 sites in 2009, *P. meandrina* had an overall abundance score of 127.45 (DeVantier and Turak 2017). In contrast, also in 2009, monitoring surveys of 18 transects found *P. meandrina* colonies on only two transects in small to moderate numbers (MCRMP unpublished data). Because one survey's results meets our definition of dominant above, and the other meets our definition of uncommon, we rate the overall abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

65. Yap Islands, Micronesia Ecoregion: Based on a survey of 54 sites in 2007, *P. meandrina* had an overall abundance score of 38.89 (DeVantier and Turak 2017). The Micronesia Coral Reef Monitoring Program (MCRMP) monitored some or all of 20 sites around Yap in 2011, 2013, 2016, and 2018, and each year *P. meandrina* was recorded at zero to five sites, sometimes in moderate numbers (MCRMP unpublished data). The results from these surveys meet our definition of uncommon provided above ("Occurs at a few sites in

moderate to large numbers."), thus we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

66. Mariana Islands Ecoregion: This ecoregion consists of two U.S. Territories, including the southernmost island of Guam, and the remainder of the archipelago, the Commonwealth of the Northern Mariana Islands (CNMI). In surveys conducted regularly since 2004 at various sites around Guam, *P. meandrina* has only rarely been recorded (Dave Burdick, Pers. Comm., March 2019). In CNMI, abundances of *P. meandrina* vary a great deal between and within islands, with high abundances observed on parts of Anatahan, Maug, Pagan (Dave Burdick, Pers. Comm., March 2019), and Farallon de Medinilla (FDM; Stephen Smith, Pers. Comm., March 2019), but low abundances observed on parts of Saipan, Tinian, and Rota (Dave Burdick, Peter Houk, Pers. Comm., March 2019). For example, MCRMP monitored 14 sites around Saipan annually from 2009 to 2012, and *P. meandrina* was only recorded in 2009 at one site, but in moderate numbers (MCRMP unpublished data). In contrast, 14 annual surveys conducted on FDM in CNMI between 1997 and 2012 recorded *P. meandrina* and *P. eydouxi* as the two most common species during all survey years (Smith and Marx 2016). Based on this information, *P. meandrina* appears to be rare on some islands, uncommon on some islands, and dominant on FDM, thus we rate the overall abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

67. Caroline Islands, Micronesia Ecoregion: MCRMP monitored some or all of 62 sites in Chuuk in 2011, 2016, and 2018, and each year *P. meandrina* was recorded at one to 16 sites, sometimes in moderate numbers (MCRMP unpublished data). The results from these surveys meet our definition of uncommon provided above, thus we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

68. Pohnpei and Kosrae, Micronesia Ecoregion: Based on a survey of 71 sites in 2005, *P. meandrina* had an overall abundance score of 40.85 (DeVantier and Turak 2017). MCRMP surveyed some or all of 18 sites around Pohnpei in 2012, 2014, and 2016, and *P. meandrina* was recorded at two sites in 2014 and 3 sites in 2016, once each year in moderate numbers. MCRMP monitored some or all of 16 sites around Kosrae in 2011, 2014, 2015, and 2017, and *P. meandrina* was only recorded in 2015 and 2017 at one site each, but in moderate numbers in 2017 (MCRMP unpublished data). The results from these surveys meet our definition of uncommon provided above, thus we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

69. Marshall Islands Ecoregion: In a survey of 104 sites on six atolls (Majuro, Rongelap, Rongerik, Mili, Bikini, Alinginae) from 2002 to 2010, *P. meandrina* was found at 37 sites (36%) and on all six atolls in moderate to large numbers (Richards and Beger, 2013). In a survey of 176 sites on four atolls (Majuro, Rongelap, Rongerik, Ailuk) in 2016, *P. meandrina* was found at 45 sites (26%) and on all four atolls, but abundance was not recorded (Doug Fenner, Pers. Comm.). MCRMP monitored 18 sites around Majuro Atoll each year in 2011, 2013, and 2015, and *P. meandrina* was found at a total of three of the 18 sites during all three years combined (17%) in low to moderate numbers (MCRMP unpublished data). In surveys of 173 sites at Kwajalein Atoll from 2012 to 2018 by the U.S. Army Kwajalein Atoll (USAKA), *P. meandrina* was recorded at 154 of the sites in moderate numbers (89%; Steve Kolinski, Pers. Comm., February 2019). This ecoregion includes the U.S. Territory of Wake Island, an isolated atoll several hundred miles to the north of the Marshall Islands, where a survey of 11 sites in 2016 found *P.*

meandrina at all 11 sites in moderate numbers (Fenner 2019). The results from most sites in this ecoregion meet our definition of common provided above, thus we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

70. Kiribati West (Gilbert Islands) Ecoregion: Based on *P. meandrina* data from a survey of 20 sites on Nauru in 2013, DeVantier and Turak's (2017) methodology was used to calculate an overall abundance score of 128.1 (Fenner 2019). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

71. Vanuatu Ecoregion: In a survey of 18 sites throughout the archipelago in the 1980s, *P. meandrina* was common at some sites (Veron 1990b), but presumably uncommon, rare, or absent at other sites. Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

72. New Caledonia Ecoregion: Based on *P. meandrina* data from surveys of 87 and 48 sites in New Caledonia in 2007 and 2008, DeVantier and Turak's (2017) methodology was used to calculate overall abundance scores of 44.5 for the 2007 survey and 19.0 for the 2008 survey (Fenner 2019). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

73. Fiji Ecoregion: Based on surveys of 43, 26, and 28 sites in 2005, 2006, and 2017, *P. meandrina* had overall abundance scores of 22.4, 30.0, and 29.0 respectively (Fenner 2019). In addition, based on surveys of 46 sites in 2010 and 2012, *P. meandrina* had an overall abundance score of 32.61 (DeVantier and Turak 2017). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

74. Samoa-Tuvalu-Tonga Ecoregion: This ecoregion includes the U.S. Territory of American Samoa, where *P. meandrina* data from surveys of 63 sites in American Samoa in 2005–2012 was used to calculate an overall abundance score of 160.8 using DeVantier and Turak's (2017) methodology (Fenner 2019). Likewise, data from surveys of 27 sites each in Tonga in 2014 and on Wallis Island in 2018 were used to calculate overall abundance scores of 22.0 for Tonga and 41.0 for Wallis (Fenner 2019). The mean of the 3 abundance scores is 74.6, thus we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

75. Kiribati Central (Phoenix Islands) Ecoregion: A survey of 20 reef slope sites on Canton Atoll in 1972 and 1973 found *P. meandrina* to be the most abundant coral species, making up 5.8% of coral cover (Jokiel and Maragos 1977). This ecoregion includes the U.S. Territories of Baker and Howland Islands, and surveys there by Pacific RAMP in 2015 and 2018 found that *P. meandrina* was one of the most common species (PIFSC 2019, unpublished data). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

76. Johnston Atoll Ecoregion: Surveys of approximately 45 reef sites in 1975–1982 found that *P. meandrina* was among the most common species on some parts of the atoll but not others (Maragos and Jokiel 1986), which was confirmed by additional surveys (Jokiel and Tyler 1992). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

77. Northwestern Hawaiian Islands/NWHI Ecoregion: In a comprehensive survey of 401 sites across the 10 primary islands and reefs of the NWHI in 2000 to 2002 conducted by Pacific RAMP in conjunction with other federal agencies, *P. meandrina* occurred at 319 of the 405 sites (80%) and was the second-most abundant species after *Porites lobata* (Maragos et al 2004). In surveys at 64 sites across eight of the 10 primary islands and

reefs of the NWHI in 2006, *P. meandrina* made up an average of 19.0% of all coral cover (1.1% to 52.4% at each location), and was the second-most abundant coral after *Porites lobata* (Friedlander et al. 2009). In towed-diver surveys covering more than 100,000 m^2 of benthic habitat and site-specific surveys at 30 sites in French Frigate Shoals in the NWHI in 2000 to 2002, *P. meandrina* was one of the most common coral species and composed 94% of the total pocilloporid cover throughout the atoll (Kenyon et al 2006). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

78. Main Hawaiian Islands/MHI Ecoregion (#78): In this well-studied ecoregion, *P. meandrina* has long been known as one of the most common coral species, dominating the areas of heavy surge that surround each island (Fenner 2005). In a compilation of coral data from 1,682 transects and sites surveyed in the early 2000s by federal and state agencies across the eight MHI islands, *P. meandrina* was the third-most common species, making up 2.4 percent of live coral cover (Friedlander et al. 2005). The Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP, a State program) has monitored 68 sites throughout the MHI since 1999, and a summary of the data through 2012 found *P. meandrina* to be the fifth-most common species (Rodgers et al. 2015). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

79. Kiribati Northeast (northern Line Islands) Ecoregion: This ecoregion includes the administrative center of Fanning Island, as well as the U.S. Territories of Kingman Reef, Palmyra Atoll, and Jarvis Island. The atolls together have extensive fringing, barrier, and platform reefs. In a survey of 50 forereef and lagoon sites at Fanning Island in the early 1970s, *P. meandrina* was one of the ten most common coral taxa at the forereef sites, and its frequency was rated as "abundant" (Maragos, 1974b). In a survey of six forereef sites around Palmyra Atoll in 2007, *P. meandrina* was one of the four most common coral species (Williams et al. 2008). In surveys of six sites in 2000, 2001, 2002, 2004, and 2006 at Jarvis Island, *P. meandrina* was rated as either dominant, abundant, or common at all sites (NMFS 2010). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

80. Kiribati Southeast (southern Line Islands) Ecoregion: Fox et al. (2018) record *P. meandrina* as a common species at 5-30 m (16-98 ft) depth at five of the ecoregion's uninhabited islands. Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

81. Cook Islands Ecoregion: Mayfield et al. (2015) found that *P. meandrina* was 27%, 23%, and 8% of *Pocillopora* samples collected from three different atolls in the Cook Islands. Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

82. Austral Islands Ecoregion: Mayfield et al. (2015) found that *P. meandrina* was 6%, 7%, and 0% of *Pocillopora* samples collected from three different atolls in the Austral Islands. Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

83. Society Islands Ecoregion: *P. meandrina* is one of the most common species on the reef slopes of this ecoregion (Penin et al. 2007). For example, it was the most abundant coral species on a 1993 survey of the outer reef slope of northern Tahiti (Drollet et al. 1994), and it is a dominant species on some of Moorea's reefs (Tsounis and Edmunds 2016). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

84. Tuamotu Archipelago Ecoregion: Coral surveys conducted in the 1980s found that *P. meandrina* was one of the most common coral species at Tikehau (Faure and Laboute

1984) and Takapoto (Kuhlmann and Chevalier 1986) Atolls. Recent surveys have found that *P. meandrina* is present, which together with *P. verrucosa* dominates reefs <15 m depth in the Tuamotu Archipelago (Gonzalo Pérez-Rosales Blanch, Pers. Comm., April 2019). Thus, we rate the abundance of *P. meandrina* as dominant in this ecoregion (Fig. 3).

85. Marquesas Islands Ecoregion: In a survey of 43 sites in 2009 and 2011, coral species abundance was recorded at 32 sites. *P. meandrina* was found at 16 of the 32 sites, and was the ninth most common reef coral of 26 species (Salvat et al. 2016). Recent surveys confirm that *P. meandrina* is a common species on some fringing reefs in the Marquesas Islands (Gonzalo Pérez-Rosales Blanch, Pers. Comm., April 2019). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

86. Pitcairn Islands Ecoregion: A survey of the main four islands in the Pitcairn Islands in 2012 found *P. meandrina* on all four islands (Friedlander et al. 2014). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

87. Easter Island Ecoregion: In three surveys of 19 sites in 1999 to 2005, *P. meandrina* was not one of the most common corals, and was found at 10 of 19 sites (Glynn et al. 2007). Thus, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

88. Gulf of California Ecoregion: In surveys of six sites on Baja California between 1989 and 2004, *P. meandrina* was present at more than 50% of the sites, and was rated as "abundant" (Reyes Bonilla 2003, Reyes Bonilla et al. 2010). Since the time these surveys were conducted, abundance of *P. meandrina* has been stable (Hector Reyes Bonilla, Pers. Comm., March 2019). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

89. Mexico West Ecoregion: In surveys of seven sites on the tropical Mexican coast and four sites in the Revillagigedo Islands between 1989 and 2001, *P. meandrina* was present at 20-50% of the sites, and was rated as "common" (Reyes Bonilla 2003). Since the time these surveys were conducted, abundance of *P. meandrina* has been stable at the sites (Hector Reyes Bonilla, Pers. Comm., March 2019). Thus, we rate the abundance of *P. meandrina* as common in this ecoregion (Fig. 3).

90. Guatemala, El Salvador, Nicaragua Ecoregion: In surveys of 15 sites on the El Salvador coast between 1993 and 2009, *P. meandrina* was reported as present, but was one of the least common coral species. In surveys of 10 sites on the Nicaragua coast in 2009, *P. meandrina* was not found (Glynn et al. 2017). Thus, we rate the abundance of *P. meandrina* as rare in this ecoregion (Fig. 3).

91. Costa Rica and Panama Ecoregion: In multiple surveys of 10 sectors spanning the Pacific coast of Costa Rica since the 1980s, *P. meandrina* was present in the five northern sectors and absent in five southern sectors (Glynn et al. 2017). In a detailed study at the Papagayo northern sector, surveys of 60 transects spread across 18 sites in 2006 and 2007 found *P. meandrina* was found on 70 percent of the transects, and was one of the most abundant coral species in the study (Jiminez et al. 2010). Several surveys at 20 sites on the Pacific coast of Panama in the 1980s and 1990s found *P. meandrina* at two sites (Mate 2003). Based on this information, *P. meandrina* is common in the northern part of this ecoregion, but absent or rare elsewhere, thus we rate its abundance as uncommon in this ecoregion (Fig. 3).

92. Columbia and Ecuador Ecoregion: Based on a compilation of survey data collected since 1990 at six sites along the Colombian coast, *P. meandrina* was only found at one site. In

contrast, at some locations in southern Ecuador, *P. meandrina* is the principal reef-building species (Glynn et al. 2017). Given that *P. meandrina* occurs at a few sites in moderate to large numbers, we rate the abundance of *P. meandrina* as uncommon in this ecoregion (Fig. 3).

93. Cocos Island Ecoregion: In a survey of 18 forereef sites in 1986, *P. meandrina* was found in small numbers at six sites and was considered rare (Guzman and Cortez 1992). Thus, we rate the abundance of *P. meandrina* as rare in this ecoregion (Fig. 3).

94. Galapagos Islands Ecoregion: Based on surveys of 17 sites throughout the Galapagos Islands from 1974 to 2000, *P. meandrina* was distributed throughout most of the archipelago but there were no more than 10 colonies at any site, and the species declined in abundance throughout this time period (Glynn 2003). Since that time, the species has declined further (Glynn et al. 2017). Thus, we rate the abundance of *P. meandrina* as rare in this ecoregion (Fig. 3).

95. Clipperton Atoll Ecoregion: In a survey of three sites around the atoll in 1997, *P. meandrina* was "relatively frequent from 5 to 10 m depth" (Carricart-Ganivet and Reyes-Bonilla 1999), thus we rate its abundance as common in this ecoregion (Fig. 3).

In summary, of the 65 ecoregions for which abundance information is available, *P. meandrina* is dominant in seven, common in 18, uncommon in 36, and rare in four ecoregions (Fig. 3). Major differences in relative abundances occur across the species' range, with higher abundances in some of the central Pacific ecoregions than elsewhere. In particular, *P. meandrina* is a nearly ubiquitous species in many of the *Pocillopora*-dominated reef coral communities of the central Pacific (e.g., Hawaiian Archipelago, Kiribati, Society Islands, Tuamotu Archipelago). The reef coral communities of the eastern Pacific are also *Pocillopora*-dominated, but as noted above, *P. meandrina* is one of the less common *Pocillopora* species in much of that area. The majority of *P. meandrina*'s range is to the west of the central and eastern Pacific in Micronesia, New Guinea, Australia, Indonesia, The Philippines, and the Indian Ocean. In most of the ecoregions of these areas, *P. meandrina* has an intermediate level of abundance (common or uncommon), and it is only rare on the western and eastern fringes of its range (Fig. 3).

3.2.2.   Absolute Abundances – 8/95 Ecoregions

Absolute abundance refers to the total number of *P. meandrina* colonies, i.e., an estimate of the total population in an ecoregion. Since 2013, Pacific RAMP has collected species-level demographic data for *P. meandrina* and other species from all jurisdictions within the U.S. Pacific Islands, which include the eight locations listed in Table 3 below. These eight locations consist of four entire ecoregions (Mariana Islands, Johnston Atoll, NWHI, and MHI) and parts of four other ecoregions (Marshall Islands, Samoa-Tuvalu-Tonga, Kiribati Central, and Kiribati Northeast). Surveys are typically conducted every three years at each location, and data are available for two years at all locations except Johnston Atoll. Surveys employed a stratified random sampling design that incorporated reef zones (back reef, lagoon, and fore reef) and three depth categories (shallow 0–6 m, mid >6–18 m, and deep >18–30 m) where present. The primary sites were randomly selected to cover all coral reef zones (back-reef, lagoon, and forereef) and depths (0–30 m) at each location. Data were collected from 19 to 178 primary sites at each location each year. Within each primary site, two 10 m^2 (108 ft^2) transects were surveyed, whereby colonies of target species including *P. meandrina* were identified to species, maximum diameter measured (adults = ≥5 cm [2 in] diameter, juveniles = <5 cm diameter), and condition assessed. Total population estimates of *P. meandrina* were calculated in the following manner:

(1) Within each reef zone – depth stratum, the mean number of adults and juveniles per m^2 (density) were estimated from primary sites; (2) stratum abundance was estimated by multiplying stratum density by stratum area; (3) population abundance estimates and associated variance were obtained by summing the respective strata estimates over all strata (Swanson et al. 2018). In some cases, survey crews were unable to count *P. meandrina* juveniles because of similarity to other *Pocillopora* species (Dione Swanson, Pers. Comm., April 2019), such as at Baker and Howland Islands in 2015 (Table 3).

Based on these data, total population estimates of *P. meandrina* were calculated for the eight areas, as shown in Table 3 below. For seven of the eight locations (all but Johnston Atoll), the estimates are the means of two annual totals. MHI had by far the highest estimate, at 1,304 million (1.3 billion) colonies, while Johnston Atoll had the lowest estimate, at 1.0 million colonies (Table 3). Of the three ecoregions that consist of archipelagos (Mariana Islands, NWHI, MHI), MHI had 10-20 times higher population estimates than the Mariana Islands or NWHI. Although 2 years of sampling is inadequate to assess temporal patterns, it should be noted that the MHI sampling occurred before (2013) and after (2016), with the most severe bleaching event ever recorded there in 2014. This event appears to be reflected in the MHI abundance data, whereby a decrease in adult colonies from 2013 to 2016 shows the population's response to colony mortality in 2014, but an increase in juvenile colonies from 2013 to 2016 suggests the initial stages of recovery from the bleaching event (Table 3).

The population of *P. meandrina* adults and juveniles in U.S. waters in 2012-2018 is estimated at 1.48 billion colonies (Table 3). We do not have enough information about the *P. meandrina* population levels outside of U.S. waters to provide a total population estimate for the species. However, the U.S. population estimate together with estimates of the proportion of the species' habitat provided by U.S. waters gives a rough idea of overall abundance.

We estimate that *P. meandrina*'s total population is at least several tens of billions of colonies. As described in the Distribution section above, the range of *P. meandrina* consists of 95 of the 133 Indo-Pacific ecoregions (including the eastern Pacific), and the countries where these ecoregions occur provide approximately 232,000 km^2 of coral reef area (including the Pacific sides of the eastern Pacific countries), of which about 2,000 km^2 is within U.S. Waters (Spalding 2001). Thus, U.S. waters provide approximately 1% of the species' range, where the *P. meandrina* population is estimated at 1.48 billion colonies (Table 3). As described in the Relative Abundance section above, *P. meandrina* is more common in U.S. waters than in most of the rest of the species' range, thus there are likely more colonies per unit area in U.S. waters than elsewhere. However, because U.S. waters represent only 1% of the species' range, it is reasonable to assume that *P. meandrina*'s total population is at least several tens of billions of colonies.

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Table 3. Absolute abundances of *P. meandrina* (millions of colonies) for U.S. Waters.

Location: Ecoregion or part thereof (ecoregion #)	Year	Adults	Standard Error	Juveniles	Standard Error	Annual Total (Adults + Juveniles)	Annual Mean
Mariana Islands (#66)	2014	34.3 M	6.0 M	4.9 M	1.5 M	39.3 M	41.9 M
	2017	38.3 M	8.6 M	6.3 M	3.6 M	44.6 M	
Wake Island in Marshall Islands (#69)	2014	20.8 M	6.1 M	16.4 M	3.8 M	37.1 M	21.1 M
	2017	4.5 M	0.5 M	0.4 M	0.2 M	4.9 M	
American Samoa in Samoa-Tuvalu-Tonga (#74)	2015	11.7 M	1.6 M	0.8 M	0.6 M	12.5 M	10.5 M
	2018	8.1 M	1.2 M	0.4 M	0.3 M	8.5 M	
Baker & Howland Islands in Kiribati Central (#75):	2015	1.5 M	0.4 M	0.2 M	0.1 M	1.9 M	1.2 M
	2018	0.4 M	0.2 M	N/A	N/A	0.4 M	
Johnston Atoll (#76):	2015	1.0 M	0.5 M	N/A	N/A	1.0 M	1.0 M
NWHI (#77):	2012	86.6 M	15.0 M	N/A	N/A	86.6 M	71.1 M
	2015	42.1 M	10.3 M	13.3 M	7.0 M	55.5 M	
MHI (#78):	2013	974.7 M	116.2 M	452.1 M	65.4 M	1,426.9 M	1,304.1 M
	2016	630.2 M	64.5 M	551.2 M	129.5 M	1,181.4 M	
Kingman Reef, Palmyra Atoll & Jarvis Island in Kiribati NE (#79)	2015	7.9 M	1.5 M	0.1 M	0.1 M	7.9 M	24.8 M
	2018	32.3 M	6.0 M	9.4 M	2.2 M	41.7 M	
Total Estimate for U.S. Waters, 2012-2018							1,475.7 M

3.2.3. Abundance Trends – 10/95 Ecoregions

Abundance trend information for *P. meandrina* is available from at least portions of 10 ecoregions, including quantitative and qualitative information. Quantitative information is available from two ecoregions (Samoa-Tuvalu-Tonga, MHI) in the form of species-level time-series abundance data collected over at least three points in time. Quantitative data from two points in time are inadequate for time-series dataset because they may not represent population trends, especially of species with large population fluctuations such as reef-building corals. Thus, although some data presented in the Absolute Abundances section above is for the same location at two different points in time (Table 3), these data cannot be used to determine abundance trends, and therefore are not referenced in the following section.

In addition to these quantitative time-series datasets, qualitative information is available from another eight ecoregions (Chagos Archipelago, GBR Far North, GBR North-central, Mariana Islands, NWHI, Society Islands, Mexico West, and Galapagos Islands) in the form of long-term abundance rankings (NWHI) and personal observations (the other seven ecoregions) by established coral scientists. Although genus-level abundance data are available for *Pocillopora* in monitoring databases and publications (e.g., Pacific RAMP), these genus-level data are not used because *Pocillopora* trends are not necessarily representative of *P. meandrina* trends. That is, the different life histories, habitat preferences, and threat susceptibilities of *Pocillopora* species (Darling et al. 2012, Fenner 2005, Veron 2000) may lead to contrasting population trends within the same coral reef community. For example, at 16 sites in Kosrae

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surveyed in 2011, 2014, 2015, and 2017, all *Pocillopora* species combined decreased in coral cover by 75% from 2011 to 2017, while at the same time *P. meandrina* cover increased (MCRMP unpublished data). Descriptions of the quantitative and qualitative population trend data and information from these 10 ecoregions are provided below.

Chagos Archipelago Ecoregion (#5): Surveys of 15 sites on five atolls 11 times over a 39 year period from 1977 to 2015 documented an approximately 90% loss in coral cover (Sheppard 1980, Sheppard et al. 2017, Sheppard and Sheppard 2019). Observations of the Chagos coral communities by the primary author of these surveys, Dr. Charles Sheppard, indicate that all Pocilloporidae (i.e., *Pocillopora, Seriatopora,* and *Stylophora* spp.) were abundant in the 1970s and the mid-1990s, but since then all have become uncommon. All species, including *P. meandrina*, have experienced population reductions of >90%. A survey of the sites in April 2019 supported these observations (Charles Sheppard, Pers. Comm., April 2019). Based on this information, we conclude that the *P. meandrina* population in this ecoregion has declined by >90% since 1975.

GBR Ecoregions (#49 & #50): In the two ecoregions that make up the majority of the GBR (GBR Far North and GBR North-central Ecoregions, Fig. 3), expert observations indicate a very different pattern of *P. meandrina* abundance over time than in the Chagos Archipelago. Unlike in some other parts of the species' range where it experienced high rates of bleaching and mortality in response to seawater warming events (e.g., Mariana Islands in 2017, Main Hawaiian Islands in 2015 – see below), *P. meandrina* has been one of the two most resistant species to bleaching on the GBR out of the hundreds of reef coral species found there (Charlie Veron, Pers. Comm. with Doug Fenner, February 2019). These observations are supported by a study of the responses of the GBR's 15 main groups of reef coral taxa to the 2016 bleaching event, where *P. meandrina* and other *Pocillopora* species except for *P. damicornis* lost the least amount of cover, and were the least sensitive to temperature stress (Hughes et al. 2018). The GBR's reef coral communities have been affected by several different types of disturbances over the past several decades, including crown-of-thorns seastar (COTS) outbreaks, tropical cyclones, land-based sources of pollution, and bleaching events, but *P. meandrina* is consistently one of the most resistant (i.e., not affected) or most resilient (i.e., quick to recover) species to disturbance. The species is one of the most abundant coral species in some locations, but we were unable to find species-level, time-series abundance data. Its high resistance and resilience will likely prove to be advantageous as coral reef conditions continue to change in the future (Andrew Baird, Pers. Comm., March 2019). Based on this information, we conclude that the populations of *P. meandrina* in these two ecoregions have most likely been stable over the last several decades.

Mariana Islands Ecoregion (#66): In surveys at Tanguisson Point on Guam in 1970 and 1971, both years *P. meandrina* was one of the 10 most common species out of approximately 100 reef coral species recorded (Randall 1973). Since then, Guam's coral reefs have been degraded by a series of COTS outbreaks, chronic land-based sources of pollution, several bleaching events including in 2014 and 2017, and other disturbances (Burdick et al. 2008), resulting in declines of susceptible reef taxa, especially *Acropora* species (Raymundo et al. 2017). In surveys conducted regularly between 2004 and 2018 at various sites around Guam including Tanguisson Point, *P. meandrina* was only rarely seen (Dave Burdick, Pers. Comm., March 2019). In the Commonwealth of the Northern Mariana Islands (CNMI), as noted above in Section 3.1, recent abundances of *P. meandrina* have been highly variable, with high abundances observed on parts of Anatahan, Maug, Pagan, and Farallon de Medinilla (FDM, Dave Burdick,

Stephen Smith, Pers. Comm., March 2019), but low abundances observed on parts of Saipan, Tinian, and Rota (Dave Burdick, Peter Houk, Pers. Comm., March 2019).

Bleaching events in 2014 and 2017 affected *P. meandrina* throughout most or all of CNMI, with high mortalities observed in Anatahan, Maug, and Saipan (Dave Burdick, Steven Johnson, Steve McKagan, Pers. Comm., March 2019). In a survey of 29 forereef sites at 9 m (30 ft) depth around Saipan in 2014, *P. meandrina* was recorded at 17 (59%) of the sites (Maynard et al. 2015). When the sites were resurveyed in 2018, *P. meandrina* was only found at four (14%) of the sites (Steve McKagan, Pers. Comm., February 2019). While *P. meandrina* can quickly recover from disturbances (Coles and Brown 2007), as of March 2019, there was no sign of recovery of the species in Saipan on reef slope habitat typically covered by surveys (Steve McKagan and Lyza Johnston, Pers. Comm., March 2019). However, in habitats not typically covered by surveys such as reef crests and lagoon patch reefs, healthy *P. meandrina* colonies have been observed since 2017 (David Benavente, Pers. Comm., April 2019). Based on this information, we conclude that *P. meandrina* has declined in this ecoregion since the 1970s, but it is not possible to estimate the extent of the decline.

Samoa-Tuvalu-Tonga Ecoregion (#74): For this ecoregion, two time-series datasets of *P. meandrina* abundance are available, both from Tutuila Island in American Samoa, but on opposite sides of the island: The National Park of American Samoa's (NPSA) Tutuila Unit on the north shore, and Fagatele Bay within the American Samoa National Marine Sanctuary near the southern tip of the island.

NPSA Tutuila Unit: The NPSA dataset was collected from annual surveys conducted from 2007 to 2017. Each survey was done on 30 transects located at 10-20 m (33-66 ft) depth on the reef slope. All transects were 25 m (82 ft) in length, and were surveyed using the "split panel" method to increase statistical power, whereby half the transects are permanently fixed (i.e., transects are initially randomly selected and marked, then surveyed every year), and the other half are temporary locations (i.e., transects are randomly selected each year, and only used one time). Quadrats are photographed every 1 m along each transect, then image analysis was conducted using suitable software such as Coral Point Count with Excel extensions to determine percent cover to the lowest possible taxon, preferably species (Brown et al. 2011). Raw data were provided by Eric Brown of the National Park Service (Pers. Comm., March 2019).

Over the 11-year period, cover of *P. meandrina* remained between zero and approximately 0.5% (Fig. 4), even though overall coral cover increased significantly from approximately 25% to 30% within the study area between 2007 and 2015 (Brown et al. 2016). Mean cover of *P. meandrina* over the 11-year period was 0.29% for the fixed transects, and 0.21% for the temporary transects. The Standard Error (SE) of each mean coral cover data point is shown by the bars in Figure 4. Low SEs and similarity of results for the fixed vs. temporary transects provide high confidence in these results (Fig. 4).

As noted above in the Relative Abundance section, *P. meandrina* is not a dominant species in this ecoregion, thus high levels of cover of this species are not expected, even in healthy coral communities like in the NPSA Tutuila Unit. Although there were COTS outbreaks and minor bleaching events on Tutuila during the 11 year sampling period, there were no major disturbances (Doug Fenner, Pers. Comm, March 2019), which may explain the stability of *P. meandrina* cover during this time.
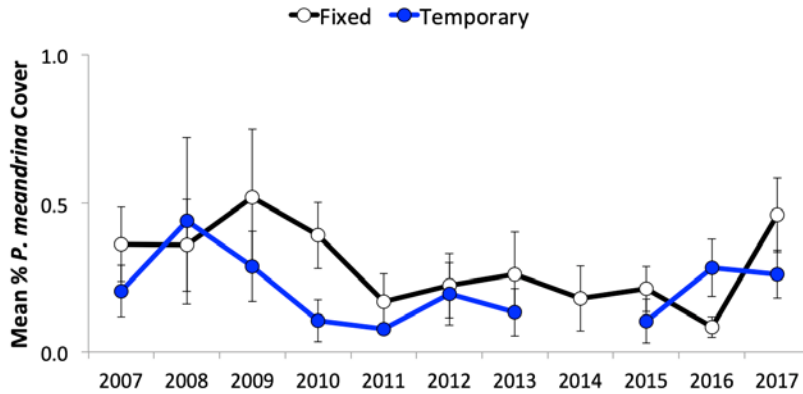
Figure 4. Mean % coral cover of *P. meandrina* in the National Park of American Samoa's Tutuila Unit at fixed and temporary transects from 10 to 20 m depth, 2007-2017 (± SE). Note y-axis scale = 0 to 1% cover.

Fagatele Bay: The second dataset is from Fagatele Bay in the National Marine Sanctuary of American Samoa on the southern tip of Tutuila, where surveys of the same fixed transects were conducted eight times over a 34-year period, including in 1985 (Birkeland et al. 1988), 1988 (Birkeland et al. 1994), 1995 (Mundy 1996), 1998, 2001 (Birkeland et al. 2004), 2002 (Fisk and Birkeland 2002), 2007 (Fenner et al. 2008), and 2018 (Charles Birkeland, Pers. Comm., March 2019). A total of six primary transects were designated in 1985 running out from the seaward edge of the reef flat to 12 m (40 ft) depth. Secondary transects were established perpendicular to the primary transects at 3 m (10 ft), 6 m (20 ft), 9 m (30 ft), and 12 m (40 ft) depth contours. Thus each of the six primary transects had four secondary transects, providing six secondary transects at each depth in the study area. Of these, the 9 m secondary transects were surveyed the most often (4-6 times during the eight years). Each secondary transect is 30 m (98 ft) in length. Coral cover of each species was estimated in 0.0625 m^2 (0.67 ft^2) quadrats measuring 25 cm by 25 cm (10 in by 10 in) haphazardly tossed at 5 m (16 ft) intervals along each transect (Birkeland et al. 1988). Raw data were provided by Charles Birkeland (Pers. Comm., March 2019).

Cover of *P. meandrina* fluctuated considerably during the eight sampled years from zero in 1988 to 1.87% in 2001, with no apparent increase or decrease in cover during the study period (Fig. 5). Mean cover of *P. meandrina* over the 34-year period was 0.63%. The fluctuations in cover at Fagatele Bay contrast with the relative stability in NPSA Tutuila Unit (Fig. 4); however, that dataset (2007-2017) only covers the final ⅓ of the Fagatele Bay dataset time period (1985-2018). In 1978, there was a major COTS outbreak on Tutuila, and from 1981 to 1991, the island was hit with four hurricanes, causing overall coral cover in Fagatele Bay to decline to approximately 10%. However, since 1991, disturbances (e.g., bleachings, extreme low tides) have been less frequent and severe, allowing overall coral cover in Fagatele Bay to rebound to 80-90% in 2001-2004 (Fenner et al. 2008), then remain at 60-80% since then (Charles Birkeland, Pers. Comm., March 2019). Maximum *P. meandrina* cover (1.87% in 2001) occurred during the period of maximum overall coral cover (2001-2004), but so did the second-lowest point just one year later (0.20% in 2002). Cover of *P. meandrina* was intermediate (0.77% in 2007, and 0.58% in 2018) during the period of stability since 2004 (Fig. 5).

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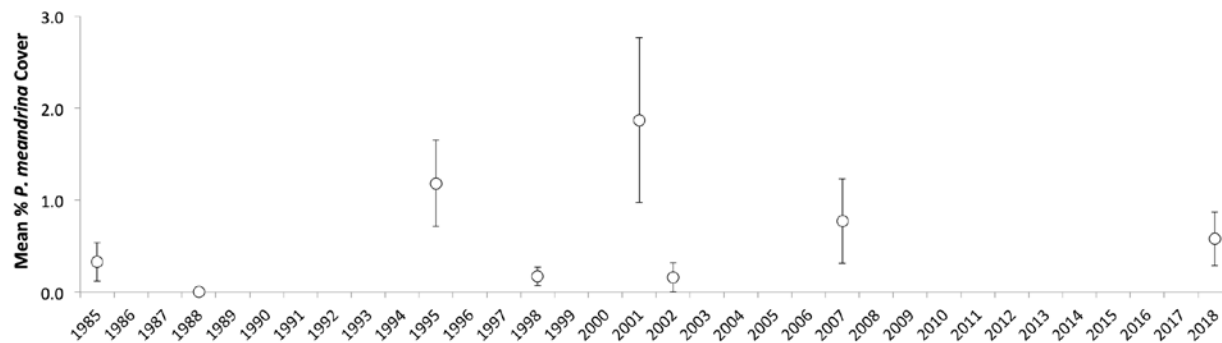
Figure 5. Mean % coral cover of *P. meandrina* in Fagatele Bay at 9 m depth during surveys done over a 34 year period from 1985 to 2018 (± SE). Note y-axis scale = 0 to 3% cover.

Summary for Samoa-Tuvalu-Tonga Ecoregion: The mean cover of *P. meandrina* at Fagatele Bay may reflect patterns in disturbance, shown by the fluctuations from zero in 1988 after multiple major disturbances to nearly 2% in 2001 after a period of recovery (Fig. 5). Since 2007, cover of *P. meandrina* has been stable both at the NPSA Tutuila Unit and at Fagatele Bay (Figs. 4 and 5). We conclude that *P. meandrina* on Tutuila Island has undergone short-term fluctuations (i.e., a few years) in response to disturbance and recovery, but that no long-term population trend is detectable over the past several decades. Based on this information, we conclude that the population of *P. meandrina* in this ecoregion has been stable over the last several decades, at least on Tutuila.

NWHI Ecoregion (#77): For this ecoregion, two types of relative abundance information for *P. meandrina* are available for most of the 10 islands and atolls over two different time periods: (1) Abundance rankings from six of the 10 islands and atolls for 1979-2004; and (2) abundance scores from eight of the 10 islands and atolls for 2000-2006. These results are based on types of qualitative judgments made at different points in time and are the best available information for this region.

Information on the relative abundances of NWHI corals, including *P. meandrina,* has been collected since 1979 using different methods. First, surveys of the relative abundances of reef-building coral species were conducted at six islands and atolls in the NWHI in 1979 (Grigg 1983), 2000-2002 (Maragos et al. 2004), and 2002-2004 (Kenyon et al. 2007, 2008a, 2008b, 2010). Second, surveys were conducted at eight islands and atolls from 2000 to 2006 except for 2005, whereby each reef coral species was assigned an abundance using the DACOR method (Dominant/D, Abundant/A, Common/C, Occasional/O, Rare/R) at each location by a team of coral experts. All surveys were done in various coral reef habitat types at depths from 2-20 m (7-66 ft). For each survey year and location, the *P. meandrina* results were converted to a percentage of the total number of sites assessed. Then the percentages were multiplied by assigned values of D=5, A=4, C=3, C=2, and R=1 to give a total DACOR score for each year and location.

Using the first method, species were ranked by abundance, *P. meandrina* did not vary by more than two ranks at any of the six locations across all years (Fig. 6a). Using the second, scores varied by location, with two increasing (Kure, Pearl and Hermes), one decreasing (French Frigate Shoals), and the other five with minimal changes (Fig. 6b, data and analysis provided by Jean Kenyon, Pers. Comm., April 2019).

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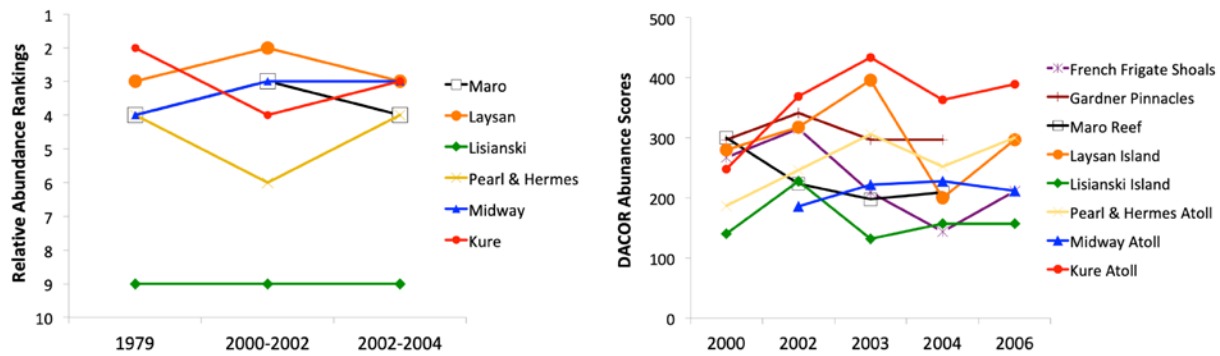
Figure 6a and 6b. Abundance rankings results for *P. meandrina* in NWHI (2-20 m depth): (6a, left) Relative abundance rankings in 1979, 2000-2002, and 2002-2004; and (6b, right) DACOR abundance scores in 2000-2006.

There are no more recent (i.e., after 2006) *P. meandrina* abundance trend data available for NWHI. However, reef-building corals including *P. meandrina* were heavily bleached in NWHI in 2014 and 2015 (Couch et al. 2017). Although no time-series *P. meandrina* abundance data are available for before and after these bleaching events, we assume that the species was affected similarly in NWHI as in the main Hawaiian Islands ecoregion, where *P. meandrina* cover substantially declined in 2016-2018 compared to 1999-2015 (Fig. 10).

Summary for NWHI Ecoregion: The relative abundance information for *P. meandrina* in NWHI from 1979 to 2004, and from 2000 to 2006 (Figs. 6a, 6b), suggest that the population was stable over the time periods surveyed. However, the population most likely declined in response to the 2014 and 2015 bleaching events. Based on this information, we conclude that *P. meandrina* was stable in NWHI until the 2014 and 2015 bleaching events, then declined since then, but it is not possible to estimate the extent of the decline.

MHI Ecoregion (#78): For this ecoregion, time-series datasets of *P. meandrina* abundance are available from several monitoring projects, including at the Kahe Power Plant outfall area on Oahu, Kalaupapa National Park on Molokai, two datasets from the Kona Coast of the Big Island, and the ecoregion-wide CRAMP. All projects monitored the percent cover of coral species within fixed transects or quadrats annually.

Kahe Power Plant, Oahu: The Kahe Power Plant is an oil-fired electricity generation facility on the Waianae coast of Oahu that began operation in 1963. Seawater is used to cool the generators, then the warmed water is discharged back into the ocean via an outfall pipe at approximately 250 m (820 ft) offshore. In order to monitor the effects of the discharge on the reef coral community, an annual monitoring program was started in 1980. Monitoring stations were established at 60 m (197 ft, Station 6B), 300 m (984 ft, Station 8A), and 520 m (1,706 ft, Station 2B) from the outfall, and a control located 2.1 km (1.3 mi, Station CTL) north of the outfall. All stations are 3-5 m (9-15 ft) m depth, and each station consists of 10 permanently-fixed photoquadrats. Photographs are taken of each photoquadrat annually in August or September, and percentage coral cover of each coral species is determined with a computer program, Coral Point Count with Excel extensions (Coles 2016). Except from 1985-90, the monitoring and data analysis has been done by Dr. Steve Coles of Bishop Museum, Honolulu. Unlike the NPSA and Fagatele Bay datasets described above, the Kahe stations were not randomly or haphazardly selected to represent coral cover across a larger area. Rather, the four Kahe stations were selected based on distance from the outfall in order to determine effects of

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the outfall on coral communities, thus the data from the four stations cannot be combined as was done for the NPSA and Fagatele Bay datasets. Raw data were provided by Steve Coles (Pers. Comm., March 2019).

Cover of *P. meandrina* at each station varied substantially during the 37-year period, with higher cover at the three stations near the outfall than at the control (Fig. 7). Declines in cover occurred at all stations after disturbances such as Hurricane Iniki in 1992, and a localized storm in 2004 (Fig. 7, Coles and Brown 2007). Mean cover of *P. meandrina* over the 37 year period was 5.5% at Station 2B, 4.8% at Station 6B, 3.9% at Station 8A, and 1.8% at Station CTL. Based on Dr. Cole's observations at Kahe and elsewhere, *P. meandrina* is one the most resilient corals in Hawai'i, and new recruits establish themselves and grow within five years after colonies are killed or reduced dramatically by disturbance. This is illustrated by recovery of *P. meandrina* cover at Station 8A after Hurricane Iniki in 1992 and an intense local storm in 2004 (Fig. 7, red line). After disturbances such as these, *P. meandrina* has always been the quickest coral species to recover (Steve Coles, Pers. Comm., March 2019). The coral bleaching events of 2014 and 2015 resulted in extensive bleaching and mortality of *P. meandrina* in other parts of the main Hawaiian Islands such as the Kona Coast on the Big Island (Kramer et al. 2016) and Hanauma Bay on Oahu (Rodgers et al. 2017). In contrast, at Kahe, *P. meandrina* cover was stable from 2014 to 2018 at Stations 6B and CTL, while *P. meandrina* cover increased at Stations 2B and 8A in the years following these bleaching events (Fig. 7).
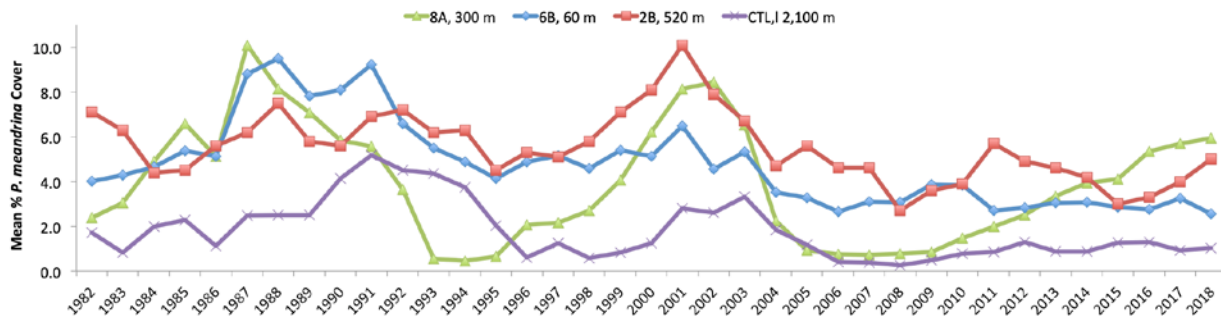
Figure 7. Mean % coral cover of *P. meandrina* each year at the monitoring stations around the Kahe Power Plant outfall on the Waianae Coast of Oahu at 3-5 m depth, 1982-2018. SEs are not shown, but ranged from 0.1 to 2.8 % cover (average = 0.9) for each data point. Note y-axis scale = 0 to 10% cover.

Kalaupapa National Park, Molokai: The data from this national park were collected using the same methodology as described above for the NPSA Tutuila Unit in the Samoa-Tuvalu-Tonga Ecoregion, i.e., 30 transects within the park, equally split between permanent and temporary transects. Data were collected annually for 13 years from 2006 to 2018. Raw data were provided by Eric Brown of the National Park Service (Pers. Comm., March 2019). Mean cover of *P. meandrina* declined from 6-8% in 2006-2008 to 2-3% in 2015 and 2016, then increased to 4-5% in 2017 and 2018 (Fig. 8). Mean cover for the 13-year period was 4.47% for the fixed transects, and 4.94% for the temporary transects. Low points in 2015 and 2016 were likely influenced by the 2014 and 2015 bleaching events.
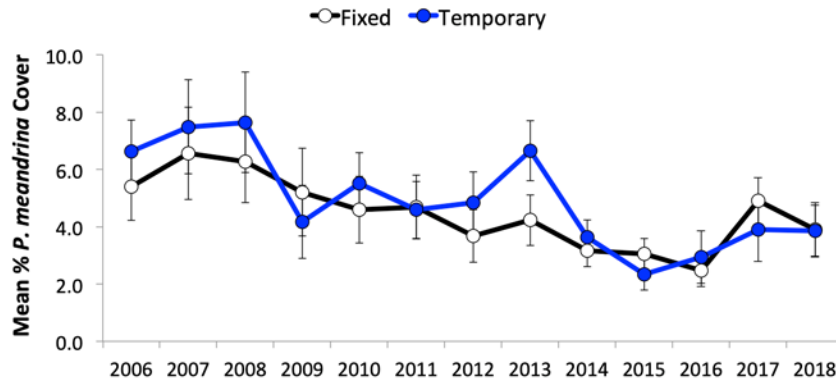
Figure 8. Mean % coral cover of *P. meandrina* at fixed and temporary transects at Kalaupapa National Park, Molokai, from 10 to 20 m depth, 2006-2018 (± SE). Note y-axis scale = 0 to 10% cover.

Kona Coast, Big Island: A pair of datasets are available from the Kona Coast on the leeward side of the Big Island (AKA West Hawai'i: (1) Kaloko-Honokohau National Park, and (2) the Hawai'i Department of Land and Natural Resources-Division of Aquatic Resources' (HI DLNR/DAR) West Hawai'i coral reef monitoring program. Both datasets document the nearly complete mortality of *P. meandrina* at the study sites in 2016 and 2017 (Figs. 9a and 9b).

NPS collects data from Kaloko-Honokohau National Park using the same methodology as described above for the NPSA Tutuila Unit in the Samoa-Tuvalu-Tonga Ecoregion, i.e., 30 transects within the park, equally split between permanent and temporary transects. Data were collected annually from 2008 to 2010, and from 2014 to 2017, but not from 2011 to 2013. Raw data were provided by Eric Brown of the National Park Service (Pers. Comm., March 2019). Mean cover of *P. meandrina* was 1-2% at the beginning of the monitoring period in 2008-2010, then declined to zero in 2016 and 2017 (Fig. 9a). The disappearance of *P. meandrina* in 2016 and 2017 was in response to the 2014 and 2015 bleaching events, which were particularly severe on the Kona Coast (Kramer et al. 2016).

HI DLNR/DAR monitors a network of coral reef sites within the West Hawai'i Regional Fishery Management Area on the Kona Coast of the Big Island. Species-level coral cover data were collected in 2003, 2007, 2011, 2014, 2016, and 2017 from 26 sites ranging from 8 m (26 ft) to 14 m (46 ft) of depth. Each site includes four fixed transects, each of which are 25 m (82 ft) in length. On each transect, photographs were taken at 1 m intervals from a standard height of 0.75 cm starting at the 0 point and ending at the 25 m mark, producing 26 images per transect. Percentage coral cover of each coral species is determined with a computer program, Coral Point Count with Excel extensions (Walsh et al. 2013). Raw data were provided by Lindsey Kramer of DAR (Pers. Comm., March 2019). Similar to Kaloko-Honokohau, mean cover of *P. meandrina* at the DAR sites was approximately 1% at the beginning of the monitoring period in 2003 and 2007, then declined to zero in 2016 and 2017 (Fig. 9b).
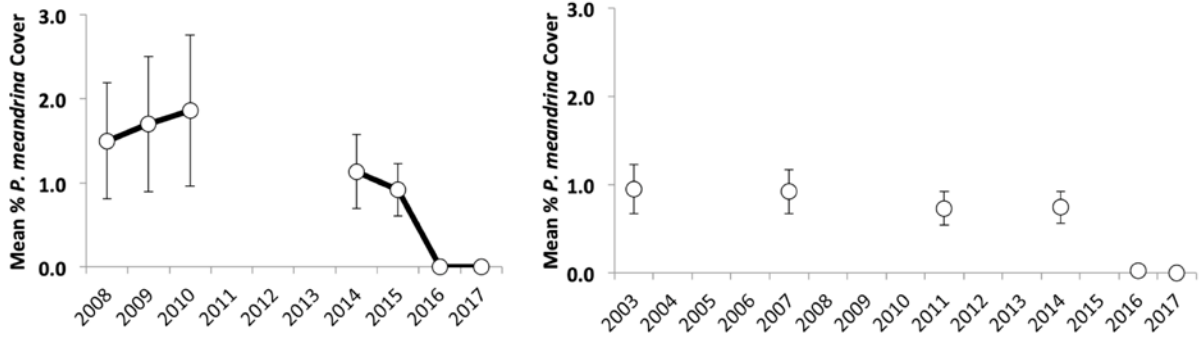
Figure 9a and 9b. Mean % coral cover of *P. meandrina* on the Kona Coast of the Big Island of Hawaii at: (9a, left) Kaloko-Honokohau National Park, Big Island, from 10 to 20 m depth, 2008-2010 and 2014-2017, and (9b, left) Hawaii DAR sites from 8 to 14 m depth over a 15 year period from 2003 to 2017 (± SE). Note y-axis scale = 0 to 3% cover.

Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP): CRAMP was established in 1999 to monitor long-term spatial and temporal trends in coral cover on MHI's coral reefs. A system of 32 sites is used, each site consisting of shallow (3 m) and deep (10 m) stations on hard substrates, plus four additional sites where only shallow stations are feasible, for a total of 68 stations. Stations are distributed throughout six of the eight MHI islands (all but Lanai and Niihau), including 12 on the Big Island, two on Kahoolawe, 12 on Kauai, 20 on Maui, six on Molokai, and 16 on Oahu. At each of the 68 stations, 10 randomly selected 10 m (33 ft) transects were permanently marked using stainless steel pins, thus CRAMP includes over 600 transects. Digital video and still photoquadrats are taken along transects at a height of 0.5 m (1.6 ft). For the video, 20 non-overlapping video frames are randomly selected from each transect video, and percentage coral cover of each coral species is determined within the frames with a computer program, PhotoGrid (Jokiel et al. 2004, Rodgers et al. 2015).

Data were collected annually from as many transects and stations as possible. From 1999 to 2018, data were collected from between 199 and 587 transects annually. Data were collected every year from most or all of the Maui transects and stations, and less frequently from the other islands. In 2011 and 2013-2015, data were only collected from the 20 Maui stations. Raw data were provided by Kuʻulei Rodgers of the Hawaiʻi Institute of Marine Biology (Pers. Comm., March 2019) and Eric Brown of the National Park Service (Pers. Comm., April 2019).

Results for MHI are shown in Figure 10. Each year, *P. meandrina* cover typically varied from zero to 10-15% cover on individual transects (maximum = 26.0% in 2017 on Kauai). From 1999 to 2015, mean cover of *P. meandrina* in MHI ranged from 0.89% to 1.52%. From 2016 to 2018, mean cover was 0.34 to 0.38%, in response to widespread bleaching in 2014 and 2015. Over the 20-year period, mean cover of *P. meandrina* declined by approximately 70%.
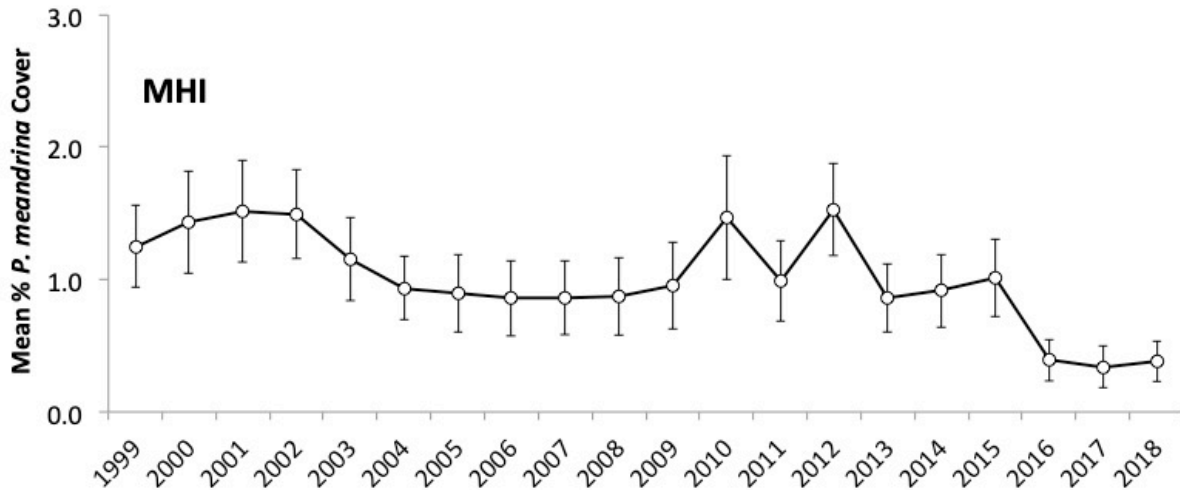
Figure 10. Mean % coral cover (± SE) of *P. meandrina* at the CRAMP monitoring sites in the main Hawaiian Islands at 3 and 10 m depths, 1999-2018. Note y-axis scale = 0 to 3% cover.

As noted above, the coral bleaching events of 2014 and 2015 resulted in extensive bleaching and mortality of *P. meandrina* in MHI. For example, Figure 9a above shows how these bleachings led to the nearly complete mortality of *P. meandrina* at Kaloko-Honokohau National Park on the Big Island. The CRAMP results confirm that widespread bleaching and mortality of *P. meandrina* occurred across the MHI in 2014 and 2015, leading to a sharp reduction in mean cover of *P. meandrina* in the ecoregion in 2016-2018 (Fig. 10). In contrast, in some locations, *P. meandrina* cover increased in 2016-2018, including at two of the four Kahe stations (Fig. 7) and Kalaupapa National Park (Fig. 8). Some signs of *P. meandrina* recovery on the Big Island were observed in 2018 at sites monitored by The Nature Conservancy (Eric Conklin, Pers. Comm., February 2019), which are separate from the CRAMP sites.

Summary for MHI Ecoregion: Spatial and temporal variability in *P. meandrina* abundance were often high, even at the same depth within one small area (e.g., Kahe, Fig. 7). CRAMP was designed to account for this variability by establishing 68 monitoring sites (each with 10 transects) across MHI, many of which are sampled annually. The CRAMP results show an approximate 70% decline in *P. meandrina* abundance in MHI over the 20-year period from 1999 to 2018. Between 1999 and 2015, mean cover of *P. meandrina* remained between 0.89 and 1.52%, before dropping to 0.34 to 0.38% in 2016-2018 (Fig. 10). Although *P. meandrina* is a competitive species that is typically among the quickest reef corals to recover from disturbances (see Section 2.3), as shown by the increase in juvenile colonies in MHI after the 2014 and 2015 bleachings (Table 3), recovery is not indicated in the 2016-2018 CRAMP data in terms of *P. meandrina* cover (Fig. 10). Based on this information, we conclude that *P. meandrina* was stable in this ecoregion until the 2014 and 2015 bleaching events, then declined by approximately 70%, with little or no recovery as of 2018.

Society Islands Ecoregion (#83): *Pocillopora meandrina* is one of the most common species on the reef slopes of this ecoregion (Penin et al. 2007, Tsounis and Edmunds 2016, Adjeroud et al. 2018). Although the ecoregion's reef coral communities have been affected by several different types of disturbances over the past several decades, including COTS outbreaks, tropical cyclones, land-based sources of pollution, and bleaching events, *Pocillopora* species

including *P. meandrina* consistently recover relatively quickly (Pratchett et al. 2011, Tsounis and Edmunds 2016). In response to the disturbances, *Pocillopora* species, including *P. meandrina,* have displaced *Acropora* and *Montipora* species on some coral reefs of Moorea (Berumen and Pratchett 2006, Pratchett et al. 2011, Edmunds 2018). For example, abundance of *Pocillopora* species increased in all four zones studied (reef flat = 1.5-2 m depth, reef crest = 3 m depth, reef slope = 8-10 m depth, and reef base = 18-20 m depth) on Moorea, and approximately tripled in all zones combined, between 1979 and 2003, a period characterized by multiple bleaching and predator outbreak events. *Pocillopora* colonies were not identified to species but were noted as being mostly *P. meandrina* and *P. verrucosa*. At the same time, *Acropora* species declined roughly proportionally (Berumen and Pratchett 2006). This pattern of *Pocillopora* recovery from disturbance is similar at most islands of the ecoregion (Mehdi Adjeroud, Pers. Comm., April 2019). While *P. verrucosa* remains the most dominant *Pocillopora* species in the Society Islands, the abundance of *P. meandrina* appears to have decreased in abundance at 5-25 m (16-82 ft) depth over the past 40 years, based on general observations (Michel Pichon, Pers. Comm., April 2019).

The above information suggests that *Pocillopora* corals have consistently recovered from disturbance in this ecoregion through displacement of less competitive species, but that *P. verrucosa* may be outcompeting *P. meandrina* at the depths most commonly surveyed (5-25 m). However, as described in the Habitat Breadth section above, *P. meandrina* favors very shallow (<5 m, 16 ft), high energy habitats, where it is more common than *P. verrucosa*. For example, surveys of two shallow (2-5 m, 7-16 ft), high energy sites on Tahiti found that *P. meandrina* was much more abundant than *P. verrucosa* (Drollet et al. 1994). Information from other ecoregions has also found *P. meandrina* to be more abundant than *P. verrucosa* in high-energy habitats (e.g. forereefs on Palmyra in the Kiribati Northeast Ecoregion, Williams et al. 2008).

Because *Pocillopora* species appear to be displacing other corals in this ecoregion across depths (Berumen and Pratchett 2006, Pratchett et al. 2011, Edmunds 2018), and *P. meandrina* favors shallow, high energy habitats, it has not necessarily decreased in abundance at <5 m depth like it appears to have at 5-25 m depth in this ecoregion. Typically, *P. meandrina* increases in abundance in the years following disturbance, especially in shallow, high-energy sites where it appears to have a competitive advantage. For example, at the Kahe sites in Hawaii (3-5 m depth), *P. meandrina* increased in abundance from 2006 to 2018 after disturbance in 2004 (Fig. 7), while decreasing during that time period at deeper sites in Hawaii (Figs. 8-10). In the Society Islands, *P. meandrina* may have increased in abundance at <5 m depth as it recovered from disturbances over the last several decades. Thus, when considering the abundance of *P. meandrina* across its entire depth range, based on the available information summarized above, we conclude that the population of *P. meandrina* in this ecoregion has been relatively stable over the last several decades.

Mexico West Ecoregion (#89): Between 1989 and 2001, seven sites on the tropical Mexican coast and four sites in the Revillagigedo Islands were surveyed multiple times, showing *P. meandrina* at 20-50% of the sites during most years (Reyes Bonilla 2003). Severe bleaching and mortality occurred in 1997, resulting in some reductions of *P. meandrina*. Since that time, surveys have been regularly conducted in 15 zones distributed throughout the ecoregion (Reyes-Bonilla et al 2010). In over two decades since the 1997 bleaching event, *P. meandrina* has remained stable (Hector Reyes Bonilla, Pers. Comm., March 2019). Based on this information, we conclude that the population of *P. meandrina* in this ecoregion has been stable over the last two decades.

Galapagos Islands Ecoregion (#94): Assuming *P. meandrina* population trends follow those of overall coral cover in the Galapagos Islands Ecoregion, it would have substantially declined since 1975, although it is not possible to estimate the extent of the decline. Numerous surveys of 30 sites on 13 islands over a 42 year period from 1975 to 2017 documented a 95% loss in of all reef-building corals combined. These losses are believed to have been precipitated by a severe bleaching event in 1982/83, followed by additional bleaching events in 1997/98 and 2007/08 combined with other problems. However, coral recovery has been occurring since 2010 in parts of the archipelago (Glynn et al. 2018). Because *P. meandrina* is a rare species in this ecoregion, it has not been possible to follow its population status throughout the changes that have occurred on the coral reefs there since 1975 (Peter Glynn, Pers. Comm., March 2019). However, based on the overall abundance trend of *Pocillopora* species in this ecoregion described above, we conclude that *P. meandrina* has substantially declined.

3.2.4.   Abundance Summary

To summarize relative abundances of *P. meandrina* in its 95 ecoregions, in the 65 ecoregions for which abundance information is available, it is dominant in seven, common in 18, uncommon in 36, and rare in four ecoregions. The majority of *P. meandrina*'s range is in the western Pacific and the Indian Oceans, where it has an intermediate level of abundance (common or uncommon). It is a very common species in many of the *Pocillopora*-dominated reef coral communities of the central Pacific and, while coral reef communities of the eastern Pacific are also *Pocillopora*-dominated, *P. meandrina* is one of the less common *Pocillopora* species in much of that area. It is only rare around the fringes of its range.

To summarize absolute abundances for *P. meandrina*, we estimate *P. meandrina*'s total population to be at least several tens of billions of colonies. The estimated total population for the eight ecoregions (four entire ecoregions and portions of four others) within U.S. waters in 2012-2018 was 1.48 billion colonies (Table 3). U.S. waters make up approximately 1% of the species' range, but relative abundances are higher in some of the ecoregions within U.S. waters (especially the MHI) than most of the rest of the species' range. We base our estimate of *P. meandrina*'s total population on estimated population abundance of *P. meandrina* in U.S. waters (1.48 billion colonies), the proportion of the species' range within U.S. waters (≈1%), and the assumption that the population density of *P. meandrina* is lower in foreign waters than U.S. waters.

To summarize abundance trends for *P. meandrina*, in the 10 ecoregions for which time-series abundance data or information are available, abundance appears to be decreasing in five ecoregions and stable in five ecoregions (Table 4). The abundance of *P. meandrina* has decreased by over 90% since 1975 in the Chagos Archipelago Ecoregion, by approximately 70% since 1999 in MHI, and appears to have also decreased by an undeterminable amount in the Marianas Islands, NWHI, and Galapagos Islands Ecoregions. In contrast, based on the abundance data and information, *P. meandrina* abundance appears to be relatively stable in the GBR Far North, GBR North-central, Samoa-Tuvalu-Tonga, Society Islands, and Mexico West Ecoregions.

Table 4. Recent observed abundance trends of *P. meandrina* in the 10 ecoregions for which data or information are available.

Ecoregion	Abundance Trend
Chagos Archipelago	Declined by >90% since 1975
Main Hawaiian Islands	Declined by approximately 70% since 1999
Marianas Islands	Declined by indeterminable amount since 1970s
Northwestern Hawaiian Islands	Declined by indeterminable amount since 2014 and 2015 bleaching events
Galapagos Islands	Declined substantially since 1975
GBR Far North	Stable over the last several decades
GBR North-central	Stable over the last several decades
Samoa-Tuvalu-Tonga	Stable over the last several decades, at least on Tutuila
Society Islands	Stable over the last several decades
Mexico West	Stable over the last two decades

We conclude that *P. meandrina*'s overall abundance is very high, but its overall abundance trend is unknown. Abundance is very high because (1) the relative abundance results indicate that *P. meandrina* is dominant or common in about one-third of its very large range; and (2) the absolute abundance results show that the U.S. population alone (which makes up only ≈1% of the species' range) is approximately 1.48 billion colonies. Because we only have abundance trend data or information from 10 of the 95 ecoregions, the trend in *P. meandrina*'s overall abundance is unknown. Of the 10 ecoregions for which abundance trend data or information are available, *P. meandrina*'s abundance appears to be decreasing in five ecoregions, and relatively stable in five ecoregions.

3.3. Productivity

The third demographic factor is productivity, as defined in the introduction to Section 3 above. In short, productivity refers to the overall population growth rate of *P. meandrina* in all 95 ecoregions combined. However, neither *P. meandrina*'s total population nor its overall population growth rate are known, based on the information presented above in Section 3.2. The most important factors influencing *P. meandrina*'s productivity (reproduction, dispersal, recruitment, growth, and adaptability) provide a qualitative indication of its productivity, thus these factors are described below.

Pocillopora meandrina has high reproductive capacity, which helps it outcompete other coral species, especially in response to disturbances (Dr. Rob Toonen, Pers. Comm., May 2019). Reproduction in *P. meandrina* can be sexual or asexual. Sexual reproduction occurs by fertilization of eggs and sperm in the water column (broadcast spawning), and each polyp is capable of producing eggs and sperm (hermaphrodites) (Kolinski and Cox 2003, Schmidt-Roach et al. 2012). Thus, *P. meandrina* is a hermaphroditic broadcast spawner like most other reef-building coral species (Baird et al. 2009). Synchronous spawning occurs 1-3 days after the full moon shortly after sunrise in the late spring or early summer (Stimson 1978, Fiene-Severns 1998; Schmidt-Roach et al. 2012). Unlike most other broadcast spawning coral species, the eggs of *P. meandrina* are seeded with zooxanthellae before spawning, supplementing maternal provisioning through photosynthesis in the free-swimming larvae (Hirose et al. 2001). In addition to sexual reproduction, *P. meandrina* reproduces asexually through fragmentation of branches (Glynn and Colley 2008). A study of *P. meandrina* colonies on Oahu that bleached in late 2015 but did not die found that all colonies had fully recovered by early 2016, and that bleaching had no detectable impact on reproductive output in 2016 or 2017 (Johnston et al. 2019).

Pelagic dispersal of *P. meandrina* larvae occurs by swimming, drifting, or rafting; the latter refers to settlement of larvae on natural or artificial flotsam which then carries the coral to permanent settlement habitat (Jokiel and Cox 2003). The length of time that larvae can survive in the water column before settling (i.e., larval competency periods) has not been determined for any broadcast-spawning *Pocillopora* species (Brainard et al. 2011). However, spawned larvae of five broadcast-spawning coral species (no *Pocillopora* spp.) had larval competency periods of 195 to 244 days (Graham et al. 2008). Since *P. meandrina* readily settles on artificial flotsam (Dave Burdick, Pers. Comm., March 2019), rafting may allow *P. meandrina* recruits to be transported long distances before settling on natural substrate. In addition, *P. meandrina*'s capacity for broad dispersal can be inferred from two characteristics of its distribution: (1) Its very large range (Fig. 2); and (2) its occurrence in a high proportion of the Indo-Pacific's most remote ecoregions and islands including, but not limited to, Cocos Keeling Atolls (Ecoregion #18), NWHI (#77), Easter Island (#87), Revillagigedo Islands (#89), and Clipperton Atoll (#95)(Table 2). Although *P. meandrina* larvae have the potential to disperse long distances, a larval dispersal model based on ocean currents, larval competency period, and other factors predicted that 82% of *P. meandrina* larvae on Molokai, Hawai'i, settle on that island (Conklin et al. 2018).

Recruitment occurs when a larva settles on a hard substrate and metamorphoses into a polyp (the primary polyp), which clones itself to produce genetically-identical polyps that become a juvenile coral colony. Recruitment of *P. meandrina* has been studied in Hawai'i, where it has been shown to be the most successful coral species at colonizing new substrates, such as a fresh lava flow on the Big Island (Grigg and Maragos 1974) and a reef denuded by a hurricane on Maui. After recruiting to the Maui reef, the growth rates of *P. meandrina* recruits were faster than recruits of other coral species, providing a competitive advantage which allowed *P. meandrina* to successfully colonize the area (Brown 2004). The capacity for high recruitment of *P. meandrina* is shown by monitoring data from Hawai'i, as exemplified by *P. meandrina* cover multiplying several fold in <10 years on several occasions at Kahe (Fig. 7). The species also recruits unusually well to a variety of artificial substrates, including metal, concrete, and PVC pipe. For example, the underside of a metal buoy that broke loose and washed ashore on Guam was covered by *P. meandrina* colonies (Dave Burdick, Pers. Comm., March 2019). Another example is provided by the outfall pipe from the Fort Kamehameha wastewater treatment plant near the mouth to Pearl Harbor on Oahu, Hawaii: After the 48 inch diameter PVC pipe and concrete supports were installed in 2003, *P. meandrina* was the first coral species to recruit to both the pipe and the supports (Steve Smith, Pers. Comm. June 2019).

Like many branching coral species, *P. meandrina* has high skeletal growth rates relative to most other Indo-Pacific reef-building coral species. For example, a study of the skeletal growth rates of 13 common reef-building corals on Johnston Atoll (including *Acropora, Pocillopora, Millepora, Montipora,* and *Pavona* species) found that *P. meandrina* colonies had annual growth rates of 17.0-31.0 cm (6.7-12.2 in) with a mean of 23.0 cm (9.1 in), the fourth highest of the 13 species (Jokiel and Tyler 1992). The same study also reported that *P. meandrina* colonies in Hawai'i had annual growth rates of 10.0-29.0 cm (3.9-11.4 in) with a mean of 14.8 cm (5.8 in), the highest growth rate of any coral in Hawai'i (Jokiel and Tyler 1992). In contrast, a study of the skeletal growth rates of seven common reef-building corals in Costa Rica (*Pocillopora, Psammocora,* and *Pavona* species) found that *P. meandrina* colonies had annual growth rates of only 1.8-5.6 cm (0.7-2.2 in) with a mean of 3.9 cm (1.5 in). While much lower than the Johnston and Hawai'i growth rates, the Costa Rica growth rates of *P.*

meandrina were the third highest of the seven species studied (Jiménez & Cortés 2003). Fast-growing corals typically have relatively brittle skeletons, like many *Acropora* and *Millepora* species. However, despite rapid skeletal growth, *P. meandrina* also has high skeletal hardness, helping it thrive in shallow high-energy habitats such as reef crests (Rodgers et al. 2003).

Size-class distributions of *P. meandrina* colonies in the Hawaiian Islands, the Mariana Islands, and American Samoa all show a sharp reduction in abundance of colonies >40 cm in diameter (Dione Swanson, Pers. Comm., April 2019), which is supported by data from Oahu (Coles and Brown 2007) and Maui (Brown 2004), indicating determinate growth in this species. That is, unlike most other reef corals, typical colonies of *P. meandrina* stop growing at around 40 cm (16 in) in diameter, although there are exceptions that grow considerably larger (Dione Swanson, Pers. Comm., April 2019). Studies in Hawai'i also indicate that *P. meandrina* has a relatively short life span compared to other corals (Brown 2004, Coles and Brown 2007). The high recruitment, rapid growth, and short life span of *P. meandrina* result in rapid turnover of the population at a given location, as shown by the approximately 15-year fluctuations between high and low cover of *P. meandrina* on the Kahe transects (Fig. 7).

Rapid turnover of *P. meandrina* populations provide capacity to adjust to changing conditions (adaptability) because the most resistant genotypes survive disturbances like bleaching events, then reproduce relatively quickly to claim open substrate (Voolstra et al. 2011, Edmunds 2018). Evidence supporting the adaptability of *P. meandrina* includes: (1) expansion of populations after disturbances on the GBR (Andrew Baird, Pers. Comm., March 2019) and French Polynesia (Berumen and Pratchett 2006, Pratchett et al. 2011); and (2) resistance of *P. meandrina* to the 2016 bleaching event in the Maldives (Muir et al. 2017) and the GBR (Charlie Veron, Pers. Comm. with Doug Fenner, February 2019), suggesting that past bleaching events selected for resistant genotypes at these locations.

The high reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability of *P. meandrina* allow it to pioneer available substrate and successfully compete for space (Coles and Brown 2007, Darling et al. 2012). These life history characteristics of *P. meandrina* provide buffering against threats such as warming-induced bleaching by providing the potential for rapid recovery from die-offs, as documented in some of the 95 ecoregions, including the MHI (Brown 2004, Grigg and Maragos 1974), the Society Islands (Gleason 1996, Adjeroud et al. 2007), and western Mexico (Jiménez and Cortés 2003). High reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability are all characteristics of high productivity, i.e., they all positively affect population growth rate.

Based on the best available information provided above, we consider *P. meandrina*'s productivity to be high, despite declining abundance trends in some ecoregions. Evidence for high productivity is provided by the species' responses to disturbance in several ecoregions, including: (1) as described in Section 3.2.2 above, demographic data suggests that recovery from back-to-back bleaching events is beginning in the MHI Ecoregion (i.e., fewer adults colonies in 2016 than in 2013 show adult colony mortality from the 2014 and 2015 bleaching events, but more juvenile colonies in 2016 than in 2013 suggests the initial stages of recovery from the bleaching events); and (2) as described in Section 3.2.3 above, studies and observations in other ecoregions (e.g., GBR, Society Islands) indicate strong recoveries in recent years from various types of disturbances at multiple locations throughout its range, by displacing less competitive coral species and becoming more abundant than before the disturbances. These responses to disturbance demonstrate continued high productivity, thus we consider *P. meandrina*'s productivity to be stable.

3.4. Diversity

The fourth demographic factor is diversity, as defined in the introduction to Section 3 above. Diversity includes both the diversity of genotypes (i.e., the genetic constitution of an individual) and phenotypes (i.e., the observable characteristics of an individual) within a population. Genotypic diversity is defined as the numbers of genotypes present in a population. For example, a population of asexually-reproduced clones originating from one individual would have zero genotypic diversity; a well-mixed, sexually-reproducing population (i.e., one in which all individuals potentially mate with one another, aka a panmictic population) would have low genotypic diversity; and a structured, sexually-reproducing population (i.e., one in which individuals only mate with a limited number of other individuals) would have high genotypic diversity. Phenotypic diversity is defined as the numbers of phenotypes present in a population, and is affected by both genotype and environmental factors. Robust populations have higher levels of genotypic and phenotypic diversity (McElhany 2000, NMFS 2017a). This section describes what is known of *P. meandrina*'s genotypic and phenotypic diversity, including factors that affect it such as spatial and temporal variability in habitat characteristics.

Theoretically, broadcast spawning and subsequent pelagic dispersal of larvae could lead to a panmictic population throughout an ecoregion or larger area (Maier et al. 2005). In reality, numerous studies of broadcast-spawning marine invertebrates including some Indo-Pacific reef-building corals have demonstrated moderate to high levels of genotypic diversity within areas much smaller than a single ecoregion (Ayre and Hughes 2000, Barshis et al. 2010, Conklin et al. 2018). That is, many reef-building corals are distributed on ecoregion or larger spatial scales (because some larvae disperse across large distances), and also have substantial genotypic diversity across reef or island spatial scales within a single ecoregion (because some larvae are locally retained) (Brazeau et al. 2011, Selkoe et al. 2016). The balancing of large-scale gene flow and small-scale retention allows for both broad distributions and local adaptation (Sanford and Kelly 2011), the latter of which leads to increased genotype diversity. Thus, species distributed across an entire ecoregion would be expected to have substantial genotypic and phenotypic diversity, and even more so for species distributed across multiple ecoregions such as *P. meandrina*.

Information on *P. meandrina*'s genotypic diversity is available from the South Pacific and Hawai'i. A study of the genetic structure of *P. meandrina* colonies from five sites in French Polynesia (three on Moorea, and one each on Tahiti and Bora Bora) found that the genotypes from one of the Moorea sites were significantly different than those of the other four sites. The study also examined the genetic structure of *P. meandrina* colonies from two sites in Tonga and found that genotypes were significantly different between Tonga and French Polynesia (Magalon et al. 2005). Preliminary results from an ongoing study of the genetic structure of *P. meandrina* in the Hawaiian Archipelago (i.e., the MHI and NWHI Ecoregions combined) show substantial genetic structure (i.e., different genotypes) on each island, similar to that found for the reef-building coral *Montipora capitata* for the same area (Concepcion et al. 2014), suggesting high genotypic diversity of *P. meandrina* within both the MHI and NWHI Ecoregions (Dr. Rob Toonen, Pers. Comm., May 2019).

Information on *P. meandrina*'s phenotypic diversity is also available from observations of contrasting responses to warming-induced bleaching events. As described in more detail below in Section 4.1, *P. meandrina* colonies responded in different ways to the warming-induced bleaching events of 2015 and 2016. In Hawai'i, *P. meandrina* was the most severely affected reef-building coral species, suffering up to 90% mortality in some locations (Kramer et al. 2016).

On the GBR, *P. meandrina* was one of the least affected corals (Hughes et al. 2018), being one of the two most resistant species to bleaching (Charlie Veron, Pers. Comm. with Doug Fenner, February 2019). In the Maldives, contrasting responses of side-by-side *P. meandrina* colonies were documented, as shown in a photograph of a bleached colony next to a resistant colony (Muir et al. 2017, Fig. 4). Such contrasting responses illustrate phenotypic diversity in the capacity of *P. meandrina* colonies to resist elevated seawater temperatures.

The spatial and temporal habitat heterogeneity of *P. meandrina*'s range is very high, contributing to the maintenance of high phenotypic diversity for the species. Phenotypic diversity can be maintained by spatial and temporal variation in habitat characteristics, because variable environmental factors result in the expression of different phenotypes. As described in Section 3.1 above, *P. meandrina* occurs in 95 ecoregions, and has a depth range of over 30 m (98 ft). The spatial variation in *P. meandrina*'s habitats is very high due to the habitat heterogeneity of its range. In addition, these habitats are exposed to a great deal of temporal variation in conditions on diurnal, lunar, seasonal, and decadal timescales. The broad geographic and depth distribution of *P. meandrina* includes nearly the entire range of habitats for Indo-Pacific reef-building corals (described in Section 2.2 of the GSA, Smith 2019).

Although there is little information available on the genotypic and phenotypic diversity of *P. meandrina*, the evidence described above suggests that both types of diversity are very high for this species, mainly because of its large distribution and habitat heterogeneity. The few species-specific studies that are available show high genotypic (Magalon et al. 2005; Dr. Rob Toonen, Pers. Comm.) and phenotypic (Hughes et al. 2018, Muir et al. 2017) diversity within portions of individual ecoregions. Furthermore, the species' distribution has not been reduced (Section 3.1). Therefore, based on the best available information provided above, we consider *P. meandrina*'s diversity to be high and stable.

3.5. Demographic Factors Conclusion
We conclude that *P. meandrina*'s distribution is very large and stable (Table 5). The geographic distribution of *P. meandrina* encompasses >230° longitude and ~60° latitude, and includes 95 of the 133 Indo-Pacific ecoregions, giving it a larger range than about two-thirds Indo-Pacific reef-building coral species. Although *P. meandrina* is usually more common at depths of <5 m (16 ft) than in deeper areas, its depth range is from the surface to at least 34 m (112 ft). There is no evidence of any reduction in its range due to human impacts, and we consider its historic and current ranges to be the same.

We conclude that *P. meandrina*'s overall abundance level is very high, but that its overall abundance trend is unknown (Table 4). The abundance of *P. meandrina* is described in terms of relative abundances in 65 of its 95 ecoregions, absolute abundances in eight ecoregions, and abundance trends in 10 ecoregions. With regard to relative abundance, it is dominant in seven, common in 18, uncommon in 36, and rare in four ecoregions. With regard to absolute abundance, the estimated total population for the eight ecoregions (four entire ecoregions and portions of four others) within U.S. waters in 2012-2018 was 1.48 billion colonies, and *P. meandrina*'s total population is at least several tens of billions of colonies. With regard to abundance trends, because we only have abundance trend data or information from 10 of the 95 ecoregions, the trend in *P. meandrina*'s overall abundance is unknown; however, in those 10 ecoregions, abundance appears to be decreasing in five ecoregions, and relatively stable in five ecoregions.

We conclude that *P. meandrina*'s productivity is both high and stable (Table 5). The high reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability

of *P. meandrina* are all characteristics of high productivity, i.e., they all positively affect population growth rate. In addition, *P. meandrina*'s abundance has remained stable in recent years in many ecoregions where information is available, whether there have been disturbances or not.

Finally, we conclude that *P. meandrina*'s diversity is both high and stable (Table 5). Genetic studies and observed responses to disturbances indicate both high genotypic and phenotypic diversity for *P. meandrina*. The species' large range (95 ecoregions) and very high habitat heterogeneity also imply high diversity.

Table 5. Conclusions on status and trends of *P. meandrina*'s demographic factors.

Demographic Factor	Status	Trends
Distribution	Broad geographic (95 ecoregions) and depth (34 m, 112 ft) ranges: <u>Very large distribution</u>.	Current range = historic range: <u>Stable distribution</u>.
Abundance	Dominant or common in ≈⅓ of range; Population in U.S. waters (≈1% of range) = 1.48 billion colonies: <u>Very high overall abundance</u>.	Of 10 ecoregions with abundance trend information, 5 decreasing, 5 stable, 0 increasing. No info for 85/95 ecoregions: <u>Unknown overall abundance trend</u>.
Productivity	High reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability: <u>High overall productivity</u>.	Recent recoveries from disturbances at many locations throughout its range indicate continued high productivity: <u>Stable productivity</u>.
Diversity	High genetic diversity within a single ecoregion; large range and very high habitat heterogeneity: <u>High diversity</u>.	Large and stable distribution; high overall abundance, and stable abundance trends in most ecoregions w/ trend information: <u>Stable diversity</u>.

4. Threats Evaluation

Section 4(a)(1) of the ESA and NMFS' implementing regulations (50 CFR 424) state that the agency must determine whether a species is endangered or threatened because of any one or a combination of the following five factors: (A) Present or threatened destruction, modification, or curtailment of habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) inadequacy of existing regulatory mechanisms; or (E) other natural or manmade factors affecting its continued existence. Based on the 2011 Status Review Report for 82 corals (Brainard et al. 2011), the 2014 final coral listing rule (NMFS 2014), and new information, the GSA (Smith 2019) describes the 10 types of threats to Indo-Pacific reef-building corals currently and in the foreseeable future (i.e., from now to 2100, as explained in next paragraph): Ocean warming, ocean acidification, sea-level rise, fishing, land-based sources of pollution, coral disease, predation, collection and trade, a group of secondary threats (weakening ocean currents, increasing tropical storms, physical damage, invasive species, and changes in salinity), and the interactions of threats.

Ocean warming, ocean acidification, sea-level rise, weakening ocean currents, and increasing tropical storms are all direct results of global climate change. Because of its prominent role in threatening reef-building corals, an overview of global climate change is provided in the GSA (Smith 2019). As also explained in the GSA, we consider the foreseeable future to be from now to the year 2100, and the International Panel on Climate Change's (IPCC) Representative Concentration Pathway 8.5 (RCP8.5) to be the most appropriate future climate change scenario. Thus, this Threats Analysis considers the time period from now to the year 2100 to be the foreseeable future, and uses RCP8.5's projections over the foreseeable future for the climate change threats of ocean warming, ocean acidification, sea-level rise below, weakening ocean currents, and increasing tropical storms.

The vulnerabilities of *P. meandrina* to each of the 10 types of threats are described below. Vulnerability of a species to a threat is a function of susceptibility and exposure, considered at the appropriate spatial and temporal scales. The spatial scale is the 95 ecoregions that make up the current range of *P. meandrina* (Fig. 2), and the temporal scale is from now through the foreseeable future (i.e., from now to 2100). Susceptibility refers to the response of *P. meandrina* colonies to the adverse conditions produced by the threat. Exposure refers to the degree to which *P. meandrina* colonies are likely to be subjected to the threats throughout its range, thus the overall vulnerability of a coral species to threats depends on the proportion of colonies that are exposed to the threats. A species may not necessarily be highly vulnerable to a threat even when it is highly susceptible to the threat, if exposure is low. Consideration of the appropriate spatial and temporal scales is particularly important, because of potential high variability in threats both spatially over *P. meandrina*'s large range, and temporally over the approximately eight decades that make up the foreseeable future (NMFS 2014).

4.1. Ocean Warming (Factor E)

Ocean warming is one of the most important threats to Indo-Pacific reef-building corals because it leads to warming-induced bleaching and mortality, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to ocean warming currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the overall susceptibility of *P. meandrina* to ocean warming to be moderate to high, but recognize that susceptibility ranges from low to high, depending on location and other factors. Genus-level surveys of warming-induced bleaching susceptibility have found that *Pocillopora* species can be among the more susceptible of reef-building corals (Barkley et al.

2018, Edmunds et al. 2014, McClanahan et al. 2007, van Woesik et al. 2011), sometimes only for the short term but sometimes seemingly for the longer term as well. Species-level studies and observations of *P. meandrina* at many locations recorded high susceptibilities to the 1998, 2014-17, and other bleaching events. In the Chagos Archipelago, widespread bleaching and mortality of *P. meandrina* occurred in the 1980s, 1998, and 2016 (Sheppard et al. 2017), which is believed to be the primary reason why *P. meandrina* has declined by over 90% there since the 1970s with little sign of recovery as of 2019 (Charles Sheppard, Pers. Comm., April 2019). In the Marianas Islands, widespread bleaching and mortality of *P. meandrina* occurred in response to the 2014 and 2017 bleaching events, with little sign of recovery as of 2019 (Dave Burdick, Steven Johnson, Steve McKagan, Pers. Comm., March 2019). In the main Hawaiian Islands, high bleaching and mortality of *P. meandrina* occurred on the west coast of the Big Island in response to the 2014 and 2015 bleaching events, with limited signs of recovery as of 2019 (Lindsey Kramer, Pers. Comm., April 2019). On the west coast of Mexico, widespread bleaching and mortality of *P. meandrina* occurred in response to the 1998 bleaching event, although some recovery also occurred (Hector Reyes-Bonilla, Pers. Comm., March 2019).

In contrast to the high susceptibilities described above, studies and observations of *P. meandrina* have also recorded high resistance to warming-induced bleaching at many locations throughout the species' range, or that bleached colonies recovered readily. In a study of the susceptibilities of 153 reef-building corals to the 2016 bleaching event on Ari Atoll in the Maldive Islands, *P. meandrina* had one of the lowest susceptibilities (Muir et al. 2017, Supplementary Information, Table S4), with many colonies showing high resistance (Muir et al. 2017, Fig. 4). Observations during 2016 at a different atoll in the Maldives (North Malé) noted that some *P. meandrina* colonies bleached but recovered well (Samantha Reynolds, Pers. Comm., March 2019). On the GBR, *P. meandrina* has been one of the two most resistant reef-building coral species to bleaching on the GBR out of the hundreds of species found there (Charlie Veron, Pers. Comm. with Doug Fenner, February 2019; Andrew Baird, Pers. Comm., March 2019). These observations are supported by a study of the responses of the GBR's 15 main groups of reef coral taxa to the 2016 bleaching event, where *P. meandrina* and other *Pocillopora* species except for *P. damicornis* lost the least amount of cover, and were the least sensitive to temperature stress (Hughes et al. 2018). In French Polynesia, some *P. meandrina* bleached in 2016, with low mortality in the Society Islands, but higher mortality in the Tuamotu Archipelago (Gonzalo Blanch, Pers. Comm., March 2019). A study of *P. meandrina* colonies on Oahu that bleached in late 2015 but did not die found that all colonies had full recovered by early 2016, and that bleaching had no detectable impact on reproductive output in 2016 or 2017 (Johnston et al. 2019). On the Pacific coasts of Mexico and Costa Rica, *P. meandrina* colonies were either resistant to bleaching, or bleached but recovered well in response to the 2017 bleaching event (Hector Reyes-Bonilla and Carlos Jiménez, Pers. Comm., March 2019).

In response to elevated seawater temperatures in 1998, *P. meandrina* off the west coast of Mexico heavily bleached, resulting in extensive mortality. But when similar conditions occurred there in 2017, the species had very low bleaching (Hector Reyes-Bonilla and Carlos Jiménez, Pers. Comm., March 2019). These contrasting responses may provide insight into the variable susceptibilities of *P. meandrina* to warming-induced bleaching. Exposure of a population of coral colonies to elevated seawater temperatures may enhance resistance to bleaching both through acclimatization (i.e., surviving colonies are acclimatized, McClanahan et al. 2017) and adaptation (i.e., progeny of surviving colonies are adapted, Palumbi et al. 2014). Strong correlation between coral resistance to bleaching and history of bleaching has been demonstrated

for several Indo-Pacific reef-building coral species at different locations (Mollica et al. 2019). Thus, susceptibility of a population of *P. meandrina* colonies to ocean warming may depend on historical exposure at that site, explaining why susceptibility ranges from low in some areas to high in others. Since susceptibility of *P. meandrina* to warming-induced bleaching has been recently observed to be high (e.g., MHI, Mariana Islands) or intermediate (e.g., Maldives, Mexico, Costa Rica) in most areas, but low in just a few areas (e.g., GBR, Society Islands), we consider the overall susceptibility of *P. meandrina* to ocean warming to be moderate to high.

Exposure of colonies of *P. meandrina* to ocean warming varies spatially with latitude, depth, habitat type, and other spatial factors (e.g., windward vs. leeward sides of islands), and temporally with tidal, diurnal, seasonal, and decadal cycles. The range of *P. meandrina* spans >230° of longitude, ≈60° of latitude, and >30 m of depth, encompassing a range of locations with variable exposure to elevated seawater temperatures. For example, during the 2016 warming event across the Indo-Pacific, most coral reefs in the archipelagos surrounding Palau and Tutuila were severely bleached (Hughes et al. 2018), while Palau's and Tutuila's corals were relatively lightly affected, likely because favorable ocean currents moderated seawater temperatures (Colin 2018; Doug Fenner, Pers. Comm., February 2019). However, as described in the GSA (Smith 2019), several factors suggest that *P. meandrina*'s exposure to ocean warming is already quite high, and increasing: (1) substantial ocean warming in the tropical/subtropical Indo-Pacific has already occurred and continues to occur; (2) ocean warming in the tropical/subtropical Indo-Pacific is projected to continue at an accelerated rate in the future; (3) substantial warming-induced mass bleaching of Indo-Pacific reef coral communities has already occurred and continues to occur; (4) warming-induced mass bleaching of Indo-Pacific reef coral communities is projected to rapidly increase in frequency, intensity, and magnitude in the foreseeable future; and (5) Indo-Pacific coral reefs will be severely affected by such warming. Thus we consider exposure of *P. meandrina* to ocean warming to be high.

We consider the current vulnerability of *P. meandrina* to ocean warming to be high, based on moderate to high susceptibility combined with high exposure. We expect vulnerability of *P. meandrina* to ocean warming to increase in the foreseeable future as climate change worsens, resulting in higher frequency, severity, and magnitude of warming-induced bleaching events.

4.2. Ocean Acidification (ESA Factor E)

Ocean acidification is one of the most important threats to Indo-Pacific reef-building corals because it leads to lower pH and aragonite saturation state, reducing skeletal growth and density of coral colonies, and also weakening reef cementation, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to ocean acidification currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the susceptibility of *P. meandrina* to ocean acidification to be high. In contrast to ocean warming, almost no species-specific information is available on the susceptibility of *P. meandrina* to ocean acidification, as the effects of this threat are difficult to study and observe in the field. Mean pH of the surface waters of the open ocean is currently approximately 8.05 units, and is projected to decrease to approximately 7.75 by 2100 (Smith 2019). A laboratory study on the effects of ocean acidification found that *P. meandrina* colonies exposed to a pH of 7.8 had reductions in calcification rate of approximately 50% over a 2-week period (Muehllehner and Edmunds 2008). A field study found that the skeletal growth rates of *P. damicornis* were lower in naturally acidic waters (pH ≈7.8) than in typical waters (pH ≈8.1; Fabricius et al. 2011). A laboratory study found that larvae of *P. damicornis* exposed to a pH of

7.8 for six hours had reductions in metabolic function (Rivest and Hofmann 2014). However, laboratory studies have found that *Pocillopora* species have some capacity to resist the effects of ocean acidification (Comeau et al. 2014, Putnam et al. 2013), likely through increased production of calcium ions within their tissues which counteracts the effects of lower pH (Comeau et al. 2019).

Little information is available on whether *Pocillopora* populations exposed to ocean acidification may acclimatize or adapt to the changing conditions, eventually developing some resistance, as has been observed for some *Pocillopora* populations repeatedly exposed to ocean warming (see Section 4.1 above). Some of the above studies (Comeau et al. 2014, 2019, Putnam et al. 2013) suggest that *Pocillopora* corals may have the capacity to acclimatize to some level of ocean acidification, but the information is inconclusive because it is based on laboratory studies. That is, the currently available information summarized above does not indicate that *P. meandrina* or other *Pocillopora* species have the capacity to acclimatize to, adapt to, or resist the effects the levels of ocean acidification expected in the foreseeable future.

Exposure of *P. meandrina* colonies to ocean acidification will likely continue to be highly variable in space, but also likely to increase over the foreseeable future because of the projected increase in ocean acidification, as described in the GSA (Smith 2019). As with seawater temperatures, seawater pH and aragonite saturation state are subject to high natural variability both spatially and temporally across coral reefs, especially in shallow, high energy (Shamberger et al. 2011) or highly-fluctuating (Shaw et al. 2012) habitats. The variability occurs from reef to global scales, driven by numerous physical and biological characteristics and processes, including seawater temperature, proximity to land-based runoff and seeps, proximity to sources of oceanic CO_2, salinity, nutrients, photosynthesis, and respiration (Mongin et al. 2016). In cooler waters, CO_2 absorption is higher, driving pH and aragonite saturation state lower, thus relatively cool coral habitats are more susceptible to acidification, such as those at higher latitudes, in upwelling areas, and in deeper environments (NMFS 2014).

We consider the current vulnerability of *P. meandrina* to ocean acidification to be high, based on high susceptibility combined with highly variable exposure. We expect vulnerability of *P. meandrina* to ocean acidification to increase in the foreseeable future as climate change worsens, resulting in higher severity and magnitude of ocean acidification.

4.3. Sea Level Rise (ESA Factor E)

As with ocean warming and acidification, sea level rise is a consequence of global climate change. While sea level rise so far during the industrial era (since the mid-19th century) has been slow and small, it is projected to rapidly accelerate in the foreseeable future. Sea level rise potentially threatens reef-building corals by requiring them to grow quickly to keep up with rising sea levels, degrading water quality through increased coastal erosion, and compounding the effects of other simultaneous threats such as warming-induced bleaching and ocean acidification, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to sea level rise currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the susceptibility of *P. meandrina* to sea level rise to be low. As far as we know, there is no species-specific information available on the susceptibility of *P. meandrina* to sea level rise. Reef-building corals that are unable to keep up with rising sea levels, unable to settle on newly available substrates, and occur in nearshore habitats such as reef flats, would be the most susceptible to sea level rise (Smith 2019). As described in Section 3 above, *P. meandrina* is a colonizing species that readily settles on newly available substrates, has relatively

rapid skeletal growth, occurs primarily on reef crests and shallow forereefs (not reef flats), and has a depth range from the surface to >30 m.

Exposure of *P. meandrina* colonies to sea-level rise will likely continue to be highly variable, but also likely to increase over the foreseeable future as sea level rise worsens. Exposure of colonies of *P. meandrina* to sea level varies spatially by area (because sea level rise is not uniform across the species' range), whereby colonies in areas where sea level rise is greatest will have the most exposure. Thus, exposure to sea level rise varies from high in areas with the highest sea level rise (e.g., Tuvalu, see Smith 2019), to lower in areas with slow sea level rise. In addition, sea-level rise varies temporally on inter-annual or decadal cycles, in response to changes in rainfall and wind patterns (Woodroffe 2008).

We consider the current vulnerability of *P. meandrina* to sea-level rise to be low, based on low susceptibility combined with highly variable exposure. We expect vulnerability of *P. meandrina* to sea-level rise to increase in the foreseeable future as climate change worsens, resulting in higher severity and magnitude of sea-level rise.

4.4. Fishing (ESA Factor A)

Fishing directly affects reef-building coral habitat by destroying and modifying benthic substrates, and indirectly by altering trophic interactions that are important in structuring coral reef ecosystems, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to fishing currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

The susceptibility of *P. meandrina* to fishing is illustrated in the main Hawaiian Islands (MHI) Ecoregion where it is one of the most common reef-building coral species. Many of the coral reefs of this ecoregion are heavily fished, especially around the more heavily populated islands of Oahu, Maui, Kauai, and the Big Island. Four fishing gears predominate in MHI coral reef fisheries: Hook-and-line (including handline), spears, fish traps, and gillnets, and these have the potential to break and entangle *P. meandrina* colonies. For example, a study of seven paired shoreline sites (i.e., adjacent fished vs. unfished areas) on Oahu, Maui, and the Big Island found that significantly more *P. meandrina* colonies in the fished areas were entangled with fishing line and dead than in the unfished areas, which the authors attributed to fishing (Asoh et al. 2004). In a related study by some of the same authors, the majority of 129 *P. meandrina* colonies in a heavily degraded site (Kewalo Park, Honolulu, next to the mouth of the Ala Wai Canal) were entangled by fishing line and dead, but the impacts of fishing could not be distinguished from the multitude of other human impacts (Yoshikawa and Asoh 2004).

We consider the susceptibility of *P. meandrina* to the direct and indirect effects of fishing to be moderate. The Western Pacific Fisheries Information Network (WPacFIN) maintains a database of catch and effort in the commercial components of the MHI hook-and-line, spear, trap, and gillnet fisheries. The database shows that all four commercial fisheries operated continuously throughout the 20-year period from 1999 to 2018 (https://www.pifsc.noaa.gov/wpacfin/, accessed May 2019). The non-commercial components of some of these fisheries are likely larger than the commercial components, thus overall effort of coral reef MHI fisheries was likely quite high in 1999-2018. However, as shown in Section 3.2 above, the abundance of *P. meandrina* in MHI remained stable through the first 17 years (1999-2015) of this 20-year period (Fig. 10 above). Similarly, despite decades of pressure from a variety of coral reef fisheries continuously operating in the Society Islands Ecoregion (Leenhardt et al. 2016), *P. meandrina* remains one of the most common reef-building coral species there (Mehdi Adjeroud, Pers. Comm., April 2019). In addition, *P. meandrina* was one of the first reef-

building coral species to return to coral reefs in Indonesia after destructive fishing stopped (Andrew Baird, Pers. Comm., March 2019).

While exposure of *P. meandrina* to fishing is high in certain areas, it is low to none in a large proportion of the species' range, resulting in low exposure overall. The species' exposure to fishing will increase over the foreseeable future as the human population and fishing pressure increase (Smith 2019). Exposure of colonies of *P. meandrina* to fishing is likely high in areas with high human population densities where fishing can be done from shore or by boat, such as Oahu, Hawaiʻi (Asoh et al. 2004), or in areas with concentrated coral reef fisheries, such as many parts of Indonesia and the Philippines (Burke et al. 2011). On the other hand, much of *P. meandrina*'s range occurs in remote areas that are difficult to reach by fishers, or in MPAs where fishing is restricted or banned. In addition, as described in Section 2.4, *P. meandrina* is found primarily on reef crests and upper reef slopes, where constant wave action discourages human access and fishing.

We consider the current vulnerability of *P. meandrina* to fishing to be low to moderate, based on moderate susceptibility combined with low exposure. We expect vulnerability of *P. meandrina* to fishing to increase in the foreseeable future as the human population and fishing pressure increase.

4.5. Land-based Sources of Pollution (ESA Factor A)

Land-based sources of pollution (LBSP) include turbidity, sediment, nutrients, and contaminants originating from coastal development, urbanization, agriculture, and other human activities on land that degrade reef-building coral habitat, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to LBSP currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat. In a systematic literature review of the effects of turbidity, sediment, and nutrients on reef-building corals, 53 sources of species-specific data were found, but none on *P. meandrina* (NMFS 2017b). Likewise, in a literature review of the effects of contaminants on reef-building corals, 47 sources of species-specific data were found, but none on *P. meandrina* (NMFS 2016a). Thus, we are not aware of any species-specific information on the effects of LBSP on *P. meandrina*. However, observations on the habitats of *P. meandrina*, and genus-level information, provide insight into its susceptibilities to turbidity, sediment, nutrients, and contaminants.

We consider the susceptibility of *P. meandrina* to turbidity to be low. As described in the Habitat Breadth section above (Section 2.4), in some locations, *P. meandrina* occurs in turbid habitats such as back-reef pools and patch reefs (David Benavente, Pers. Comm., April 2019), atoll lagoons (Doug Fenner, Pers. Comm., March 2019), and intertidal habitat with large tidal range (Richards et al. 2015). We therefore assume it is able to tolerate a range of turbidity conditions.

We consider the susceptibility of *P. meandrina* to sediment and nutrients to be moderate. For sediment and nutrients, some information is available on the general susceptibilities of the *Pocillopora* genus: *Pocillopora* species are commonly found in areas with relatively high sediment in the eastern Pacific (Rogers 1990), but in Hawaiʻi and other parts of the Pacific, the only *Pocillopora* species that commonly occurs in such areas is *P. damicornis* (Fenner 2005, Erftemeijer et al. 2012). Very little information is available on the susceptibilities of *Pocillopora* species to excess nutrients. In a two-year field study on the effects of artificial nutrient enrichment on three reef-building coral species (two *Acropora* species and *P. damicornis*) on offshore GBR patch reefs, mortality increased under the high nutrients treatment in *P. damicornis* (Koop et al. 2001).

We consider the susceptibility of *P. meandrina* to contaminants to be high. Numerous studies have shown adverse effects of exposure to various contaminants on *P. damicornis*, including reduced photosynthesis and growth in response to copper (Bielmyer et al., 2010), increased oxidative stress in response to iron chloride (Vijayavel et al. 2012), early larval release in response to natural gas condensate (Villanueva et al. 2011), adult mortality in response to unleaded gasoline and engine oil (Te 1991), and larval mortality in response to oxybenzone (Downs et al. 2016). Other studies have shown adverse effects of exposure to various contaminants on *P. verrucosa*, including reduced respiration in response to diesel together with high seawater temperatures, and tissue loss in response to linear alkylbenzene sulfonate, a surfactant commonly used in detergents and soaps (Kegler et al. 2015).

We consider *P. meandrina*'s overall susceptibility to all LBSPs combined to be moderate. LBSPs include turbidity, sediment, nutrients, and contaminants, and susceptibilities to each type of LBSP vary: As described above, we assume *P. meandrina*'s susceptibilities are low for turbidity, moderate for sediment and nutrients, and high for contaminants.

Exposure of colonies of *P. meandrina* to turbidity, sediment, nutrients, and contaminants is likely high in areas subject to intense coastal development, urbanization, agriculture, and other human activities on land. However, *P. meandrina* is most commonly found in high-energy habitats such as shallow forereefs where wave action is high, moderating exposure to turbidity, sediment, nutrients, and contaminants through dispersal of LBSPs to lower energy habitats such as lagoons and reef slopes. In addition, much of *P. meandrina*'s range is far from human activities on land (e.g., uninhabited atolls, islands, barrier reefs, etc.), also limiting exposure. Thus, exposure of *P. meandrina* to turbidity, sediment, nutrients, and contaminants is high in some areas, but low to none in a large proportion of the species' range, resulting in low exposure overall. The species' exposure will increase over the foreseeable future as the human population and coastal development increase (Smith 2019).

We consider the current vulnerability of *P. meandrina* to LBSP to be low to moderate, based on moderate overall susceptibility combined with low overall exposure. We expect vulnerability of *P. meandrina* to LBSP to increase in the foreseeable future as the human population and coastal development increase.

4.6. Coral Disease (ESA Factor C)

Coral disease refers to infectious diseases of reef-building corals (not to coral bleaching or toxicological effects, which are covered above in the Ocean Warming and Land-based Sources of Pollution sections, respectively). Coral diseases adversely affect various coral life history stages by causing adult mortality, reducing reproductive success, and impairing colony growth, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to coral disease currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the susceptibility of *P. meandrina* to disease to be low. A coral disease survey in the Northwestern Hawaiian Islands found that *P. meandrina* was the least affected coral species, with only a single colony of *P. meandrina* exhibiting any sign of disease among several thousand colonies examined (Aeby 2006), and a coral disease survey of 142 sites across the entire Hawaiian Archipelago did not record disease on *Pocillopora* colonies (Aeby et al. 2011). Likewise, a coral disease survey conducted at 30 sites on the Big Island of Hawaiʻi between 2007 and 2011 found that *P. meandrina* was the least affected coral species, with *P. meandrina* colonies at only one of the 30 sites exhibiting any sign of disease (Walsh et al. 2013).

Furthermore, genus and family level information indicate low susceptibilities of *Pocillopora* and Pocilloporidae to coral disease relative to other reef-building corals. In 2003, 2005, and 2007, 13 of the 15 islands in the Marianas Archipelago were surveyed for coral disease to the genus level. Mean coral disease prevalence (proportion of all reef-building coral colonies affected on all islands combined) was 0.19%. *Pocillopora* species were not among the most affected genera on any island except Saipan (Brainard et al. 2012). In 2006, the six islands of American Samoa were surveyed for coral disease to the genus level. Mean coral disease prevalence was 0.34%. *Pocillopora* species were not among the most affected genera on any island except on Rose Atoll (Brainard et al. 2008). Much higher coral disease prevalences have been recorded on the GBR (1.3%) and the Philippines (4.6%) for all reef-building corals combined, but genus-level information is not available. However, a family-level analysis of coral disease prevalences in 15 Indo-Pacific reef-building coral families showed that Pocilloporidae had the third-highest abundance, but the sixth-highest disease prevalence (Ruiz-Moreno et al. 2012), indicating relatively low disease susceptibility in the Pocilloporidae compared with other families.

Exposure of colonies of *P. meandrina* to coral disease depends on exposure to other threats, especially ocean warming and LBSP (Ruiz-Moreno et al. 2012). As noted above, exposure of *P. meandrina* to ocean warming and LBSP is highly variable across the species' range, but for different reasons. Exposure to both threats is expected to increase in the foreseeable future. Thus, *P. meandrina*'s exposure to coral disease is likely highly variable across its range, but will increase over the foreseeable future as ocean warming, LBSP, and other threats increase.

We consider the current vulnerability of *P. meandrina* to coral disease to be low, based on low susceptibility combined with highly variable exposure. We expect vulnerability of *P. meandrina* to coral disease to increase in the foreseeable future as ocean warming, LBSP, and other threats increase, because these threats generally produce conditions that favor coral disease.

4.7. Predation (ESA Factor C)

Predation refers to feeding upon reef-building corals by corallivorous species of invertebrates (e.g., snails and seastars) and fish, and is considered an important threat to Indo-Pacific reef-building corals because of the observed and projected increases in human disturbances which allow predation to affect corals more than it otherwise would, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to predation currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the susceptibility of *P. meandrina* to predation to be moderate. A variety of seastars, mollusks, crabs, fishes, and other predators feed on *Pocillopora* species including *P. meandrina* by either scraping tissue away the skeleton (seastars, mollusks, crabs, some fishes) or biting off pieces of tissue and skeleton (some fishes; Glynn 2004). The crown-of-thorns seastar (COTS; *Acanthaster planci*) is considered the most important predator because of its large size, potential for extremely large outbreaks, high coral tissue consumption rate, and capacity to remove tissue from entire coral colonies (Glynn 1976, Pratchett et al. 2017). Other seastars such as the cushion seastar (*Culcita novaeguineae*) are also common predators on *P. meandrina* in some locations (Glynn and Krupp 1986). Small mollusks such as *Drupella* species in the western Pacific and *Jenneria pustulata* in the eastern Pacific can overwhelm *Pocillopora* colonies with feeding aggregations of 50-100 individuals per colony. Some small crabs scrape away tissue from parts of *P. meandrina* colonies, while others occur within its branches as mutualistic

symbionts, as described below. Pufferfishes, parrotfishes, and filefishes bite off colony branch-tips, while butterflyfishes, angelfishes, and damselfishes scrape tissue away (Glynn 2004).

While *Acropora* species are the most favored coral prey of COTS, and sharp reductions in *Acropora* populations in response to COTS outbreaks have been recorded across the Indo-Pacific, *Pocillopora* species are sometimes also heavily impacted by COTS (Glynn 1985, Kayal et al. 2012, Pratchett et al. 2014, Keesing et al. 2019). In the main Hawaiian Islands (where *Acropora* colonies are very rare), small colonies of *P. meandrina* are preyed upon by COTS more than any other coral species (Chess et al. 1997, Kenyon and Aeby 2009). However, after colonies of *P. meandrina* and other *Pocillopora* species attain a size of approximately 10 cm in diameter, small crabs and shrimp take up residence in the spaces between colony branches, and are very effective at warding off COTS and other predators (Glynn 1976, Pratchett et al. 2001). Thus, COTS predation on *P. meandrina* is much lower on colonies >10 cm in diameter than on smaller colonies (Chess et al. 1997, Kenyon and Aeby 2009), substantially reducing the susceptibility of larger colonies to predation (Pratchett et al. 2017, Keesing et al. 2019). The presence of large fields of *Pocillopora* in the eastern tropical Pacific serve as barriers to protect preferred massive corals from COTS – a barrier broken down during severe bleaching and mortality of *Pocillopora* in 1983 (Glynn 1985).

Aside from COTS, other predators can result in colony damage and mortality of *Pocillopora* species including *P. meandrina*, especially after bleachings or other events that weaken the colonies. For example, after the 2016 bleaching event in the Maldives, an outbreak of *Drupella* snails caused additional damage and mortality of *Pocillopora* colonies (Samantha Reynolds, Joali Maldives, Pers. Comm., March 2019). However, generally these other predators do not cause severe damage because they typically remove a small portion of tissue or skeleton, and do not often occur in large numbers (Glynn 2004, Jokiel et al. 2008).

Exposure of colonies of *P. meandrina* to predation depends on predator abundances. Generally, predator abundances and exposure are low most of the time on coral reefs, interspersed with brief periods of high abundances and subsequent high exposure. High abundances of predators may be triggered by nutrient availability, reductions in corallivore predators, and other factors (Brainard et al. 2011). For example, high abundances of COTS often occur a few years after major pulses of nutrients generated by terrestrial runoff from tropical storms, which apparently results in greatly increased survival of COTS larvae (Birkeland 1982, Fabricius et al. 2010). Coral reefs that are subject to LBSP, fishing, and other threats typically have more predator outbreaks, and thus higher exposure to predation, which tends to be acute and localized (Brainard et al. 2011). Thus, *P. meandrina*'s exposure to predation is likely highly variable across its range, but will increase over the foreseeable future as LBSP, fishing, and other threats increase.

We consider the current vulnerability of *P. meandrina* to predation to be moderate, based on moderate susceptibility combined with highly variable exposure. We expect vulnerability of *P. meandrina* to predation to increase in the foreseeable future as LBSP, fishing, and other threats increase, because these threats generally produce conditions that favor predators.

4.8. Collection and Trade (ESA Factor B)

Collection and trade refers to the physical process of taking reef-building corals from their natural habitat (collection) for the purpose of sale in the marine aquarium and ornamental industries (trade), as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to collection and trade currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

We consider the susceptibility of *P. meandrina* to collection and trade to be moderate. In a genus-level analysis of reef-building coral demand, *Pocillopora* was not among the top ten genera in the marine aquarium industry (Jones 2008). As of May 2019, none of the largest marine aquarium coral wholesalers in the United States, an industry that sells a vast diversity of both captive bred and wild caught corals, had *P. meandrina* listed for sale, nor does it appear to have been sold over the last 15 years. The species is very difficult to keep alive in captivity, as are most or all *Pocillopora* species except *P. damicornis*. While there are currently two living colonies of *P. meandrina* in the Waikiki Aquarium, they have been difficult to maintain, and have grown into shapes quite different from those in the wild (Johnathan Casey, Waikiki Aquarium, Pers. Comm., May 2019).

In contrast to its lack of popularity in the marine aquarium industry, in another genus-level analysis of reef-building coral demand, *P. meandrina* was among the top four genera in the ornamental industry (Thornhill 2012). Skeletons are cleaned and sold as curios or decorations, and colonies of *Acropora* and *Pocillopora* species are especially popular in many countries. In coral reef areas dominated by *Pocillopora* species such as the eastern Pacific and Hawaiʻi, demand for *Pocillopora* skeletons can be high. By the 1990s, the collection of corals for the curio trade had virtually eliminated *Pocillopora* species from areas near the tourist destinations of Acapulco (Mexico), Bahia Culebra (Costa Rica), Taboga Island (Panama), and parts of the coast of Ecuador (Glynn 2001). In Hawaiʻi, collection of *P. meandrina* colonies for the curio trade was carried out historically (Gaffney 2018), but became illegal in 1998 (NMFS 2012). The extent and effects of collection on the *P. meandrina* population in Hawaiʻi are unknown, because large-scale monitoring did not begin until 1999 (see Section 3.2), a year after collection became illegal. *Pocillopora* skeletons, including *P. meandrina*, are still sold in gift shops in Hawaiʻi (Damien Beri, Pers. Comm., June 2019), presumably legally imported.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international treaty that regulates international trade in plants and animals listed in one of three CITES Appendices. Species listed under Appendix II (including *P. meandrina* and most other reef-building corals) can only be internationally traded with permits, and trade is tracked and recorded in the CITES database https://trade.cites.org/ (NMFS 2012). As of May 2019, the database showed 145 records of *P. meandrina* international trade between 1986 and 2017 (CITES 2019a), and 2,095 records of unidentified *Pocillopora* species (which may include *P. meandrina*) between 1985 and 2017 (CITES 2019b). The traded corals included "raw corals" (unprocessed coral skeletons for the curio trade), "live corals" (living colonies for the marine aquarium trade), "carvings" (carved coral skeletons for the curio trade), and "specimens" (samples used for scientific research), the majority of which were raw corals and live corals. The total "units" (CITES does not use a standard unit – for corals, a "unit" refers to a colony or a piece, unless specified as a kilogram) globally imported and exported annually are shown in Figures 11a (*P. meandrina*) and 11b (all *Pocillopora* spp.). Both categories show erratic quantities from the 1980s through the early 2000s (no explanation could be found for the sharp spikes in 1999 and 1992), then increasing trends over the last 10-15 years (Figs. 11a, 11b). The primary exporters were Indonesia, Fiji, and Australia, and the primary importers were the US and European countries. Although most of the traded specimens were harvested from the wild, during the latter part of the recorded period, some were produced by coral farms (CITES 2019 a,b).
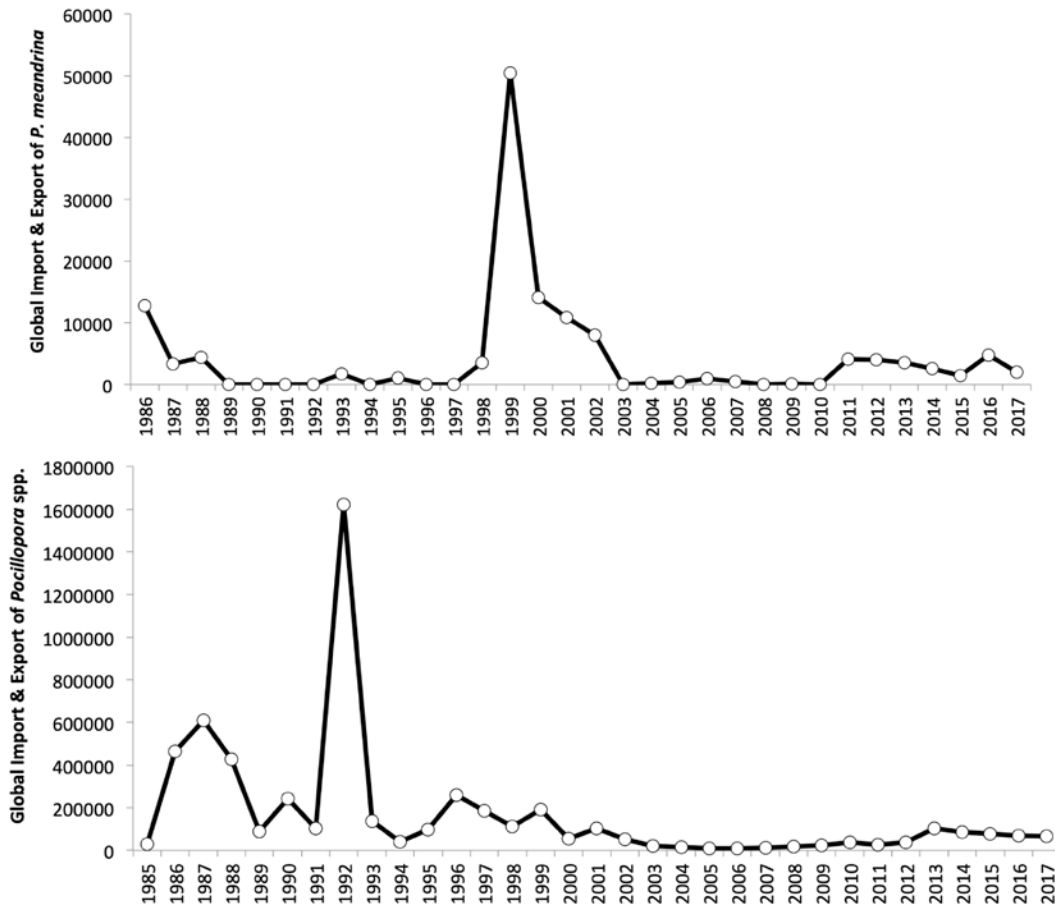
Figure 11a and 11b. Global imports and exports of *P. meandrina* and *Pocillopora* species, 1985-2017, in "units" (usually colonies or pieces; CITES 2019a,b). Note differences in y-axes.

The CITES data only includes corals that are traded across international boundaries. However, a large proportion of demand for ornamental corals is domestic, and thus is not included in the CITES data. That is, in many countries, coral colonies are collected and sold domestically as curios to tourists. For example, the above-cited collection of *Pocillopora* colonies in Mexico, Costa Rica, Panama, and Ecuador for the curio trade near tourist destinations is mostly or entirely domestic, and therefore would not appear in the CITES data at all. Yet the collection was reported to have virtually eliminated *Pocillopora* species from areas near the tourist destinations (Glynn 2001). Such collection is likely occurring elsewhere within the range of *P. meandrina*, but is not monitored or reported, as far as we know. Thus, collection of *Pocillopora* species including *P. meandrina* for the domestic curio trade may be substantial in many countries, but such collection is generally not monitored, so we cannot quantify it. However, because of the great extent of tourism in many coastal areas within the range of *P. meandrina*, domestic collection of the species may exceed the amount that is internationally traded and reported by CITES.

Harvest of *P. meandrina* from its natural habitat involves removing all or part of the colony by breaking it away from the colony or substrate. Harvest of the entire colony obviously results in its loss from the population. Harvest of some branches from a colony may result in its eventual mortality if disease or parasites gain a foothold on the exposed skeleton before it heals

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over, however colonies of *Pocillopora* species can survive if some branches are removed (Henry and Hart 2005). For example, in a transplant experiment of *P. eydouxi* in American Samoa, two branches were broken off of each of 14 source colonies to be used as transplants (Smith et al. 2008). One year later, 100% of the source colonies appeared healthy and in good condition, with new skeletal growth and healthy tissue covering the old breaks (Lance Smith, Personal Observation, 2006). Thus while *P. meandrina* colonies harvested in their entirety are lost to the population, harvest of branches most likely would allow the colony to survive. In addition, *P. meandrina*'s skeleton is one of the hardest of all reef-building corals (Rodgers et al. 2003), discouraging its harvest.

We consider the exposure of *P. meandrina* to collection and trade to be low. Exposure of colonies of *P. meandrina* to collection and trade depends on the proportion of the total population that is harvested annually. As described in Section 3.2.2, *P. meandrina*'s total population is at least several tens of billions of colonies. The above CITES data for *Pocillopora* species and *P. meandrina* suggests that a maximum of a few tens of thousands of "units" (i.e., colonies or pieces thereof) of *P. meandrina* are traded internationally every year. However, domestic collection for tourism curio markets is likely substantial in many countries within the range of *P. meandrina*, and may exceed international trade, but is not monitored or recorded as far as we know. In addition, we assume there is also some illegal domestic and international collection and trade. Based on the above, total annual harvest of *P. meandrina* for the ornamental industry is not likely to be more than a few hundreds of thousands to a few millions of colonies. Even if a few million colonies are collected annually, that is still relatively small compared to the tens of billions of colonies in *P. meandrina*'s total population, thus exposure to collection and trade is considered to be low.

We consider the current vulnerability of *P. meandrina* to collection and trade to be low to moderate, based on moderate susceptibility combined with low exposure. We expect vulnerability of *P. meandrina* to collection and trade to increase in the foreseeable future, because future domestic and international demand for ornamental corals is expected to grow as the human population and affluence grow.

4.9. Other Threats

In addition to the above eight primary threats, other threats to *P. meandrina* include two global threats (changes in ocean circulation and tropical storms), and three local threats (human-induced physical damage, invasive species, and changes in salinity). These are not considered primary threats because they are either uncertain (the global threats) or highly localized on small spatial scales (the local threats), as described in the GSA (Smith 2019). The vulnerabilities of *P. meandrina* to these other threats currently and over the foreseeable future are described here in terms of its susceptibility and exposure to these five threats.

We consider the susceptibilities of *P. meandrina* to changes in ocean circulation and tropical storms to be low. The weakening of ocean circulation, and the increasing intensity of tropical storms, are both results of global climate change. The weakening of ocean currents could reduce *P. meandrina* connectivity among ecoregions, which is essential for providing larvae to foster recovery from disturbance as well as long-term gene flow. However, the amount of weakening that has occurred so far is highly uncertain, and projected weakening even more so. Similarly, the intensity of tropical storms appears to be increasing in the Indo-Pacific, and is projected to increase in the foreseeable future, although uncertainty is very high (IPCC 2013). Branching coral species such as *Acropora* and *Pocillopora* species typically lose the most colonies and parts thereof to tropical storms, but storm damage is not necessarily a problem for

their populations because: (1) they are able to more quickly colonize storm-denuded substrates and recover than other corals; and (2) broken branches are a source of asexual reproduction (Baird et al. 2018; Andrew Baird, Pers. Comm., March 2019).

We consider the susceptibilities of *P. meandrina* to human-induced physical damage, invasive species, and changes in salinity to be low. Human-induced physical damage (i.e., breakage of colonies by vessels or equipment), invasive marine species, and changes in salinity are all highly localized threats. Human-induced physical damage to *P. meandrina* can result from a variety of human activities, including planned projects such as coastal construction and development, as well as accidents such as vessel groundings, which cause injury or mortality from colony breakage. These activities are typically one-time events at any given location, rather than continuous through time. Colonies of *P. meandrina* are extremely hard and recover well from breakage (Rodgers et al. 2003). Introduced marine invertebrates and algae can become invasive species if they settle near reef-building corals and are able to grow fast enough to outcompete them for space. However, as described in Section 2.4, *P. meandrina* is found primarily on reef crests and upper reef slopes, where constant wave action prevents or discourages the settlement of most other species. In addition, as described in Section 3.3, *P. meandrina* is one of the fastest-growing reef-building corals, which helps it compete well with other species. Nearshore coral reef habitats like reef flats, lagoons, and fringing coral reefs can experience extreme salinity changes. For example, severe rain events can produce catastrophic local coral bleaching, such as occurred in Kaneohe Bay in Hawai'i in 1987, which caused mass mortality of inshore corals such as *Pocillopora damicornis* and *Montipora verrucosa* (Jokiel et al. 1993). However, since *P. meandrina* is found primarily on reef crests and upper reef slopes where constant wave action keeps seawater well-mixed, changes in salinity are much less of a problem for this species than inshore species.

Exposure of colonies of *P. meandrina* to changes in ocean circulation and tropical storms is highly variable, both spatially and temporally. As with ocean warming, ocean acidification, and sea-level rise, these two threats are also subject to many types of spatial and temporal variability at many different scales. In addition, uncertainty is higher about the degree to which these two threats are currently occurring, and especially how much they will increase in the foreseeable future (IPCC 2013). Based on this information, exposures of *P. meandrina* colonies to changes in ocean circulation and tropical storms will likely continue to be highly variable, but also likely to increase over the foreseeable future because of the projected increase in global climate change, as described in the GSA (Smith 2019).

Exposure of colonies of *P. meandrina* to human-induced physical damage, invasive species, and changes in salinity occurs on very small spatial scales: Human-induced physical damage results from collisions of vessels and equipment with coral colonies, which even in the case of large ships is limited to a tiny proportion of an ecoregion, let alone the species' range (Brainard et al. 2011). Exposure of *P. meandrina* to invasive species is limited by the fact that invasive marine species are concentrated in harbors and nearby habitats, but their density rapidly declines with distance from harbors (Paulay et al. 2002, Eldredge and Smith 2001). However, *P. meandrina* usually does not occur in harbors, and its occurrence in nearby habitats is concentrated on reef crests and shallow reef slopes with high wave energy that discourages the establishment and proliferation of invasive species. Exposure of *P. meandrina* to changes in salinity is limited by the fact that rain-induced drops in salinity affect reef flats and lagoons (not *P. meandrina*'s preferred habitat) much more than reef crests and shallow forereefs (*P. meandrina*'s preferred habitat). Based on this information, we assume that *P. meandrina* has

very low exposures to human-induced physical damage, invasive species, and changes in salinity, but also that exposures will increase over the foreseeable future because of the projected increases in human population and subsequent human activities, as described in the GSA (Smith 2019).

We consider the current vulnerabilities of *P. meandrina* to the two other global threats (changes in ocean circulation and tropical storms) to be low, based on low susceptibilities combined with highly variable exposures. We expect vulnerabilities of *P. meandrina* to changes in ocean circulation and tropical storms to increase in the foreseeable future as climate change worsens.

We consider the current vulnerabilities of *P. meandrina* to the three other local threats (human-induced physical damage, invasive species, and changes in salinity) to be very low to low, based on low susceptibilities combined with very low exposures. We expect vulnerabilities of *P. meandrina* to human-induced physical damage, invasive species, and changes in salinity to increase in the foreseeable future as human activities increase and climate change worsens.

4.10. Interactions of Threats

The threats described above often affect Indo-Pacific reef-building corals simultaneously or sequentially, thus threats may interact with one another to affect *P. meandrina* in different ways than they would individually. Because of the large number of threats to Indo-Pacific reef-building corals, and the fact that multiple threats can interact with one another, there are many types of potential interactions, as described in the GSA (Smith 2019). The vulnerability of *P. meandrina* to the interactions of threats currently and over the foreseeable future is described here in terms of its susceptibility and exposure to this threat.

As described above, the threats to which *P. meandrina* have the highest vulnerabilities are ocean acidification, ocean warming, fishing, LBSP, predation, and collection and trade. However, there is very little information available on the interactions of these or the other threats with one another for *P. meandrina* or other *Pocillopora* species. A laboratory study on the effects of ocean acidification and elevated seawater temperatures found that *P. meandrina* colonies exposed to low pH and average seawater temperatures had reduced calcification rates, but that simultaneous exposure to low pH and elevated seawater temperatures had no effect, indicating a positive interaction (Muehllehner and Edmunds 2008). After the 2016 bleaching event in the Maldives, an outbreak of *Drupella* snails caused additional damage and mortality of *Pocillopora* colonies (Samantha Reynolds, Joali Maldives, Pers. Comm., March 2019). The weakening of the coral colonies by bleaching may have exacerbated the predator outbreak. Also in the Maldives after the 2016 bleaching, many bleached *Pocillopora* colonies initially survived, but later died, possibly because they were infected by disease from neighboring *Acropora* colonies that bleached, were infected by disease, and died (Perry and Morgan 2017).

We consider the current vulnerabilities of *P. meandrina*'s to the interactions of the threats with one another to be unknown. Interactions of these threats with one another may be either negative (i.e., impacts are exacerbated) or positive (i.e., impacts are alleviated) on reef-building corals (Brainard et al. 2011). As noted above, currently the available information is inadequate to determine *P. meandrina*'s susceptibilities to the interactions of threats. Likewise, the available information is inadequate to determine exposure, thus we consider *P. meandrina*'s susceptibilities and exposures to the interactions of threats to be unknown. However, based on the available information on the effects of the interactions of these threats on other Indo-Pacific reef-building corals, as described in the GSA (Smith 2019), we consider it likely that the overall

effect of the interactions of these threats with one another on *P. meandrina* is negative, and that these impacts will worsen in the foreseeable future as nearly all threats worsen.

4.11. Inadequacy of Existing Regulatory Mechanisms (ESA Factor D)

Existing regulatory mechanisms refers to treaties, agreements, laws, and regulations at all levels of government globally that may affect the continued existence of reef-building corals. Relevant regulatory mechanisms include thousands of treaties, agreements, laws, and regulations at the international, national, state, local, and other levels that are intended to control global and local threats to marine resources including coral reefs, as described in the GSA (Smith 2019). The inadequacy of existing regulatory mechanisms does not constitute a direct physical or biological threat to *P. meandrina* like the other threats. However, this factor is included in the Threats Evaluation because existing regulatory mechanisms influence the direct threats to *P. meandrina*. The management of global threats (i.e., GHG management) and local threats for Indo-Pacific reef-building corals are described in the GSA (Smith 2019), and are directly relevant to *P. meandrina*. Based on the information in the GSA, we conclude that current global regulatory mechanisms for management of GHG emissions are expected to be unsuccessful at reducing global climate change-related impacts to *P. meandrina*. Likewise, based on the information in the GSA, we conclude that current regulatory mechanisms are ineffective at reducing the impacts of local threats to *P. meandrina*.

4.12. Threats Evaluation Conclusion

The current susceptibilities, exposures, and subsequent vulnerabilities of *P. meandrina* to the threats, and the expected trends in vulnerabilities in the foreseeable future, are shown in Table 6 below, based on information provided in this Threats Evaluation. For each threat, vulnerability is a function of susceptibility and exposure, as explained above. Based on these vulnerability ratings, the six worst threats to *P. meandrina* currently are ocean warming (high), ocean acidification (high), predation (moderate), fishing (low to moderate), land-based sources of pollution (low to moderate), and collection and trade (low to moderate). There is not enough information to determine *P. meandrina*'s vulnerability to the interactions of threats. Vulnerabilities to all threats are expected to increase in the foreseeable future (Table 6).

Table 6. Current susceptibilities, exposures, and vulnerabilities (a function of susceptibility and exposure) of *P. meandrina* to the threats. The expected trends in vulnerabilities in the foreseeable future are also shown.

Threat	Current Susceptibility	Current Exposure	Current Vulnerability	Future Vulnerability*
Ocean Warming	Moderate to High	High	High	↑
Ocean Acidification	High	Variable	High	↑
Sea-level Rise	Low	Variable	Low	↑
Fishing	Moderate	Low	Low to Moderate	↑
LBSP	Moderate	Low	Low to Moderate	↑
Coral Disease	Low	Variable	Low	↑
Predation	Moderate	Variable	Moderate	↑
Collection & Trade	Moderate	Low	Low to Moderate	↑
Other Threats (global)	Low	Variable	Low	↑
Other Threats (local)	Low	Very Low	Very Low to Low	↑
Interactions of Threats	Unknown	Unknown	Unknown	↑

*   ↑ = a negative upward trend

5. Extinction Risk Assessment

This extinction risk assessment (ERA) was carried out as specified in the "Guidance on Responding to Petitions and Conducting Status Reviews under the Endangered Species Act" (Listing guidance, NMFS 2017a), and in the "Guidance for Treatment of Climate Change in NMFS Endangered Species Act Decisions (Climate guidance, NMFS 2016b). As per the Listing guidance (NMFS 2017a), an ERA Team was established, consisting of the seven members identified in the Acknowledgements section at the beginning of this document. The Team used the information provided in both the GSA (Smith 2019) and this Status Review Report to provide the quantitative ratings of *P. meandrina*'s demographic risk, threats, and overall extinction risk, assuming that RCP8.5 is the most likely future climate scenario, and that the time period from now to 2100 is the foreseeable future.

Draft and final ratings were conducted by the Team in September and October 2019, using the same set of written information (the GSA, this Status Review Report, and the climate guidance). Before the final ratings, a Team meeting was held on September 30, 2019, to ensure that all Team members had a common understanding of the ERA process, and to discuss comments and questions. The importance of the climate change assumptions to the ERA process were emphasized, in particular that conditions consistent with RCP8.5 will be realized within the range of *P. meandrina* over the entire 21st century (i.e., the foreseeable future).

At the September 30, 2019, meeting, Team members requested clarification of the terms "immediate future" and "imminent", which appear in the definitions of risk categories for threats and extinction (definitions provided in Sections 5.2-5.3 below). These terms were clarified for the Team as follows before final ratings were completed: "Immediate future" and "imminent" are intended to help distinguish between the High (i.e., occurring in the immediate future, or imminent) and Moderate (not occurring in immediate future, not imminent) ratings for threats and extinction risk, emphasizing the temporal distinction between High and Moderate. For the purposes of the *P. meandrina* extinction risk assessment, the Team agreed that both "immediate future" and "imminent" refer to the time period between the present and 2030.

At the meeting, the Team also requested clarification of the term "extinct", in reference to the term "extinction", which appears in the definitions of risk categories for demographic factors, threats, and extinction (definitions provided in Sections 5.1-5.3 below). This term was clarified for the Team as follows before final ratings were completed: The term "extinct" refers to Webster's definition (no longer existing), i.e., not a single living individual in existence anywhere, even in captivity. Thus, the term "extinction" refers to the process leading to the demise of every individual in the entire species (i.e., not a single living individual remaining in existence anywhere), as opposed to the concept of "functional extinction" whereby some individuals of the species remain living but the population is no longer viable. The results of the draft and final ERA ratings are provided below.

5.1. Demographic Risk Factors Assessment

The demographic risk assessment utilizes the information provided in this report on *P. meandrina*'s four demographic risk factors of distribution, abundance, productivity, and diversity. ERA Team members were instructed to assign a risk score to each of the four demographic risk factors using the following definitions, assuming that RCP8.5 is the most likely climate change scenario over the foreseeable future (now to 2100). Table 7 below shows the mean results of the Team's draft and final ratings.

- 0 = Unknown: The current level of information is either unavailable or unknown for this demographic factor, such that the contribution of this factor to the extinction risk of the species cannot be determined.
- 1 = Low risk: It is unlikely that this demographic factor contributes or will contribute significantly to the species' risk of extinction.
- 2 = Moderate risk: It is likely that this demographic factor contributes or will contribute significantly to the species' risk of extinction.
- 3 = High risk: It is highly likely that this demographic factor contributes or will contribute significantly to the species' risk of extinction.

Table 7. Results of 7-member ERA Team's draft and final ratings of *P. meandrina*'s demographic risk factors.

Demographic Factors	Mean Draft Ratings (± Standard Deviation)	Mean Final Ratings (± Standard Deviation)
Distribution	1.1 (±0.38)	1.1 (±0.38)
Abundance	1.6 (±0.53)	1.6 (±0.53)
Productivity	1.0 (±0.00)	1.0 (±0.00)
Diversity	1.1 (±0.38)	1.0 (±0.00)

The Team rated *P. meandrina*'s distribution as a low risk in both the draft and final ratings (Table 7). The distribution of *P. meandrina* is larger than about two-thirds of Indo-Pacific reef-building coral species, and includes most coral reefs in the Indo-Pacific as well as a depth range of >30 m (>98 ft). There is no evidence of any reduction in its range due to human impacts, thus its historic and current ranges are considered to be the same. Although all threats are projected to greatly increase in the foreseeable future under RCP8.5, *P. meandrina*'s distribution is not likely to contribute significantly to extinction risk.

The Team rated *P. meandrina*'s abundance as a moderate risk in both the draft and final ratings (Table 7). In the 10 ecoregions for which time-series abundance data or information are available, abundance appears to be decreasing in five ecoregions and stable in five ecoregions. Because of these declines in abundance that have already been observed, and projections of greatly increasing threats in the foreseeable future, *P. meandrina*'s abundance is likely to contribute significantly to extinction risk.

The Team rated *P. meandrina*'s productivity as the lowest possible risk in both the draft and final ratings (Table 7). Productivity of *P. meandrina* is high due to its high reproductive capacity, broad dispersal, high recruitment, rapid skeletal growth, and adaptability, i.e., these characteristics of the species all positively affect population growth rate. Although all threats are projected to greatly increase in the foreseeable future under RCP8.5, *P. meandrina*'s productivity is not likely to contribute significantly to extinction risk.

The Team rated *P. meandrina*'s diversity as a low risk in both the draft and final ratings (Table 7). Diversity of *P. meandrina* is due to high genotypic and phenotypic diversity, and a large range with very high habitat heterogeneity. There is no evidence that either productivity or diversity have been reduced. Although all threats are projected to greatly increase in the foreseeable future under RCP8.5, *P. meandrina*'s diversity is not likely to contribute significantly to extinction risk.

In conclusion, *P. meandrina*'s demographic factors are indicative of a robust and resilient species that is better suited for responding to ongoing and projected threats than most other reef-building coral species. While abundance has declined in some ecoregions in recent years, the species' high productivity provides capacity for recovery. All threats are projected to greatly

worsen in the foreseeable future, assuming that RCP8.5 is the most likely climate scenario, but *P. meandrina*'s demographic factors moderate its extinction risk.

5.2. Threats Assessment

The threats assessment utilizes the information provided in this report on *P. meandrina*'s 10 threats. ERA Team members were instructed to assign a risk score to each of the 10 threats, based on information in the GSA (Smith 2019) and this Status Review Report, using the following definitions, assuming that RCP8.5 is the most likely climate change scenario over the foreseeable future (now to 2100). Table 8 below shows the results of the Team's draft and final ratings.

- 0 = Unknown: The current level of information is either unavailable or unknown for this threat, such that the contribution of this threat to the extinction risk of the species cannot be determined.
- 1 = Low: It is unlikely that this threat contributes significantly to risk of extinction.
- 2 = Moderate: This threat contributes significantly to risk of extinction in the foreseeable future, but does not in itself constitute a danger of extinction in the immediate future.
- 3 = High: This threat contributes significantly to risk of extinction in the foreseeable future, and is likely to significantly contribute to risk of extinction in the immediate future.

Table 8. Mean results of 7-member ERA Team's draft and final ratings of *P. meandrina*'s threats.

Threats	Mean Draft Ratings (± Standard Deviation)	Mean Final Ratings (± Standard Deviation)
Ocean warming	2.1 (±0.69)	1.9 (±0.38)
Ocean acidification	1.9 (±0.90)	1.7 (±0.76)
Sea-level rise	1.0 (±0.00)	1.0 (±0.00)
Fishing	1.4 (±0.53)	1.2 (±0.39)
Land-based sources pollution	1.3 (±0.49)	1.3 (±0.49)
Coral disease	1.3 (±0.49)	1.3 (±0.49)
Predation	1.3 (±0.49)	1.3 (±0.49)
Collection and trade	1.2 (±0.39)	1.2 (±0.39)
Other threats	0.7 (±0.52)	0.7 (±0.52)
Interactions of threats	1.9 (±0.69)	1.9 (±0.38)

In both the draft and final ratings, the Team rated ocean warming, ocean acidification, and the interactions of threats as posing moderate risk to the species (1.7 – 2.1), while the other seven threats were rated as posing low risk (0.7 – 1.4; Table 8). Ocean warming and the interactions of threats were rated as posing the highest risk to *P. meandrina* in both the draft and final ratings. The worst threats to *P. meandrina* include those caused by global climate change (ocean warming and ocean acidification), and the Team unanimously agreed that these threats stem from the inadequacy of regulatory mechanisms for greenhouse gas emissions management (described in Section 4 of the GSA, Smith 2019). Ocean warming and ocean acidification were both rated as posing relatively high risk (Table 8), because of observed impacts already, but mostly because the frequency, severity, and magnitude of both threats are likely to greatly worsen in the foreseeable future under RCP8.5.

The interactions of threats was also rated as posing relatively high risk to *P. meandrina* in both the draft and final ratings (Table 8). While there is very little information available on the

effects of the interactions of threats on *P. meandrina* (Section 4 above), general information on the negative effects of interactions of threats on reef-building corals indicates a large number of negative interactions (Section 4 of GSA, Smith 2019). In addition, there are likely to be many negative interactions that are still unknown, and these interactions are likely to become much worse in the foreseeable future under RCP8.5.

While the other seven threats were all rated as relatively less severe in both the draft and final ratings (Table 8), at least some of them can be severe on small spatial scales, and most or all have the potential to negatively interact with other threats. For example, fishing, land-based sources of pollution, and predation heavily impact *P. meandrina* in portions of its range, and may negatively interact with one another and other threats.

In conclusion, *P. meandrina* faces a multitude of growing, interacting threats that are projected to greatly worsen in the foreseeable future, assuming that RCP8.5 is the most likely climate scenario. The Team also noted that all threats are exacerbated by the inadequacy of existing regulatory mechanisms. The species' strong demographic factors moderate all threats, but the gradual worsening of threats is expected to result in a steady increase in extinction risk throughout the foreseeable future.

5.3. Overall Extinction Risk Assessment

Guided by the results from their demographics risk and threats assessments, each ERA Team member applied their professional judgment to rate the overall extinction risk of *P. meandrina* across its range, using the definitions below, assuming that RCP8.5 is the most likely climate change scenario over the foreseeable future (now to 2100). In contrast to the demographic risk and threats ratings, extinction risk was rated using the "likelihood point" method, whereby each Team member had 10 'likelihood points' that could be distributed among the three extinction risk categories. The likelihood point method allows expression of uncertainty by Team members: For example, all 10 points could be assigned to one extinction risk category if uncertainty is low, or the 10 points could be distributed among all three extinction risk categories if uncertainty is high (NMFS 2017a). Table 9 shows the results of the Team's draft and final ratings:

- Low risk: A species may be at low risk of extinction if it is not facing threats that result in declining trends in distribution, abundance, productivity, or diversity. A species at low risk of extinction is likely to show stable or increasing trends in abundance and productivity with connected, diverse populations.
- Moderate risk: A species is at moderate risk of extinction if it is on a trajectory that puts it at a high level of extinction risk in the foreseeable future. A species may be at moderate risk of extinction due to projected threats or declining trends in distribution, abundance, productivity, or diversity.
- High risk: A species with a high risk of extinction is at or near a level of distribution, abundance, productivity, or diversity that places its continued persistence in question. The demographics of a species at such a high level of risk may be highly uncertain and strongly influenced by stochastic or depensatory processes. Similarly, a species may be at high risk of extinction if it faces clear and present threats (e.g., confinement to a small geographic area; imminent destruction, modification, or curtailment of its habitat; or disease epidemic) that are likely to create present and substantial demographic risks.

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Table 9. Draft, final, and mean results of 7-member ERA Team's ratings of *P. meandrina*'s overall extinction risk.

Extinction Risk	Number and % of Likelihood Points (± Standard Deviation) Draft rating	Number and % of Likelihood Points (± Standard Deviation) Final Rating	Number and % of Likelihood Points (± Standard Deviation) Mean of Both Ratings
Low	33.5 (47.9%)	24.5 (35.0%)	29 (41.4%)
Moderate	26.5 (37.9%)	39.5 (56.4%)	33 (47.1%)
High	10 (14.3%)	6 (8.6%)	8 (11.4%)
Total	70	70	n/a

The Low extinction risk category received 33.5 points (47.9%) in the draft rating, and 24.5 points (35.0%) in the final rating, for a mean of 29 points (41.4%; Table 9). Several Team members moved likelihood points from Low to Moderate for the final rating following the September 30, 2019, Team meeting at which the climate guidance was emphasized (i.e., assumption that RCP8.5 is most likely climate scenario from now to 2100). Species at Low extinction risk have stable or increasing trends in abundance and productivity with connected, diverse populations, and are not facing threats that result in declining trends in distribution, abundance, productivity, or diversity. Currently, *P. meandrina* has high and stable productivity and diversity, a very large distribution, and stable (five ecoregions) or decreasing (five ecoregions) abundance in the 10 ecoregions for which abundance trend data or information are available. The species has life history characteristics that provide resilience to disturbances and a high capacity for recovery. However, *P. meandrina* faces multiple threats, the worst of which are expected to greatly increase in the foreseeable future, and be exacerbated by the inadequacy of existing regulatory mechanisms. Thus, on one hand, most demographic factors provide arguments for Low extinction risk of *P. meandrina*, but on the other hand, recent declining abundance trends five of the 10 known ecoregions, as well as increasing threats under RCP8.5 in the foreseeable future, provide arguments for higher extinction risk.

The Moderate extinction risk category received 26.5 points (37.9%) in the draft rating, and 39.5 points (56.4%) in the final rating, for a mean of 33 points (47.1%; Table 9). Several Team members moved likelihood points from Low to Moderate, and one Team member moved likelihood points from High to Moderate, for the final rating following the September 30, 2019, Team meeting. Species at Moderate extinction risk are on a trajectory that puts them at a high level of extinction risk in the foreseeable future, due to projected threats or declining trends in distribution, abundance, productivity, or diversity. While *P. meandrina*'s distribution, productivity, and diversity are currently strong and stable, recent abundance trends are declining in half of the ecoregions for which data or information are available (five of 10 ecoregions). In addition, all threats are expected to worsen in the foreseeable future under RCP8.5, especially the most important threats to the species. Ocean warming and ocean acidification are projected to greatly worsen in the foreseeable future, resulting in increased frequency, magnitude, and severity of warming-induced coral bleaching, reduced coral calcification, and increased reef erosion. These climate change threats are likely to be exacerbated by localized threats such as fishing and land-based sources of pollution throughout much of *P. meandrina*'s range. All threats are expected to be exacerbated by the inadequacy of existing regulatory mechanisms.

The High extinction risk category received 10 points (14.3%) in the draft rating, and 6 points (8.6%) in the final rating, for a mean of 8 points (11.4%; Table 9). One Team member moved likelihood points from High to Moderate, for the final rating following the September 30, 2019, Team meeting in response to clarification regarding the temporal distinction between High

and Moderate extinction risk (see introduction to Section 5 above). Species at High extinction risk are those whose continued persistence is in question due to weak demographic factors, or that face clear and present threats such as imminent destruction. However, *P. meandrina* has strong demographic factors, with the possible exception of abundance. While climate change projections under RCP8.5 are likely to greatly worsen the most important threats to *P. meandrina* such as warming-induced bleaching in the foreseeable future (i.e., present to 2100), impacts so severe as to place *P. meandrina* at high extinction risk are not expected in the immediate future (i.e., present to 2030).

In conclusion, the information in the GSA (Smith 2019), this Status Review Report, and the ERA Team's results lead to the following conclusions regarding *P. meandrina*'s extinction risk currently and in the foreseeable future (now to 2100), assuming that RCP8.5 is the most likely climate change scenario: (1) the species is currently at low risk of extinction throughout its range, despite current threats, because of its strong demographic factors; and (2) as threats worsen in the foreseeable future, the species is expected to face a low to moderate risk of extinction throughout its range, moderated by its strong demographic factors. We conclude that *P. meandrina* is currently at low risk of extinction throughout its range, and that it will be at low to moderate risk of extinction throughout its range in the foreseeable future, assuming that RCP8.5 is the most likely climate change scenario.

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