**NCRMP Pacific Benthic metadata**

**How are the data calculated:**

NCRMP mean domain estimates $(\overline{D}_{st})$ were calculated for each indicator as the sum of the weighted means of each strata. Strata means $(\overline{D}_h)$ were calculated as the mean of all primary sample units (surveyed sites; $h$) within a given strata ($j$). Weighting values were calculated as the proportion of area for a given stratum relative to the entire sampling domain ($wh$; Smith et al 2011).

$$\overline{D}_{st} = \sum_h wh\overline{D}_h$$

$$\overline{D}_h = \frac{1}{nh}\sum_j D_{hj}$$

$$wh = \frac{Nh}{\sum_h N_h}$$

Sub-jurisdiction and sector means for individual species $(\overline{D}_{spp})$ were calculated for each indicator as the sum of the weighted means of each strata. ($w_h$; Smith et al 2011):

$$\overline{D}_{spp} = \sum_h w_h \overline{D}_{hspp}$$

where $w_h = \dfrac{Nh}{\sum N_h}$

Strata means $(\overline{D}_{hspp})$ were calculated as the mean for each species at all primary sample units (surveyed sites; $h_{spp}$) within a given strata ($j$):

$$\overline{D}_{hspp} = \frac{1}{nh_{spp}}\sum_j D_{h_{spp^j}}$$

Disease or bleaching prevalence were calculated as the percentage of colonies with any bleaching or disease ($S_{db}$) out of the total number of corals ($S_{total}$) for each species for all sites.

$$h_{spp} = \left(S_{db} \div \sum S_{total}\right) \times 100$$

Note these species specific subjurisdiction means are subsamples of the entire population and do not directly represent that species contribution to the composite sub-jurisdiction mean.

See Smith et al. (2011) for more details on the sampling design and equations for variance and standard error.

Smith SG, Swanson DS, Chiappone M, Miller SL, Ault JS. 2011. Probability sampling of stony coral populations in the Florida Keys. Environ Monit and Assess. 183:121-138. https://doi.org/10.1007/s10661-011-1912-2

**How are the data collected:**

*Sampling Design*

Coral abundance metrics are typically heterogeneous and vary in space according to environmental covariates, such as depth, topographic complexity, and patchiness of reef habitats (Smith et al. 2011; Swanson 2011). To account for such variation, a stratified random sampling design (StRS) was applied to more effectively and efficiently sample coral populations across defined strata (Cochran 1977; Swanson et al. 2018).

Jurisdictions are defined by geopolitical boundaries, e.g. U.S. states and territories. Subjurisdiction refers to reef systems surrounding islands, atolls or on submerged reef. Sub-island sector refers to island and sub-island spatial units. Sector boundaries reflect broad differences in oceanographic exposure, reef structure, local human population density and management status. Therefore, sub-island sectors only exist for larger populated islands such as Tutuila, Guam and the main Hawaiian Islands, which have different levels of management (e.g., protected areas) and exposure to oceanographic conditions as a means to sub-divide these broader geographic areas into smaller units (Heenan et al., 2017).

The stratification scheme for these surveys incorporates (1) three depth categories (shallow: 0–6 m; mid-depth: >6–18 m; and deep: >18–30 m); (2) sub-island sectors; (3) reef zone components, including back reef, lagoon, and fore reef. This scheme creates a survey domain that encompasses the majority of the mapped area of reef and hard bottom habitats from 0 to 30 m and provides a mechanism in which to allocate random samples across strata based on the stratum's proportional area and the variance structure of the population within the stratum.

Digital spatial databases of benthic habitats, reef zones, bathymetry, and marine reserve boundaries are integrated within a geographical information system (GIS) framework to facilitate the spatial delineation of the sampling survey domain and strata. A shapefile containing individual grid cells of size 50 m × 50 m containing more than 25% hard-bottom reef habitats is overlaid onto the survey domain. Grid cells are randomly selected as survey sites. Following a power analysis of colony density, Pacific NCRMP moved to a single stage sampling scheme in 2018, such that within each selected grid cell, a fixed area of 10 m² is surveyed along a single belt transect.

Since 2013, annual survey effort is determined based on the number of days spent at each island and the number of sites allocated mainly by strata area and variance of four target species (abundant and widespread, widespread but low abundance, and abundant but not widespread).

*Benthic survey components*
Surveys at each site are conducted in situ on SCUBA along one 30 m belt transect and include the following suite of observations:
- Adult coral colony (≥5 cm) abundance, size, partial mortality, and disease/condition
- Juvenile coral colony (<5 cm) abundance and size
- Benthic cover

*Adult coral colonies*
Adult coral colonies (≥5 cm) are surveyed within four (1.0 m × 2.5 m) segments at 5 m increments along a single 30 m transect in the following manner: 0−2.5 m (segment 0); 5.0−7.5 m (segment 5); 10−12.5 m (segment 10); and 15−17.5 m (segment 15). The combined survey area of the segments is 10 m² per site. In this study design, replicate segments are used to capture heterogeneity in benthic communities rather than quantify within transect variance. All colonies whose center falls within 0.5 m on either side of each transect line within each segment, are identified to lowest taxonomic level possible (genus or species), measured for size (maximum diameter to nearest cm), morphology
noted, and assessed for partial mortality and condition. Note that bottom time and/or air limitations on SCUBA may reduce the number of completed segments from four to three, particularly at deep sites where corals are abundant. A minimum of three completed segments is the target.

Partial mortality is estimated as percent of the colony in terms of old dead and recent dead, and the cause of recent mortality (or recent tissue loss) is identified when evident. Colony condition, including disease (i.e., all lesions other than recent tissue loss) and bleaching (medium to severe pigmentation loss). The lowest taxonomic level for coral taxa is genus, except for a select number of species that can be consistently identified to species by all divers conducting the surveys. The species list may change for each survey year depending on the experience and training of the benthic divers conducting the surveys.

*Juvenile coral colonies*
Juvenile coral colonies (< 5 cm) are surveyed within three (1.0 m × 1.0 m) segments along the same transect: 0−1.0 m (segment 0); 5.0−6.0 m (segment 5); and 10.0−11.0 m (segment 10). The combined survey area of the segments is 3 m² per site. Juvenile colonies are distinguished in the field by a distinct tissue and skeletal boundary (not a fragment or remnant of larger colony). The size of each juvenile colony larger than 0.5 cm is measured by recording the maximum diameter to the nearest 0.5 cm. Similar to adult corals, juvenile corals are identified to genus given that in most cases, juvenile corals will likely be too small to be positively identified to the species level.

*Benthic cover*

Estimates of benthic cover are generated from benthic substrate photographs (hereafter referred to as photoquadrats), which are taken along the same 30 m transect at the demographic surveys at each site. Photoquadrats are collected at 1 m intervals along one side of the transect line, starting at the 1 m mark, for a total of 30 photoquadrats per site. Digital images (3-10 MB and 0.7 to 1 $m^{-2}$ per image) were taken with a Canon PowerShot SD1200IS (2013-2014), Canon PowerShot S110 (2015-2017), and Canon PowerShot G9x (2018-present).Benthic cover data were extracted from images using Coral Point Count with extensions (2013-2014) and the web-based image annotation tool, CoralNet (Beijbom et al., 2015) (2015-2019). The benthic elements falling directly underneath each point are identified to two functional group levels: Tier 1 (e.g., hard coral, soft coral, macroalgae, turf algae), and Tier 2 (hard coral by morphology: massive, branching, foliose, encrusting, etc.). The standard operating procedures for the analysis of benthic substrate imagery can be accessed at Lozada-Misa et al. (2017), which includes the codes for Tiers 1 and 2.

**Please refer to:**
Winston, M., Couch, C., Huntington, B. and Vargas-Ángel, B., 2020. Ecosystem Sciences Division Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Benthic Surveys, 2019 Update.