# Hanauma Bay data for Bates et al. Pan-Env't collaboration

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### Part 1: Water clarity

**Project summary** The goal of this study (led by K. Rogers and S. Severino) is to quantify the suspended sediment in the water column in the absence of visitors (snorkelers and waders) to determine if this is a limiting factor to coral health.

Corals utilize light to produce their energy source, therefore, if the water is more turbid (murky) the corals have less light available from which to harvest their energy This could also mean they have to rely on active feeding strategies to make up this defeiit. If the coral cannot produce enough food or collect enough food from the water column, overall health will decrease.

In addition to light limitation, sedimentation is a threat to coral reefs for two main reasons: (1) Sediment falling onto live coral tissue causes them to use energy to produce mucus to slough the sediment off their tissues. The production of this mucus uses energy that could otherwise be utilized for increased fecundity in reproduction and/or resilience in the face of other stressors. (2) Large particles of sand that have been kicked up by a snorkeler or wader could fall onto live coral tissue and in the washing back-and-forth in the waves can act as sandpaper scraping the delicate tissue, acting like sandpaper. This process is referred to as 'sand scour'. Not only does this decrease the corals' overall health, but it can also leave them susceptible to infection and disease.

**Methods** In addition to sediment traps, another way we can study sediment is by looking at how much of it is suspended in the water column. To quantify suspended sediment, we use a white disk that is attached to a transect tape and suspended horizontally between two snorkelers. Snorkeler 1 holds the white disk stationary as Snorkeler 2 swims away with the meter tape. Snorkeler 2 swims away until the white disk disappears from sight and the distance value on the measure tape is recorded. Snorkeler 2 swims further away from the white disk, to eliminate bias, and then turns back around and swims toward the white disk again. On the way back toward the disk, Snorkeler 2 will record the distance on the measure tape when the white disk comes back into vision. The average of these two values is termed the "secchi disk water clarity" value. This method is a visual representation of water clarity and is subjective, since vision is unique between observers. It is also important to note the environmental conditions during the time of sampling, as wave action, cloud cover, and tidal coefficient can be influential in water clarity values.

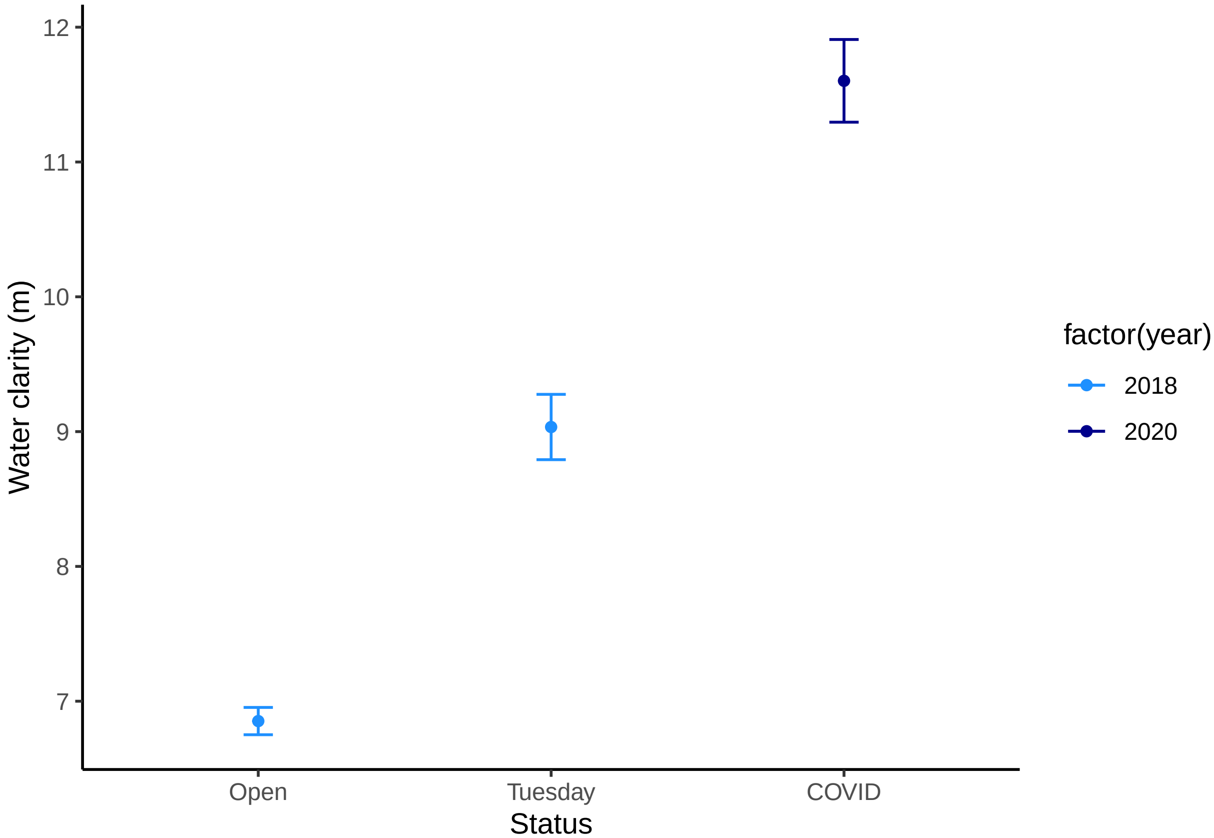
We measured water clarity over three treatments:

- "Open", days in 2018 in which an average of ~3000 visitors per day are present
- "Tuesday", the weekly closures in 2018 in which no visitors are present
- "COVID", the long-term closure in 2020 in which no visitors are present

In order to explore responses before vs. during COVID, while accounting for temporal autocorrelation in the data, we used a temporal autocorrelation model to account for this time series. We did so using the 'gls' function in the package 'nlme', where the autocorrelation term simply accounts for the temporal trend, but our interest is in any post-COVID difference.

#### Data summary

```
##    status year   n      mean       sd        se
## 1   COVID 2020 144 11.602083 3.681469 0.3067891
## 2    Open 2018 544  6.852574 2.360768 0.1012171
## 3 Tuesday 2018 224  9.034062 3.625156 0.2422159
```




**Results**

***Figure 1: Comparison of water clarity over days in which Hanauma Bay was open to the public (2018; "Open"), closed for one day per week to the public (2018; "Tuesday"), and closed long-term to the public due to the COVID-19 lockdown (2020; "COVID").***

```
## Generalized least squares fit by REML
##   Model: water_clarity_m ~ status_factor
##   Data: claritydata_short
##        AIC      BIC    logLik
##   3535.858 3564.732 -1761.929
##
## Correlation Structure: ARMA(0,2)
##  Formula: ~1 | time
##  Parameter estimate(s):
##     Theta1    Theta2
## 0.9983220 0.5698874
##
## Coefficients:
##                          Value Std.Error  t-value p-value
## (Intercept)           6.794558 0.1751549 38.79172       0
## status_factorCOVID    4.705760 0.3756925 12.52556       0
## status_factorTuesday 2.180140 0.3243238  6.72211       0
##
```

```
##  Correlation:
##                      (Intr) s_COVI
## status_factorCOVID   -0.466
## status_factorTuesday -0.540  0.252
##
## Standardized residuals:
##         Min          Q1         Med          Q3         Max
## -3.37919606 -0.80235083 -0.03803782  0.72627519  4.23401321
##
## Residual standard error: 2.485893
## Degrees of freedom: 912 total; 909 residual
```

**Questions**

1. Autocorrelation term ("time") is based on number of **days** since first survey date (t = 0) because there are only two years (2018 and 2020) in the study. Months seemed like the preferable unit of time to use for the autocorrelation term, but I had great headaches trying to calculate months since t = 0, so I went with days since t = 0 instead. However, I'm not sure if this is OK. Advice welcome.
2. We have two pre-COVID treatments: "Open" (when the bay is open to the public) and "Tuesday" (when it is closed weekly to the public, but before COVID). I've left both pre-COVID treatments in and set "Open" as the reference treatment, but can remove "Tuesday" if it's a problem. Let me know if so.

**Interpretation** As compared to measurements of water clarity from 2018, insore areas of Hanauma Bay are 42% clearer during the 2020 COVID-19 closure than on a day open to the public, and 18% clearer during the COVID-19 closure than on Tuesdays when the bay is closed to the public. The bay is significantly clearer during this closure, which could be the result of having consecutive days of no visitor use. This could be indicative that the smallest sediment particles are taking longer than the 24hr closure on Tuesdays to settle out of the water column. The clearer water during the closure may allow corals to produce more energy for themselves which could lead to higher resilience in the face of other stressors.

It is also worth noting that because our surveys occurred with a ~1.5 year gap, it is possible that inter-annual factors may also affect these results.

### Part 2: Monk seal presence

**Project summary** The goal of this study (led by K. Rogers and S. Severino) is to quantify the presence of endangered Hawaiian monk seals at Hanuama Bay in the presence and absence of tourists (snorkelers and waders) to determine if visitor presence affects habitat use by monk seals.

A prolonged decline of the Hawaiian monk seal population in the Northwestern Hawaiian Islands (NWHI) occurred after the late 1950s, lasting until very recently. This decline has been attributed to a number of factors, but low juvenile survival, likely related to inadequate prey availability, has been found to be the primary driver of the decline during the past 25 years. The Hawaiian monk seal population is now estimated to be ~1400 seals, with ~1100 seals in the Northwestern Hawaiian Islands and ~300 seals in the main Hawaiian Islands (the latter of which is where Hanuama Bay is situated). (Source: NOAA)

**Methods** People ("people_per_count_n") refers to the average number of humans counted on the beach or in the water from three daily counts (8 am, 11 am and 2 pm) within the entire bay. Number of monk seals ("seals_n") refers to the total number of seals observed over all three daily counts. Seals may have been present at one or more counts; the same seal was only counted once if it appeared over more than one count. Note that one day (10-Jun-2018) had only two daily counts, thus it is possible that a seal was present at the 2pm count but was not observed.

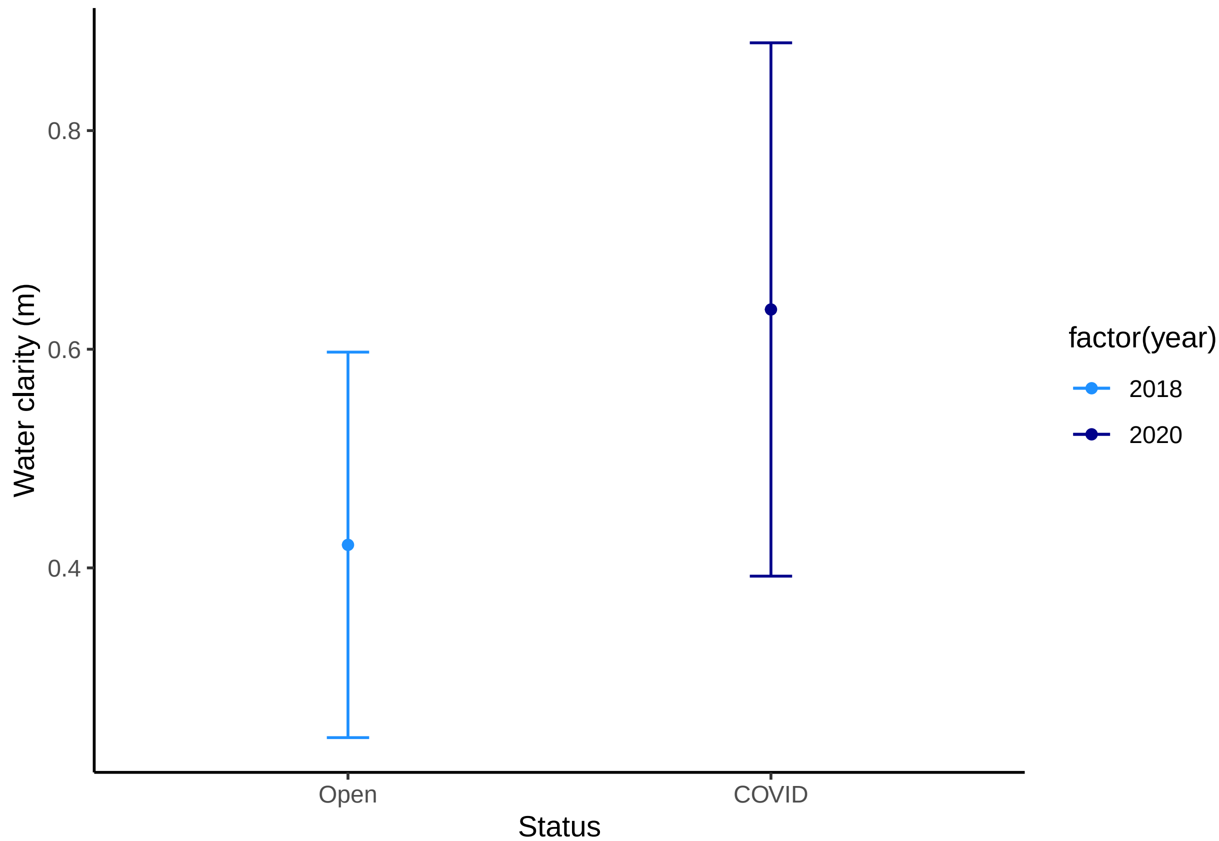
We measured seal presence over two treatments:

- “Open”, days in 2018 in which an average of ~3000 visitors per day are present
- “COVID”, the long-term closure in 2020 in which no visitors are present

In order to explore responses before vs. during COVID, while accounting for temporal autocorrelation in the data, we used a temporal autocorrelation model to account for this time series. We did so using the ‘gls’ function in the package ‘nlme’, where the autocorrelation term simply accounts for the temporal trend, but our interest is in any post-COVID difference.

### Data summary

```
##   status year  n      mean        sd        se
## 1  COVID 2020 11 0.6363636 0.8090398 0.2439347
## 2   Open 2018 19 0.4210526 0.7685332 0.1763136
```




### Results

***Figure 2: Comparison of monk seal presence over days in which Hanauma Bay was open to the public (2018; “Open”) vs. closed long-term to the public due to the COVID-19 lockdown (2020; “COVID”).***

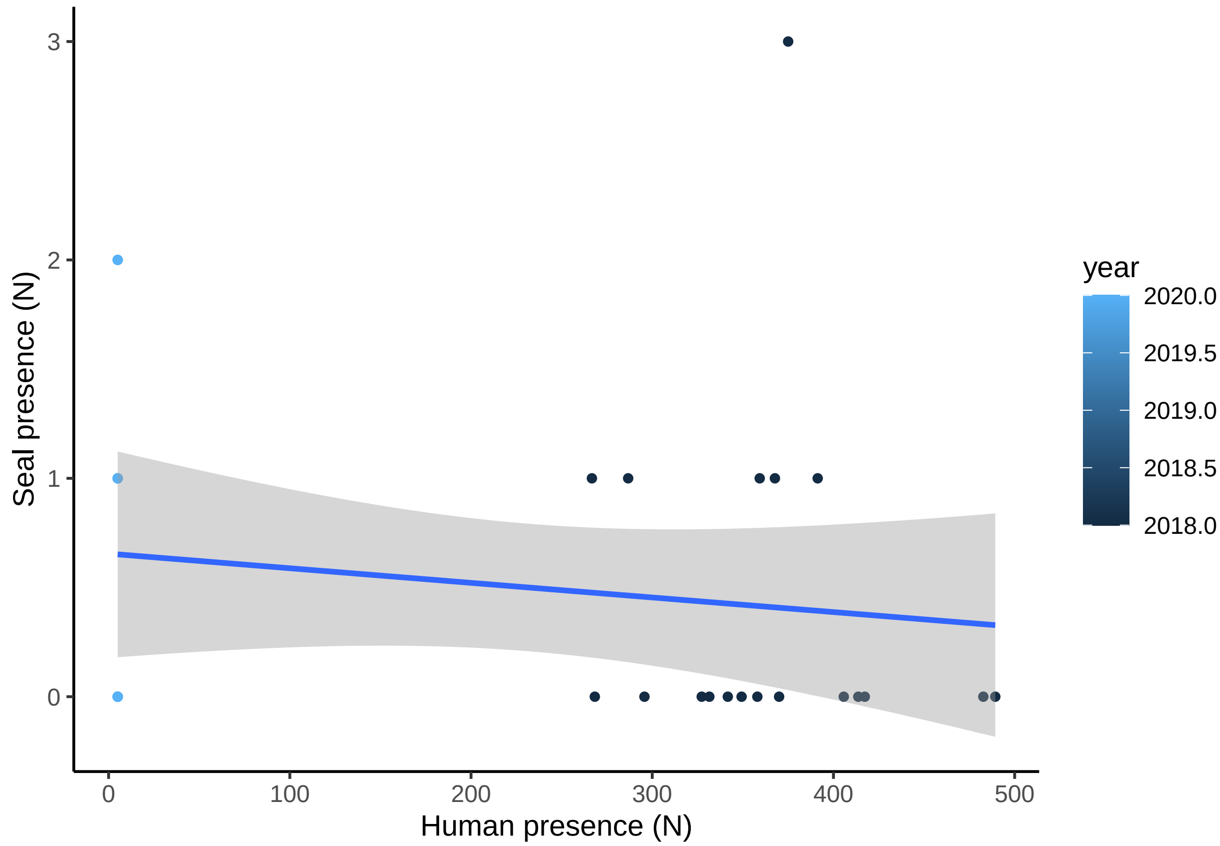



***Figure 3: Comparison of monk seal presence as a fucntion of the average number of visitors to the bay from thrice-daily counts.***

```
## Generalized least squares fit by REML
##   Model: seals_n ~ status_factor
##   Data: sealdata_short
##        AIC      BIC    logLik
##   81.12122 87.78224 -35.56061
##
## Correlation Structure: ARMA(0,2)
##  Formula: ~1 | time
##  Parameter estimate(s):
## Theta1 Theta2
##      0      0
##
## Coefficients:
##                         Value Std.Error   t-value p-value
## (Intercept)         0.4210526 0.1796877 2.3432473  0.0264
## status_factorCOVID 0.2153110 0.2967444 0.7255773  0.4741
##
##  Correlation:
##                    (Intr)
## status_factorCOVID -0.606
##
## Standardized residuals:
##        Min         Q1        Med          Q3         Max
## -0.8124755 -0.5375778 -0.5375778  0.6704450  3.2926640
```

```
##
## Residual standard error: 0.7832404
## Degrees of freedom: 30 total; 28 residual
```

**Interpretation** The presence and absence of monk seals at the Bay began being recorded during a pre-COVID study in 2018. When comparing monk seal presence during the COVID-19 closure to that of the 2018 studies, we see an increase in presence of monk seals in the bay, however, this is not statistically significant due to the low numbers of sampling dates.

It is also worth noting that because our surveys occurred with a ~1.5 year gap, it is possible that inter-annual factors (such as population size changes, etc.) may also affect these results.