#### Functional group multivariate regression with random intercept for site

# fit\_re

Model:

* Bayesian multivariate regression with four negative binomial models run jointly
  + Response variables: each of the four functional groups (Herbi, Meso, Inverti, and HTLP)
* Link function: log(mu) -> expected counts are modelled on the log scale
* Shape is modeled with identiy link -> allows for dispersion to vary with group

Formula

* Each response modeled as: Functional group ~ Classifciation (1 | p | site)
* Fixed effect: classification (fringing, pinnacle, shipwreck)
* Random intercept for each site, with a group level correlation structure across the functional groups
* **Hierarchical model**allows for site-level variation and correlation between groups

Data

* 280 observations (surveys!)
* 6000 post warmup posterior draws (4 chains x 1500 post-warmup draws)
* All Rhat = 1.00, and effective sample sizes (ESS) are high → the model has converged well.

Fixed effects (Classifcation)

These are log-scale effects:

| Response | Intercept (Shipwreck) | Fringing Effect | Pinnacle Effect |
| --- | --- | --- | --- |
| Herbivore | 4.77 | +0.44 | +0.63 |
| Invertivore | 4.37 | –0.02 | +0.51 |
| Mesopredator | 5.20 | –0.54 | +0.40 |
| HTLP | 3.90 | –0.99 | +0.18 |

Interpretation:

* **Shipwreck** is the reference level (the intercept)
* Fringing reefs show:
* Slight **increase** in herbivores (+0.44), but 95% CI overlaps 0
* Fewer mesopredators (–0.54) and much fewer HTLPs (–0.99)
* Pinnacles show:
* More herbivores, invertivores, and mesopredators (positive effects)
* Slight increase in HTLPs (+0.18), but not statistically clear

Overall:  
Shipwrecks are intermediate, pinnacles are richer in fish, and fringing reefs show lower abundance for higher trophic groups.

Distributional Parameters:

* Herbivores: 2.07 shape estimate => lower overdispersion
* Mesopredators: 1.17 => More overdispersed
* HTLPs: 1.30 => Highest variability in counts across surveys *(this is why we used a negative binomial tho)*

Summary:

* There is strong **site-level variation** in fish abundance, and this variation is correlated across trophic groups.
* **Pinnacles** tend to support **higher fish abundances**, particularly mesopredators and invertivores.
* **Shipwrecks** are intermediate, and **fringing reefs** tend to support **lower abundance** of higher trophic groups (especially HTLPs).
* The **posterior uncertainty** is relatively wide for many effects (CI spans 0), suggesting ecological trends but not high statistical certainty in all contrasts.

Other things to note from random effects (for location) [i.e. Multilevel hyperparameters]

*Looking at Standard Deviations (sd)*

* Sites with more herbivores also tend to have more invertivores
* Herbivores and invertivores vary moderately across sites
* More variation in mesopredators counts between sites
* HTLPs vary the most across sites
* => Some functional groups are more spatially variable than others

*Correlations between site intercepts (cor)*

* These indicate whether sites that are high in one group also tend to be high in others
* General positive corvariance => good sites are good across groups, rather than trader-offs (e.g. predator-dominated vs grazer-dominated systems)

## from fit\_re – **predicted values**

| Functional Group | Shipwreck | Fringing | Pinnacle |
| --- | --- | --- | --- |
| Herbivore | 118 | 183 | 222 |
| Invertivore | 79 | 78 | 132 |
| Mesopredator | 182 | 106 | 272 |
| HTLP | 50 | 18 | 59 |

Predicted abundance estimates revealed functional group-specific patterns across reef types. Herbivores were most abundant at pinnacles (222), followed by fringing reefs (183) and shipwrecks (118). Invertivores showed similar abundance at shipwrecks (79) and fringing reefs (78), but were more numerous at pinnacles (132). Mesopredators exhibited the strongest pattern, with much higher predicted abundance at pinnacles (272) compared to shipwrecks (182) and fringing reefs (106). Higher trophic level predators (HTLPs) were least abundant on fringing reefs (18), and most abundant at pinnacles (59), with shipwrecks intermediate (50). These patterns support the hypothesis that shipwreck assemblages more closely resemble pelagic pinnacles, particularly for higher trophic groups.

Possible interpretations:

* Herbs: highest at pinnacles then fringing then shipwrecks
  + Suggests reef-associated grazers benefit **from natural reef structure** more than wrecks.
* Invertivores: similar between fringing and shipwrecks, substantially higher at pinnacles
  + Indicates pelagic pinnacle systems may offer more foraging opportunities for invertivores.
* Mesopredators: Highest at pinnacles (272)=> shipwrecks (182) => Substantially lower at fringing reefs (106).
  + Suggests that pinnacles and shipwrecks provide habitat/refuge or hunting opportunities for these groups, compared to fringing reefs.
* HTLPs: Pinnacles & Shipwrecks similar ==> lowest at fringing reefs (59-50 v 18)
  + Clearest signal that fringing reefs may lack the structural complexity needed to support top predators

#### Looking at using “zone” (nearshore vs pelagic) instead of fringing vs pinnacle

Zone Effects (relative to nearshore)

| Functional Group | Pelagic Effect | Wreck Effect | Interpretation |
| --- | --- | --- | --- |
| Herbivore | +0.40 | –0.42 | More herbivores at pelagic, fewer at wreck |
| Invertivore | +0.16 | –0.21 | Small effect, not clearly different from nearshore |
| Mesopredator | +0.60 | +0.21 | More mesopredators at pelagic (stronger) and wreck (weaker) |
| HTLP | +1.03 | +0.65 | Higher top predator abundance at both pelagic and wreck zones |

Credible intervals are wide, so these are trends more than strict statistical conclusions.

**Interpretation**

* **Pelagic zones** (likely pinnacles) support **higher predicted abundance across all functional groups**, particularly HTLPs and mesopredators.
* **Wreck zones** (artificial reefs) support **more mesopredators and HTLPs** than nearshore reefs, but **fewer herbivores**.
* **Nearshore reefs** appear less supportive of higher trophic levels.

Zone-based analysis revealed similar patterns to the classification model. Pelagic sites had higher predicted abundances of all functional groups compared to nearshore reefs, particularly mesopredators (+0.60) and higher trophic level predators (+1.03). Wreck sites also supported more mesopredators and HTLPs than nearshore zones, but were characterized by lower predicted herbivore abundance (–0.42). ~~These results reinforce the view that shipwrecks share stronger ecological resemblance with pelagic pinnacles than with fringing reefs.~~ These results suggest that for higher trophic levels (mesopredators and HTLPs), fish assemblages on shipwrecks more closely resemble those at pelagic pinnacles than at fringing reefs. However, herbivores and invertivores are less abundant on shipwrecks than on natural reefs, indicating that artificial reefs may not fully replicate the ecological conditions of either natural reef type.

## sanity check: are they actually resembling pelagic pinnacles?

**Shipwreck predicted abundances** are *generally intermediate* between fringing and pinnacle for most groups.

| **Group** | **Fringing** | **Pinnacle** | **Shipwreck** |
| --- | --- | --- | --- |
| Herbivore | 183 | 222 | 118 ← clearly lower |
| Invertivore | 78 | 132 | 79 ← similar to fringing |
| Mesopredator | 106 | 272 | 182 ← intermediate, leaning toward pinnacle |
| HTLP | 18 | 59 | 50 ← much closer to pinnacle |

* **HTLPs and mesopredators** on shipwrecks are closer to pinnacles than fringing reefs, both in direction and magnitude.
* **Invertivores** on shipwrecks look **identical** to fringing reef values.
* **Herbivores** are clearly **lowest** on shipwrecks.

Sooooo….

* For **mesopredators and HTLPs**, the data clearly support this.
* For **invertivores**, the resemblance is ambiguous — shipwrecks are nearly identical to fringing reefs.
* For **herbivores**, **shipwrecks are the lowest** — they resemble neither closely, and diverge especially from pinnacles.

“These results suggest that **for higher trophic levels** (mesopredators and HTLPs), fish assemblages on shipwrecks more closely resemble those at pelagic pinnacles than at fringing reefs. However, herbivores and invertivores are less abundant on shipwrecks than on natural reefs, indicating that artificial reefs **may not fully replicate the ecological conditions of either natural reef type**.”

## species specific analysis = summary(results\_all\_species$fit\_mv)

Model Structure

* Each species modeled separately as:  
  Abundance ~ Classification
* Distribution: Negative binomial (with separate overdispersion estimates per species)
* Reference level: **Fringing reefs**
* Effects shown for **Pinnacle** and **Shipwreck** compared to Fringing

**Species significantly more abundant at Shipwrecks** (vs. Fringing)

| **Species** | **Shipwreck Effect (Estimate ± SE)** | **Interpretation** |
| --- | --- | --- |
| **Sweetlips** | +1.44 ± 0.35 | Clear increase on shipwrecks |
| **Large Snapper** | +2.51 ± 0.30 | Very strong increase |
| **Small Snapper** | +1.17 ± 0.30 | Strong increase |
| **Trevally** | +0.89 ± 0.24 | Moderate increase |
| **Emperorfish** | +0.53 ± 0.22 | Slight increase |
| **Batfish** | +0.92 ± 0.49 | Credible interval overlaps 0, but suggestive |
| **Squirrel/Soldierfish** | +0.00 ± 0.31 | Estimate = 0, highly uncertain |
| **Cleaner Wrasse** | **–1.09 ± 0.18** | Strongly less abundant |
| **Thicklip Wrasse** | **–1.84 ± 0.19** | Strong decline |
| **Slingjaw Wrasse** | **–2.34 ± 0.23** | Very strong decline |
| **Butterflyfish** | **–0.86 ± 0.13** | Clear decline |
| **Triggerfish** | –0.62 ± 0.18 | Moderate decline |
| **Small Grouper** | **–0.76 ± 0.15** | Clear decline |

Interpretation:

* Shipwrecks favor **predatory and schooling fish** (snappers, trevally, sweetlips, emperors).
* They are **less suitable for reef-associated wrasses and butterflyfish**.

**Species significantly more abundant at Pinnacles**

| **Species** | **Pinnacle Effect (Estimate ± SE)** | **Interpretation** |
| --- | --- | --- |
| **Batfish** | +2.17 ± 0.37 | Strong increase |
| **Sweetlips** | +1.20 ± 0.28 | Strong increase |
| **Large Snapper** | +1.63 ± 0.24 | Strong increase |
| **Small Snapper** | +1.50 ± 0.24 | Strong increase |
| **Trevally** | +1.68 ± 0.18 | Strong increase |
| **Emperorfish** | +0.86 ± 0.17 | Moderate increase |
| **Squirrel/Soldierfish** | +1.44 ± 0.24 | Strong |
| **Parrotfish** | **–0.56 ± 0.11** | Decline |
| **Slingjaw Wrasse** | **–1.33 ± 0.14** | Strong decline |
| **Triggerfish** | **–0.34 ± 0.13** | Moderate decline |
| **Thicklip Wrasse** | **–0.62 ± 0.13** | Moderate decline |

Interpretation:

* **Pinnacles host large predatory and schooling fish**, similar to shipwrecks.
* Also have **fewer grazing species**, possibly due to less coral cover or limited foraging area.

Ecological Summary

* **Pinnacles and shipwrecks both support higher abundances of snappers, emperors, trevally, and sweetlips**.
* **Fringing reefs** are important for **wrasses, parrotfish, butterflyfish, and small groupers** — species tied to coral or fine-scale structure.
* **Shipwrecks replicate the predator assemblages of pinnacles**, but **lack the full reef community**, especially coral-dependent species.

Note: smallish sample size:

Classification Number\_of\_Surveys

1 Fringing 126

2 Pinnacle 105

3 Shipwreck 49

> survey\_level %>%

+ count(Site, Classification) %>%

+ arrange(desc(n))

# A tibble: 14 × 3

Site Classification n

<fct> <fct> <int>

1 White Rock Pinnacle 42

2 Twins Fringing 40

3 Red Rock Fringing 36

4 Green Rock Fringing 28

5 No Name Wreck Shipwreck 26

6 No Name Pinnacle Pinnacle 25

7 Sattakut Shipwreck 16

8 No Name AR Fringing 13

9 Hin Pee Wee Pinnacle 12

10 Chumphon Pinnacle 10

11 Aow Mao Fringing 9

12 Shark Island Pinnacle 8

13 Southwest Pinnacle 8

14 Aow Mao Wreck Shipwreck 7

IF WE CONTINUE TO SUM ACROSS SURVEYS - "Raw survey data included multiple observations per dive collected by individual observers. However, data were aggregated across observers within each site-date combination prior to analysis, resulting in a single summary count per survey. As such, within-survey variation was not explicitly modeled, and estimates reflect average site-date level abundances."