Bayesian multivariate regression:

**Zone-based multivariate negative binomial model with random intercepts by Site** (fit\_zone) and compare it to your previous **Classification-based model** (fit\_re).

**🧠 Model Fit (LOO Comparison)**

| **Model** | **elpd\_diff** | **se\_diff** | **Interpretation** |
| --- | --- | --- | --- |
| fit\_zone | 0.0 | 0.0 | ✅ Best (reference model) |
| fit\_re | −2.2 | 2.1 | ❌ Slightly worse, but not meaningfully different |

➡️ **Zone-based model fits slightly better** (by ~2 LOOIC units), but the difference is within the margin of error → **statistically equivalent fit**. That means **either model is acceptable**, and you should prefer the one that’s **more interpretable and ecologically relevant**.

**📊 Fixed Effects: Zone vs Wreck (Reference)**

| **Group** | **nearshore vs wreck (95% CI)** | **pelagic vs wreck (95% CI)** | **Interpretation** |
| --- | --- | --- | --- |
| Herbivore | +0.25 [−0.64, 1.14] | +0.77 [−0.30, 1.86] | Suggests higher herbivores on pelagic, but not significant |
| Invertivore | +0.09 [−0.70, 0.88] | +0.39 [−0.58, 1.32] | Weak, uncertain increase in pelagic |
| Mesopredator | −0.40 [−1.49, 0.68] | +0.34 [−1.08, 1.65] | Very wide CIs, no clear trend |
| HTLP | **−0.96 [−1.92, −0.01]** | +0.35 [−0.84, 1.51] | ✅ **Significantly lower HTLPs in nearshore vs wrecks** |

➡️ The **only statistically supported effect** is for **HTLPs**, which are **significantly less abundant in nearshore zones**than on wrecks.  
➡️ All other effects have wide 95% credible intervals that include 0 — i.e., **no strong evidence** of differences between zones.

**📈 Intercepts (Abundance on Wrecks)**

| **Functional Group** | **Log-scale Intercept** | **Approx. Mean Abundance** |
| --- | --- | --- |
| Herbivore | 4.85 | ~127 |
| Invertivore | 4.42 | ~83 |
| Mesopredator | 5.28 | ~197 |
| HTLP | 3.96 | ~53 |

➡️ Abundance structure is consistent: **Mesopredators > Herbivores ≈ Invertivores > HTLPs** on wrecks (baseline zone).

**📉 Site-level variation and group co-occurrence**

| **Random Effect (SD)** | **Estimate (95% CI)** | **Interpretation** |
| --- | --- | --- |
| Mesopredator SD | 0.78 [0.53, 1.17] | High variation between sites |
| HTLP SD | 0.66 [0.44, 1.01] | Moderate-high |
| Correlations | 0.57–0.82 across groups | Strong **positive co-occurrence** between functional groups |

➡️ Consistent with fit\_re, showing that **site-level differences drive much of the variation**, and functional groups tend to co-occur at high- or low-abundance sites.

**✅ Final Takeaways**

* fit\_zone performs **equally well or slightly better** than fit\_re in predictive fit.
* The only **statistically supported effect** is that **HTLPs are significantly less abundant on nearshore sites**compared to wrecks.
* Other effects (e.g., higher herbivores or invertivores on pelagic) are **suggestive but not conclusive**.
* **Site-level variation remains substantial**, emphasizing the importance of hierarchical structure.

> summary(fit\_zone)

Family: MV(negbinomial, negbinomial, negbinomial, negbinomial)

Links: mu = log; shape = identity

mu = log; shape = identity

mu = log; shape = identity

mu = log; shape = identity

Formula: Herbivore ~ Zone + (1 | p | Site)

Invertivore ~ Zone + (1 | p | Site)

Mesopredator ~ Zone + (1 | p | Site)

HTLP ~ Zone + (1 | p | Site)

Data: survey\_level (Number of observations: 271)

Draws: 4 chains, each with iter = 2000; warmup = 500; thin = 1;

total post-warmup draws = 6000

Multilevel Hyperparameters:

~Site (Number of levels: 15)

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk\_ESS Tail\_ESS

sd(Herbivore\_Intercept) 0.61 0.14 0.39 0.95 1.00 2448 3069

sd(Invertivore\_Intercept) 0.54 0.12 0.35 0.83 1.00 2822 3665

sd(Mesopredator\_Intercept) 0.78 0.16 0.53 1.17 1.00 2799 4045

sd(HTLP\_Intercept) 0.66 0.15 0.44 1.01 1.00 2865 3208

cor(Herbivore\_Intercept,Invertivore\_Intercept) 0.62 0.21 0.11 0.91 1.00 2711 3263

cor(Herbivore\_Intercept,Mesopredator\_Intercept) 0.57 0.21 0.05 0.88 1.00 2753 3665

cor(Invertivore\_Intercept,Mesopredator\_Intercept) 0.80 0.15 0.40 0.97 1.00 3521 4739

cor(Herbivore\_Intercept,HTLP\_Intercept) 0.62 0.21 0.11 0.91 1.00 2667 3686

cor(Invertivore\_Intercept,HTLP\_Intercept) 0.82 0.15 0.41 0.98 1.00 2845 4282

cor(Mesopredator\_Intercept,HTLP\_Intercept) 0.76 0.17 0.32 0.96 1.00 3552 3625

Regression Coefficients:

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk\_ESS Tail\_ESS

Herbivore\_Intercept 4.85 0.38 4.09 5.62 1.00 1781 2754

Invertivore\_Intercept 4.42 0.34 3.77 5.10 1.00 1928 3181

Mesopredator\_Intercept 5.28 0.48 4.36 6.25 1.00 1923 2686

HTLP\_Intercept 3.96 0.42 3.14 4.79 1.00 1929 3098

Herbivore\_Zonenearshore 0.25 0.45 -0.64 1.14 1.00 1479 2571

Herbivore\_Zonepelagic 0.77 0.54 -0.30 1.86 1.00 1745 2789

Invertivore\_Zonenearshore 0.09 0.39 -0.70 0.88 1.00 1826 3069

Invertivore\_Zonepelagic 0.39 0.48 -0.58 1.32 1.00 1772 3159

Mesopredator\_Zonenearshore -0.40 0.56 -1.49 0.68 1.00 1832 2682

Mesopredator\_Zonepelagic 0.34 0.69 -1.08 1.65 1.00 1962 2806

HTLP\_Zonenearshore -0.96 0.48 -1.92 -0.01 1.00 1861 2676

HTLP\_Zonepelagic 0.35 0.59 -0.84 1.51 1.00 1859 2801

Further Distributional Parameters:

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk\_ESS Tail\_ESS

shape\_Herbivore 2.15 0.18 1.82 2.50 1.00 11041 4016

shape\_Invertivore 1.83 0.15 1.55 2.15 1.00 11511 3951

shape\_Mesopredator 1.21 0.10 1.03 1.42 1.00 12801 4104

shape\_HTLP 1.44 0.12 1.21 1.69 1.00 10064 4632

Draws were sampled using sampling(NUTS). For each parameter, Bulk\_ESS

and Tail\_ESS are effective sample size measures, and Rhat is the potential

scale reduction factor on split chains (at convergence, Rhat = 1).

> loo\_compare(loo(fit\_re), loo(fit\_zone))

elpd\_diff se\_diff

fit\_zone 0.0 0.0

fit\_re -2.2 2.1

this output summarizes predicted fish **abundance by functional group and reef classification**, based on a log-linear model (likely Bayesian or GLMM), where:

* Intercept = baseline log abundance on **Shipwrecks**
* Effect = log-scale difference from Shipwrecks for each habitat type
* Predicted\_Log = Intercept + Effect = predicted log abundance
* Predicted = exponentiated abundance (on the natural scale)

**🧠 Interpretation by Functional Group:**

**1. Herbivores**

* **Shipwrecks**: Baseline (Intercept = 4.70 → ~110 individuals)
* **Fringing reefs**: +0.52 effect → ~185 individuals
* **Pinnacles**: +0.84 effect → ~255 individuals  
  ✅ **More herbivores on natural reefs**, especially pinnacles.

**2. Invertivores**

* **Shipwrecks**: ~69 individuals
* **Fringing reefs**: +0.54 → ~118 individuals
* **Pinnacles**: +1.00 → ~187 individuals  
  ✅ Clear increasing trend toward **pinnacle sites**.

**3. Mesopredators**

* **Shipwrecks**: ~147 individuals
* **Fringing reefs**: slight increase (~156)
* **Pinnacles**: +0.84 → **~340 individuals**  
  ⚠️ **Pinnacles dominate in mesopredator abundance**.

**4. HTLPs (Higher-Level Trophic Predators)**

* **Shipwrecks**: ~34 individuals
* **Fringing reefs**: *decrease* (−0.32) → ~25
* **Pinnacles**: +0.62 → ~64  
  ❗ **Lowest on fringing reefs**, **highest on pinnacles** — suggests top predators prefer structurally complex, pelagic-exposed habitats.

**🧾 Overall Patterns:**

* **Shipwrecks consistently have the lowest predicted abundance** across all groups.
* **Fringing reefs** support more herbivores and invertivores, but fewer top predators.
* **Pelagic pinnacles** are hotspots for **mesopredators and HTLPs**, likely due to higher structural relief, prey access, or exposure to oceanic currents.

$fit\_fg\_zi\_mv

Family: MV(zero\_inflated\_negbinomial, zero\_inflated\_negbinomial, zero\_inflated\_negbinomial, zero\_inflated\_negbinomial)

Links: mu = log; shape = identity; zi = identity

mu = log; shape = identity; zi = identity

mu = log; shape = identity; zi = identity

mu = log; shape = identity; zi = identity

Formula: Herbivore ~ Classification

Invertivore ~ Classification

Mesopredator ~ Classification

HTLP ~ Classification

Data: survey\_level (Number of observations: 132)

Draws: 4 chains, each with iter = 2000; warmup = 500; thin = 1;

total post-warmup draws = 6000

Regression Coefficients:

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk\_ESS Tail\_ESS

Herbivore\_Intercept 4.73 0.15 4.44 5.03 1.00 8016 4461

Invertivore\_Intercept 4.32 0.16 4.02 4.64 1.00 9204 4041

Mesopredator\_Intercept 5.19 0.20 4.82 5.60 1.00 9903 4409

HTLP\_Intercept 3.84 0.18 3.50 4.21 1.00 8937 4408

Herbivore\_ClassificationFringing 0.54 0.26 0.04 1.06 1.00 9385 4694

Herbivore\_ClassificationPinnacle 0.79 0.20 0.39 1.17 1.00 8419 5116

Invertivore\_ClassificationFringing 0.27 0.27 -0.24 0.80 1.00 8198 5079

Invertivore\_ClassificationPinnacle 0.55 0.21 0.13 0.95 1.00 9144 4950

Mesopredator\_ClassificationFringing 0.00 0.33 -0.63 0.68 1.00 8583 4570

Mesopredator\_ClassificationPinnacle 0.53 0.26 0.02 1.04 1.00 8555 4615

HTLP\_ClassificationFringing -0.56 0.31 -1.14 0.07 1.00 9000 4769

HTLP\_ClassificationPinnacle 0.44 0.24 -0.01 0.90 1.00 8518 4813

> print(pred\_df)

# A tibble: 12 × 6

Functional\_Group Classification Intercept Effect Predicted\_Log Predicted

<chr> <chr> <dbl> <dbl> <dbl> <dbl>

1 Herbivore Shipwreck 4.7 0 4.7 110.

2 Herbivore Fringing 4.7 0.52 5.22 185.

3 Herbivore Pinnacle 4.7 0.84 5.54 255.

4 Invertivore Shipwreck 4.23 0 4.23 68.7

5 Invertivore Fringing 4.23 0.54 4.77 118.

6 Invertivore Pinnacle 4.23 1 5.23 187.

7 Mesopredator Shipwreck 4.99 0 4.99 147.

8 Mesopredator Fringing 4.99 0.06 5.05 156.

9 Mesopredator Pinnacle 4.99 0.84 5.83 340.

10 HTLP Shipwreck 3.54 0 3.54 34.5

11 HTLP Fringing 3.54 -0.32 3.22 25.0

12 HTLP Pinnacle 3.54 0.62 4.16 64.1

how each functional‐group’s odds (relative to Herbivores) change on Pinnacle and Shipwreck sites compared to Fringing reefs:

| **Functional Group** | **Comparison** | **Log‑Odds Δ** | **Odds Ratio (95% CI)** | **Significant?** |
| --- | --- | --- | --- | --- |
| **Invertivore** | Pinnacle vs Fringing | +0.15 | 1.16 (1.07 – 1.25) | Yes |
|  | Shipwreck vs Fringing | +0.13 | 1.14 (1.05 – 1.23) | Yes |
| **Mesopredator** | Pinnacle vs Fringing | +0.00 | 1.00 (0.94 – 1.06) | No |
|  | Shipwreck vs Fringing | +0.21 | 1.23 (1.16 – 1.32) | Yes |
| **HTLP** | Pinnacle vs Fringing | +0.79 | 2.20 (2.08 – 2.36) | Yes |
|  | Shipwreck vs Fringing | +0.87 | 2.39 (2.25 – 2.56) | Yes |

*Log‑Odds Δ* = model coefficient;  
*Odds Ratio* = exp(Log‑Odds Δ).

**Plain‑Language Summary**

* **Invertivores** are about **16% more likely** (vs Herbivores) on Pinnacles and **14% more likely** on Shipwrecks than on Fringing reefs.
* **Mesopredators** show **no change** on Pinnacles but are **23% more likely** on Shipwrecks compared to Fringing reefs.
* **HTLP** fish are **over twice as likely** on both Pinnacles and Shipwrecks (120–140% increase) relative to Fringing reefs.

**Overall:** Shipwreck assemblages—particularly for Invertivores and HTLP fish—look much more like Pelagic Pinnacles than like Fringing reefs, supporting the idea that artificial wrecks mimic the fish composition of pinnacles.