Identifying reef habitat states using machine learning applied to the global *Reef Life Survey* dataset

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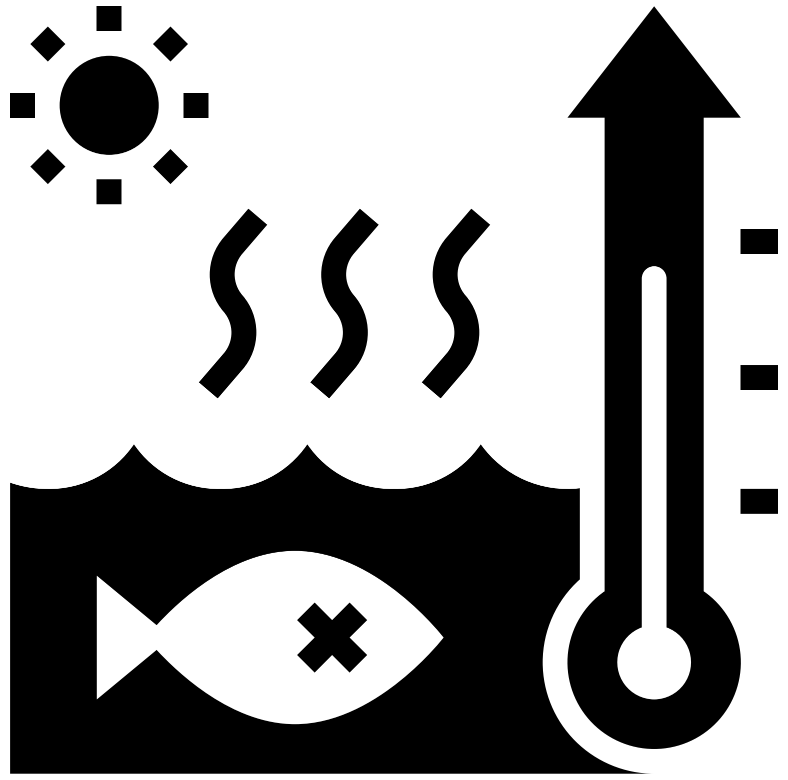
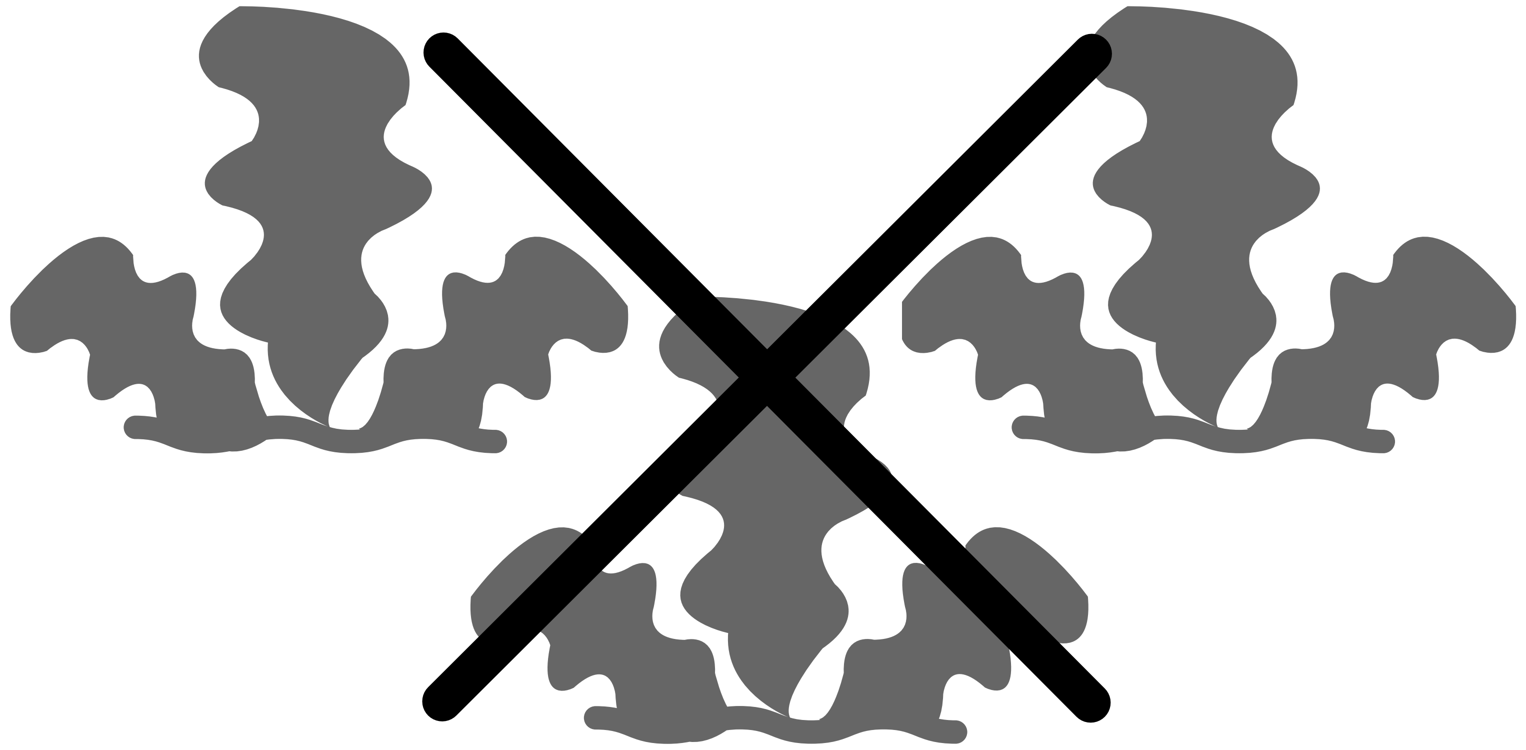
Introduction

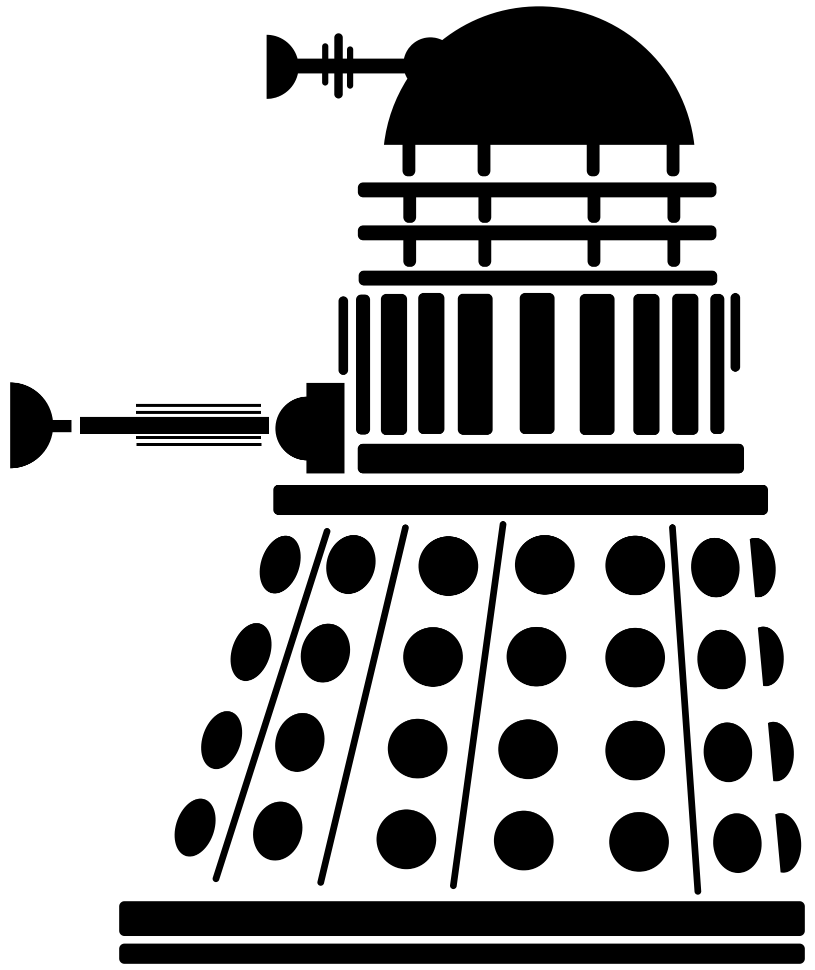
Coastal ecosystems are affected by multiple stressors



Climate change

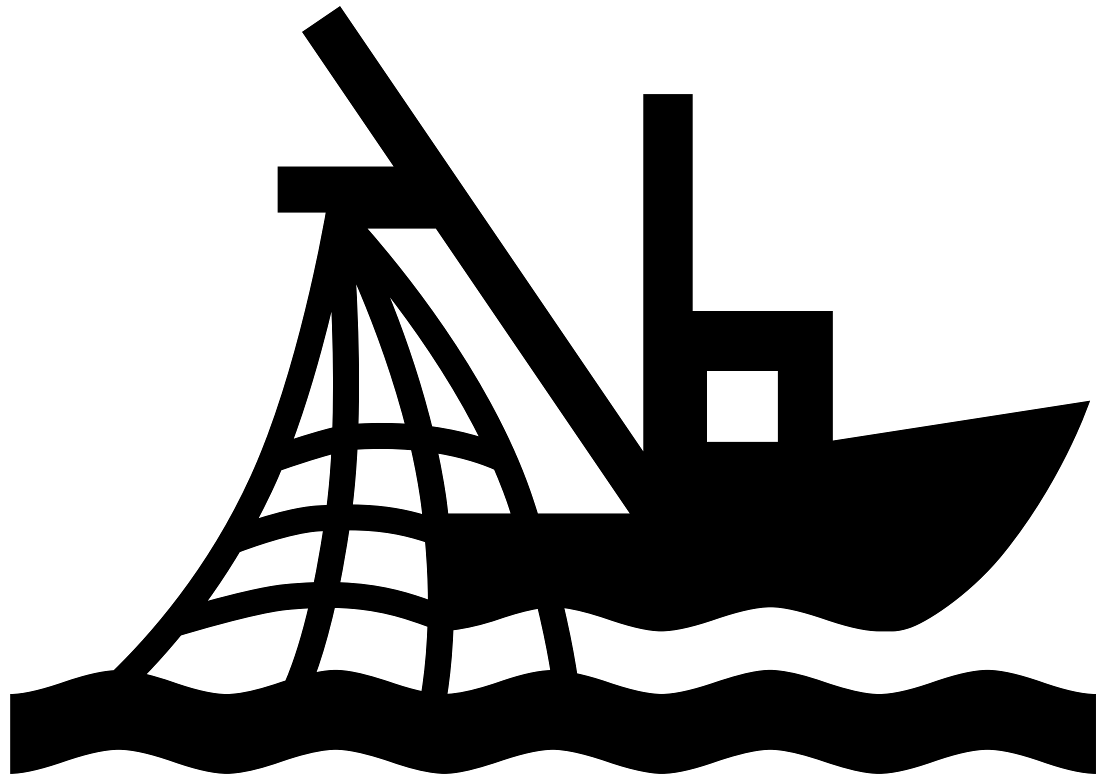


Habitat loss



Invasive species

Pollution



Overfishing

A typical exemple of alternative ecological states

Marine forests

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- Complex & heterogenous tri-dimensional habitats
- High species richness
- High persistence

Sea-urchins barrens

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- Homegenous and low complexity habitats
- Low species diversity
- High persistence

Bernal-Ibáñez *et al.* 2021

Challenges of identifying alternative ecological states

1. Complexity of ecosystems:
    - Many components and processes maintain an ecosystem in a given state

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Challenges of identifying alternative ecological states

1. Complexity of ecosystems:
2. Variability of ecosystems:
   - Ecosystems are dynamics and can exhibit natural fluctuations
   - Sparse observations

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Challenges of identifying alternative ecological states

1. Complexity of ecosystems
2. Variability of ecosystems
3. Changes between alternative states can be fast and non-linear
    - Difficulties to identify threshold and/or observe transitions

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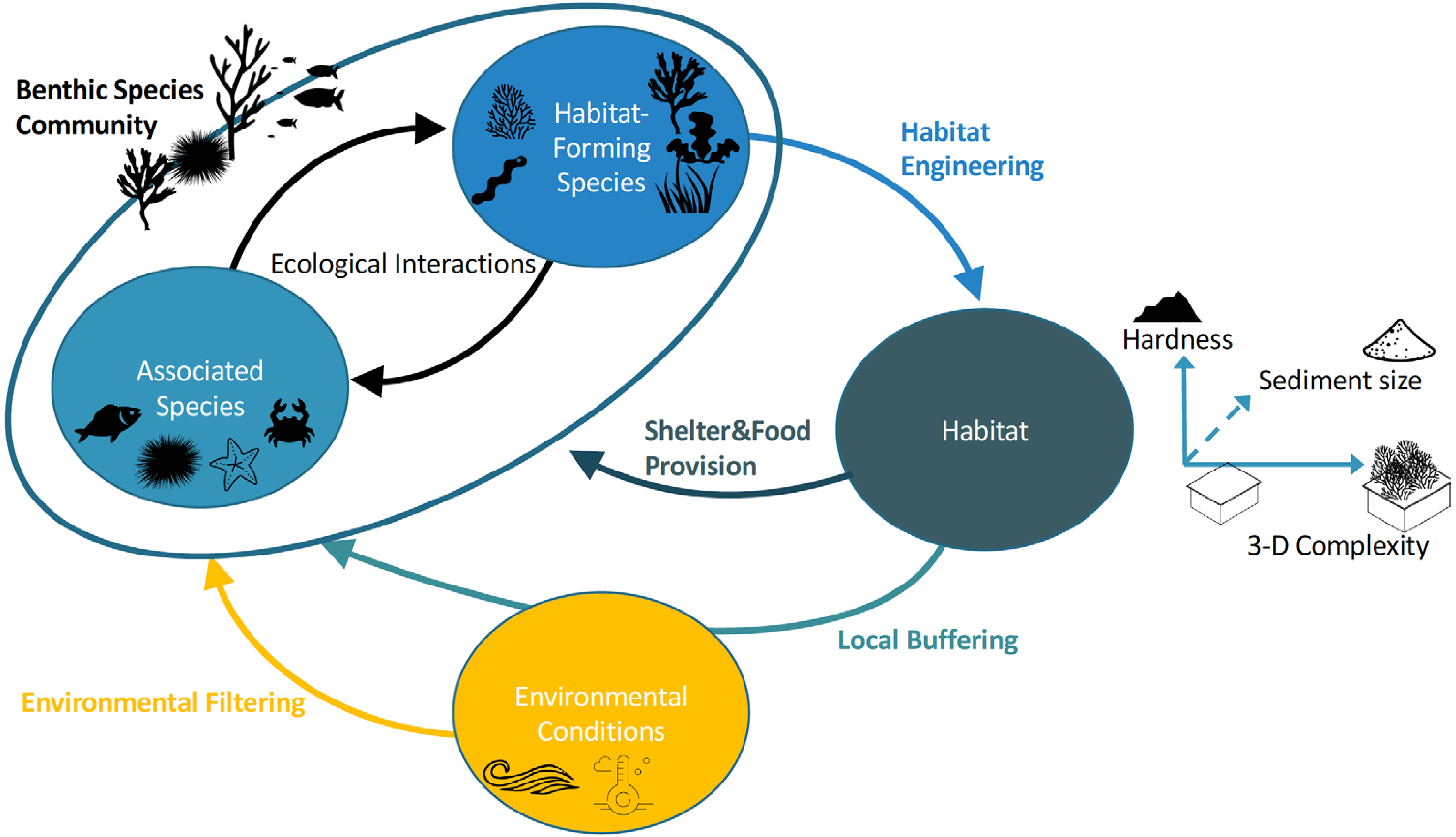
A need for a systematic assessment of dominant benthic habitat states



Dominant habitat types can serve as proxys for ecological states on reef systems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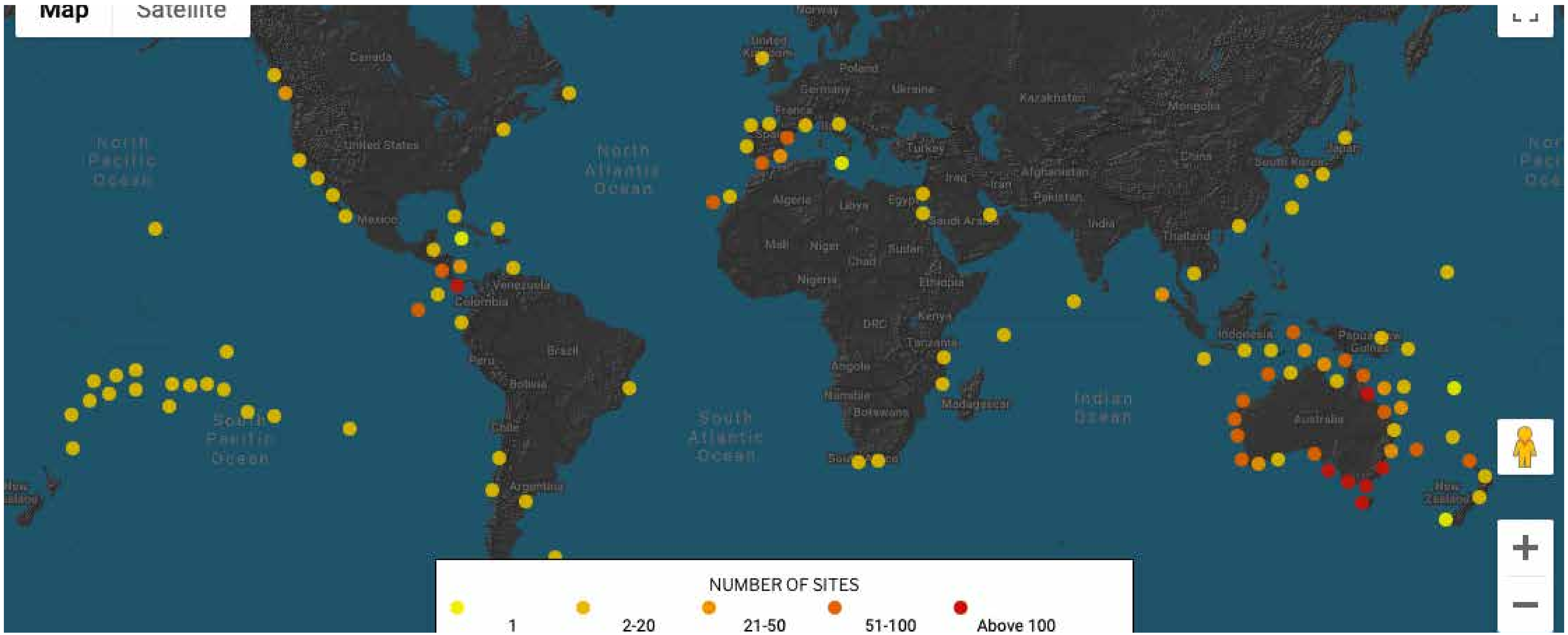
A need for a systematic assessment of dominant benthic habitat states

1. **Data-driven identification of dominant benthic habitat states at a global scale**
2. Characterise spatial distribution of dominant benthic habitat states and quantify influence environmental conditions and anthropogenic impacts (across global gradients)

Material & Methods

Reef Life Survey Program

6642 sites around the world



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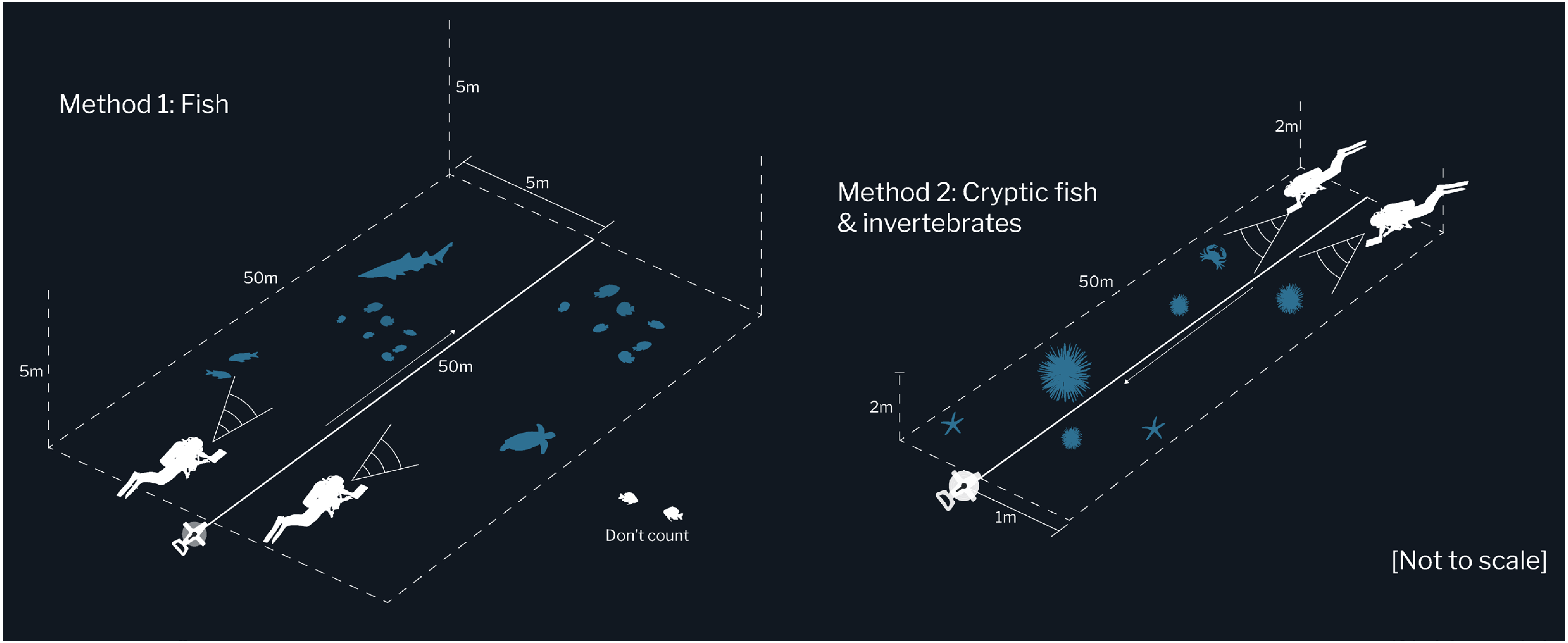
Reef Life Survey Program



Reef Life Survey Program

Photoquadrats every 2.5m

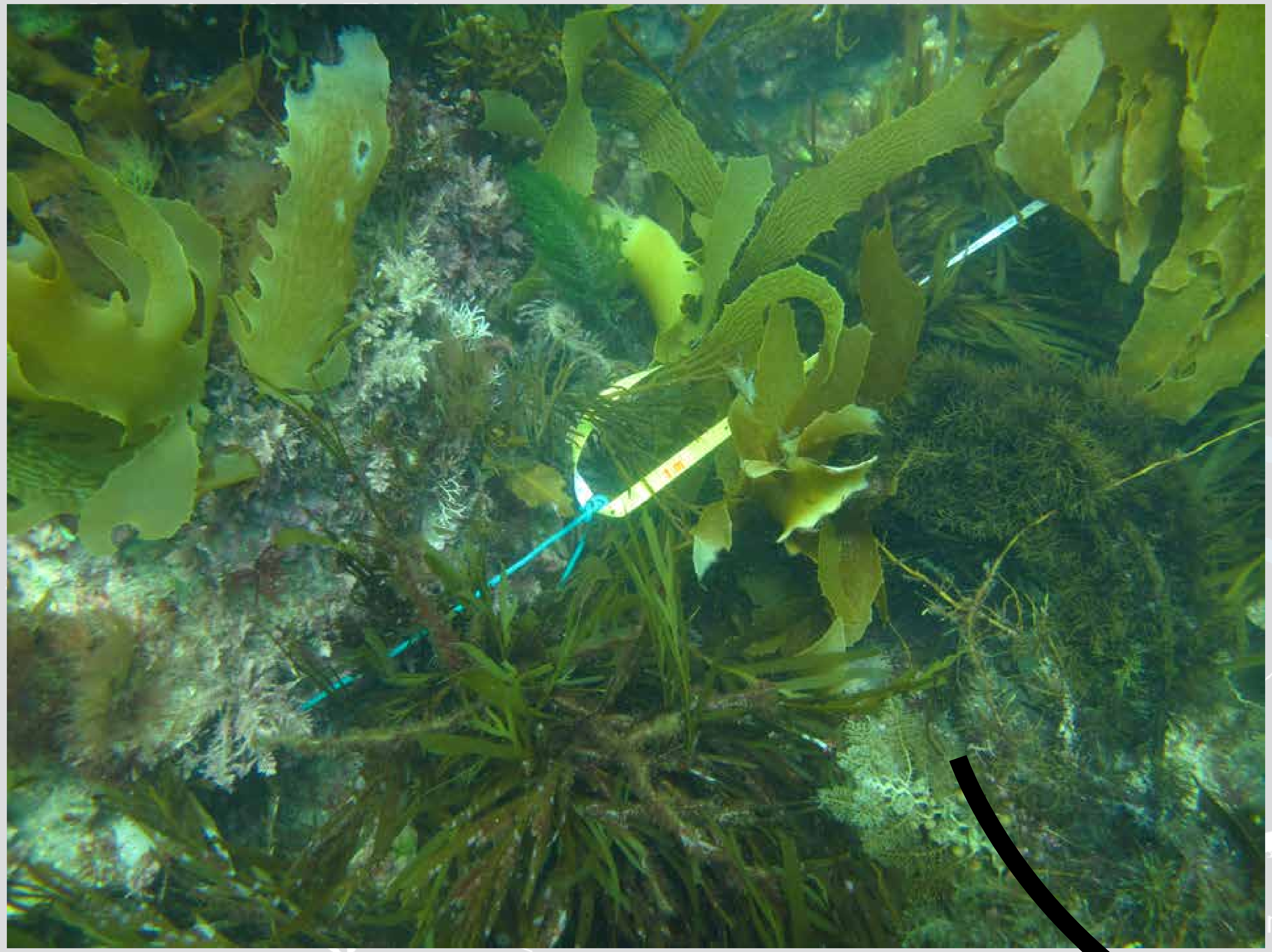
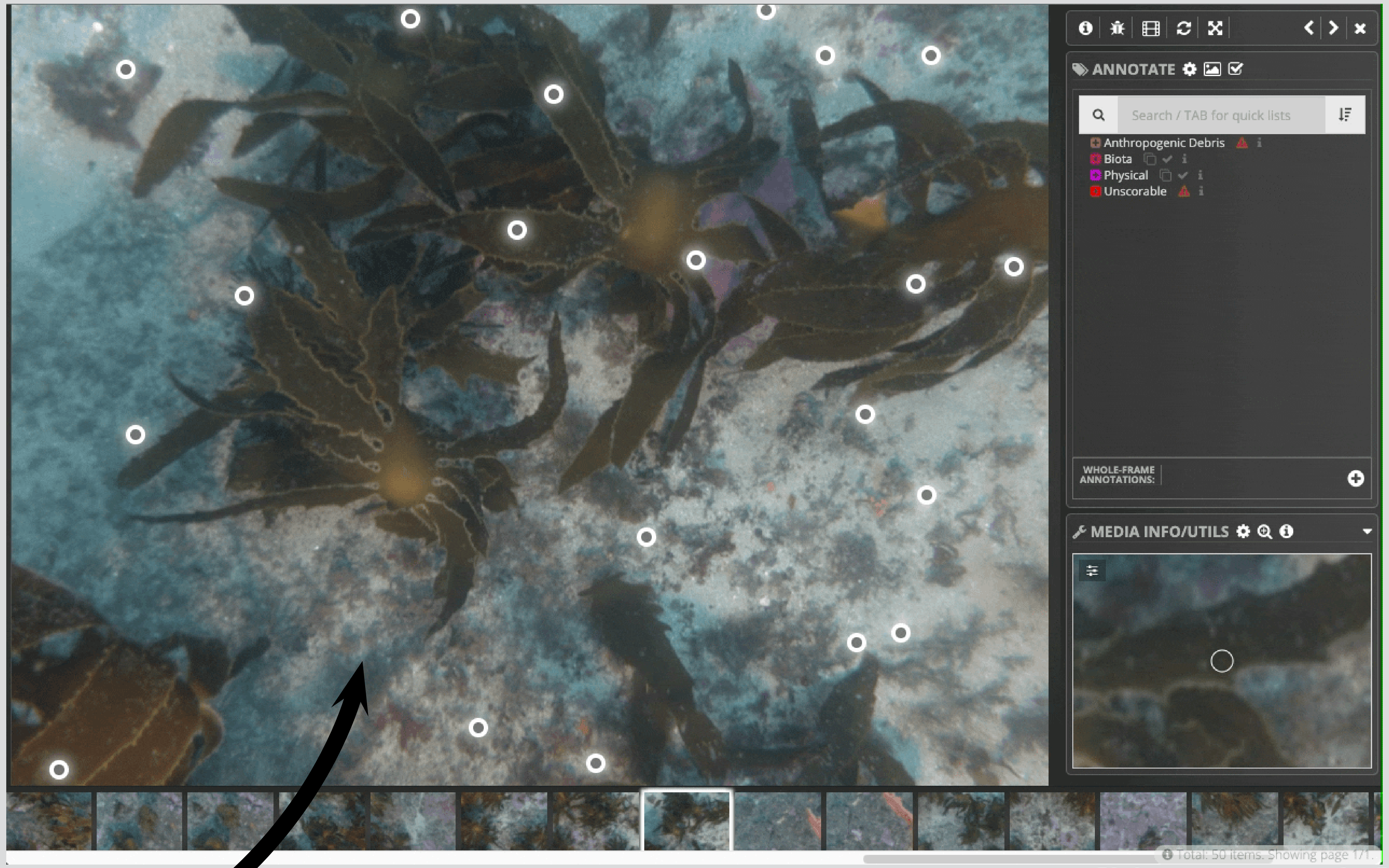


Image annotation on Squidle+



[Not to scale]

Reef Life Survey Program

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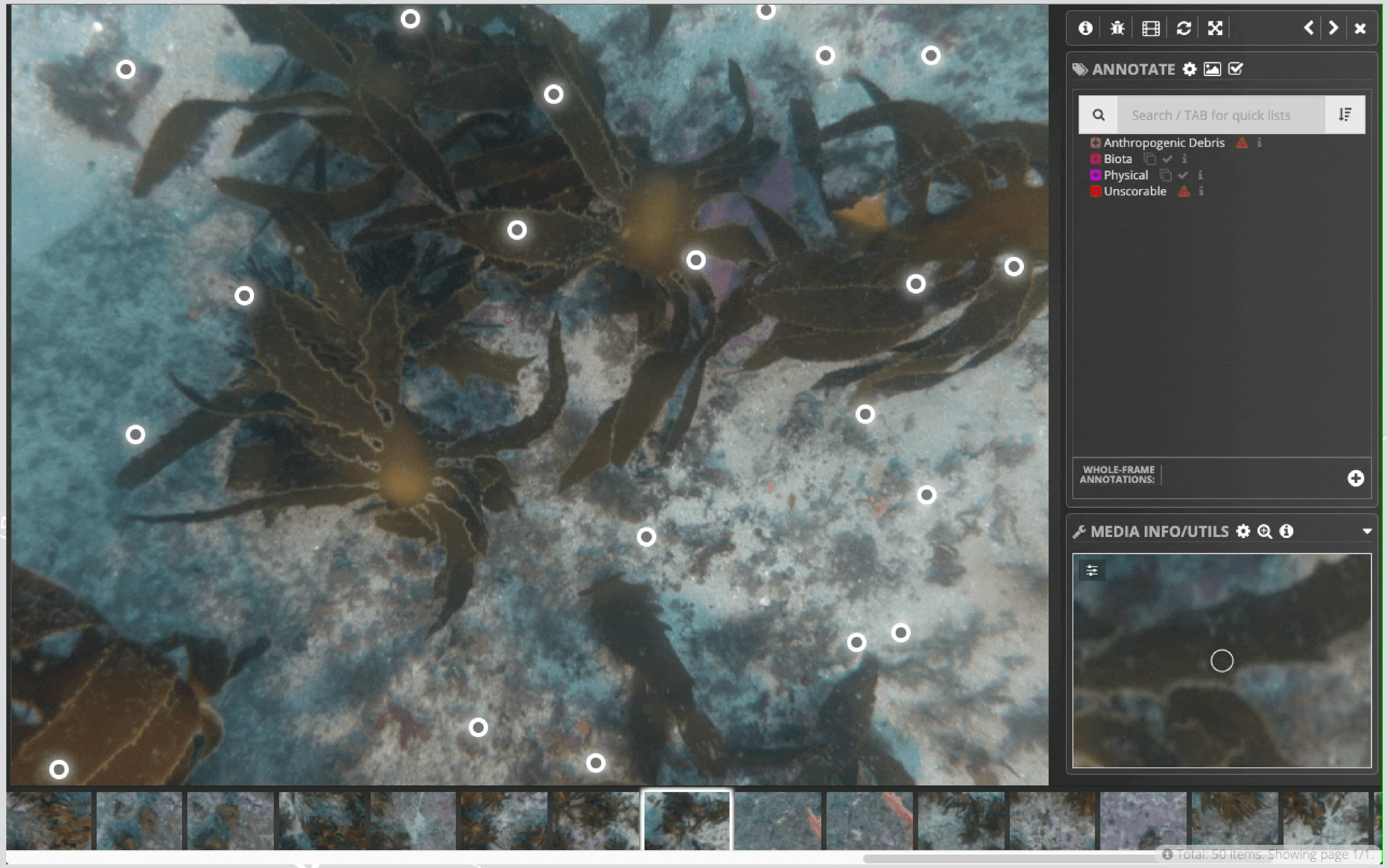


% Cover 15 habitat types

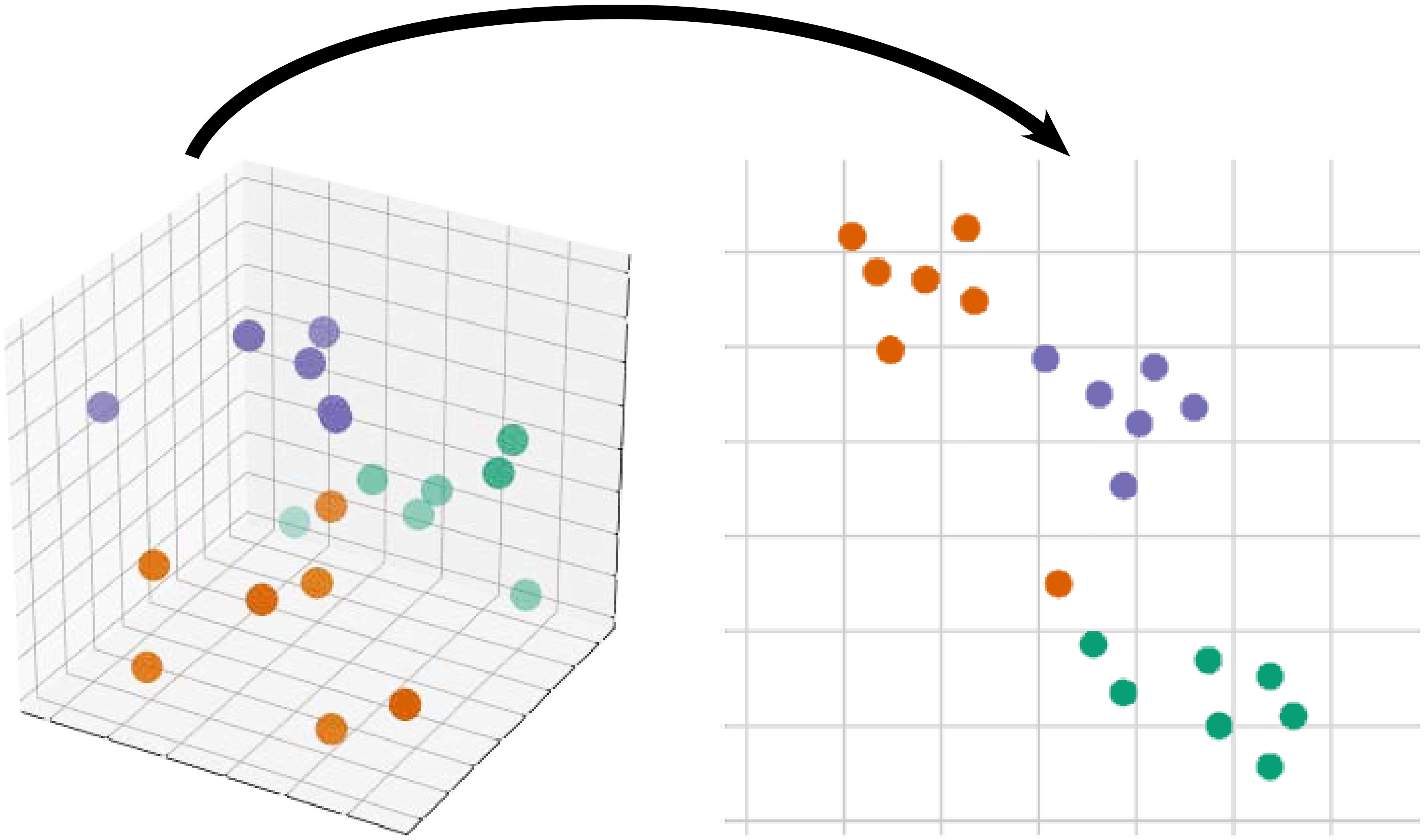
- Seagrasses
- Kelps
- Fucoids
- Turf alge
- Green algae
- Brown algae
- Red algae
- Filamentous epiphytes
- Encrusting algae
- Calcified algae
- Corals
- Hydrocorals
- Sessile invertebrates
- Non-living
- Sand

[Not to scale]

Clustering pipeline

Dimension reduction

UMAP (*McInnes et al.*, 2020)



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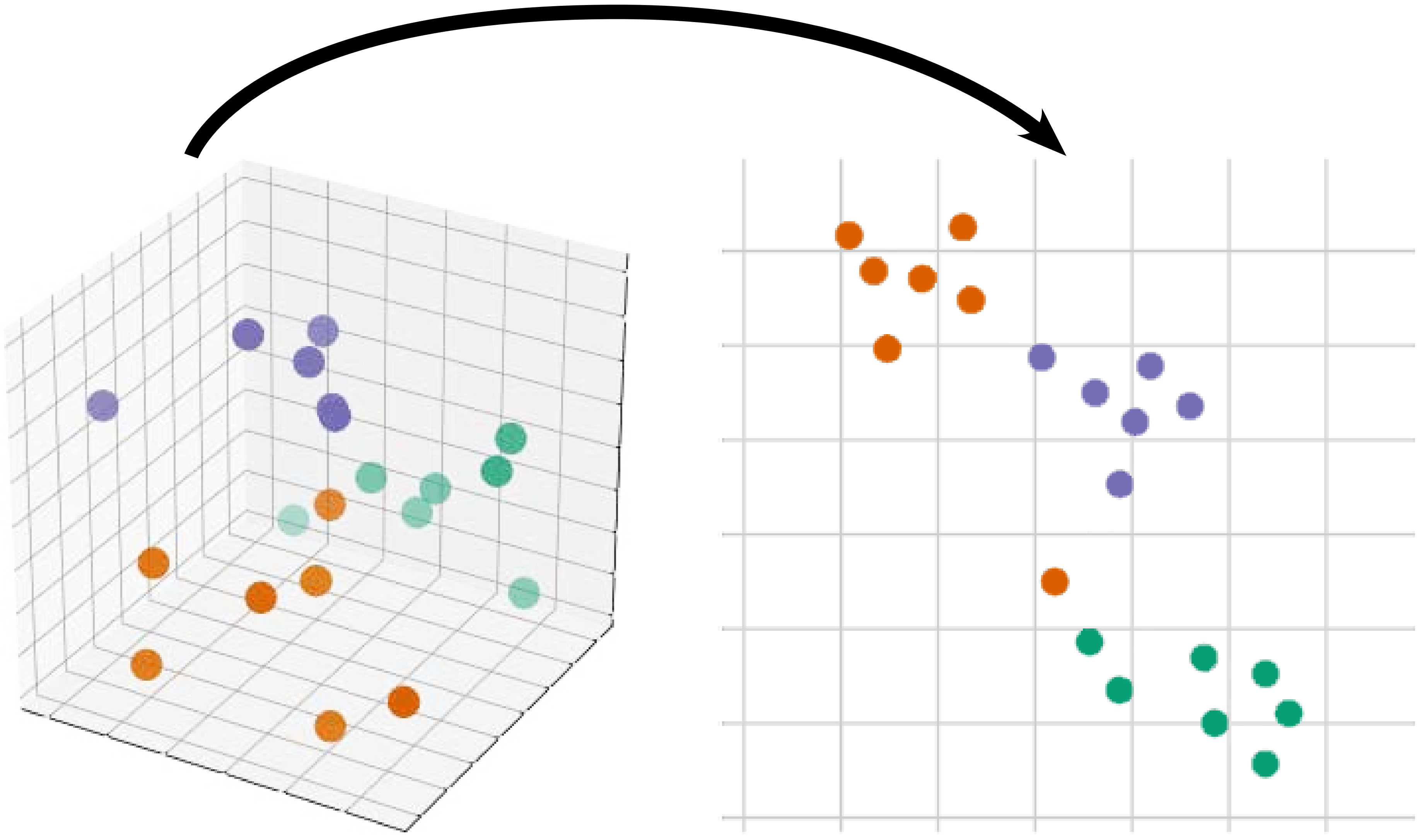
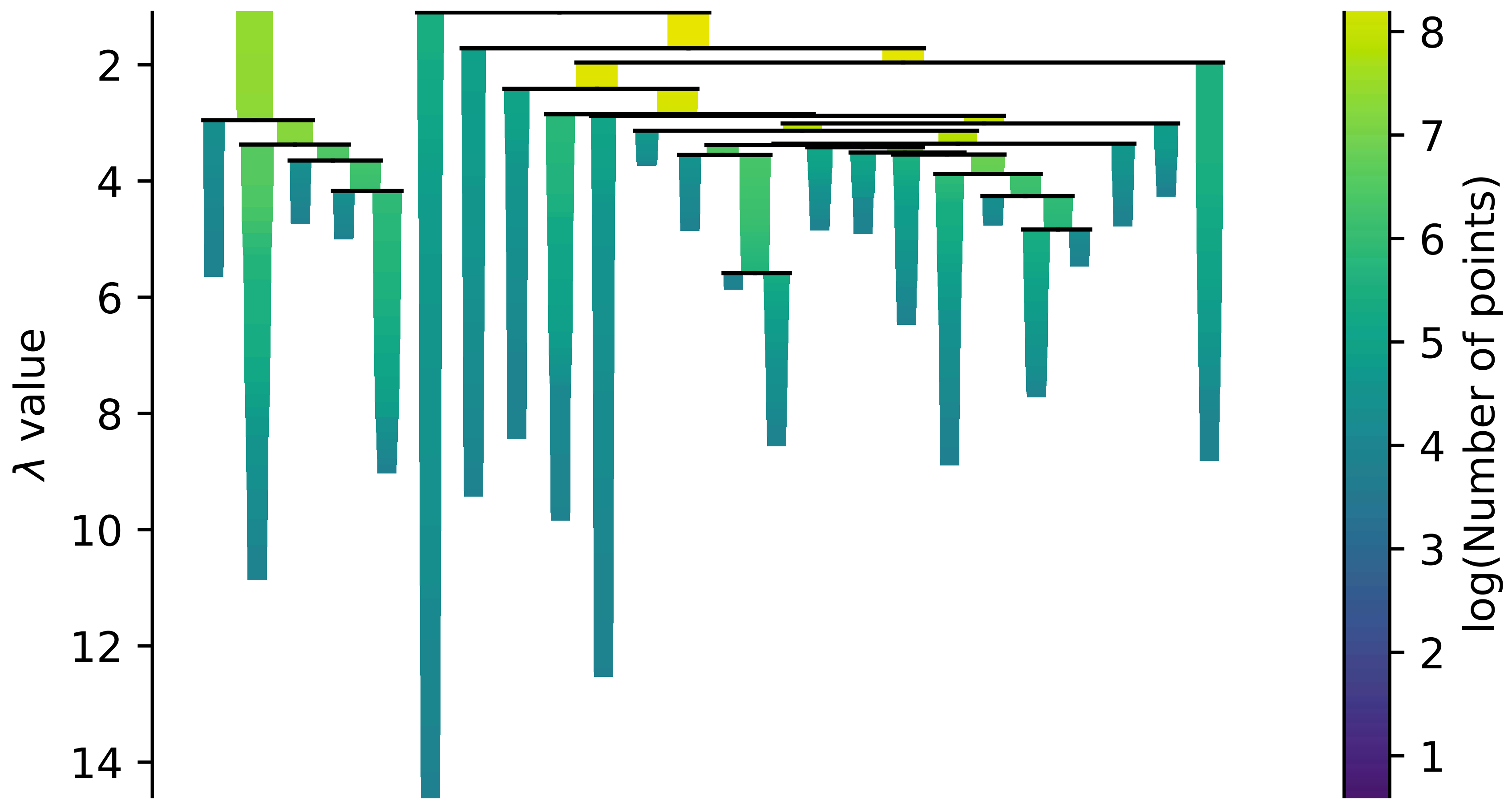


Clustering

HDBSCAN (*McInnes and Healy*, 2017)



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Clustering pipeline

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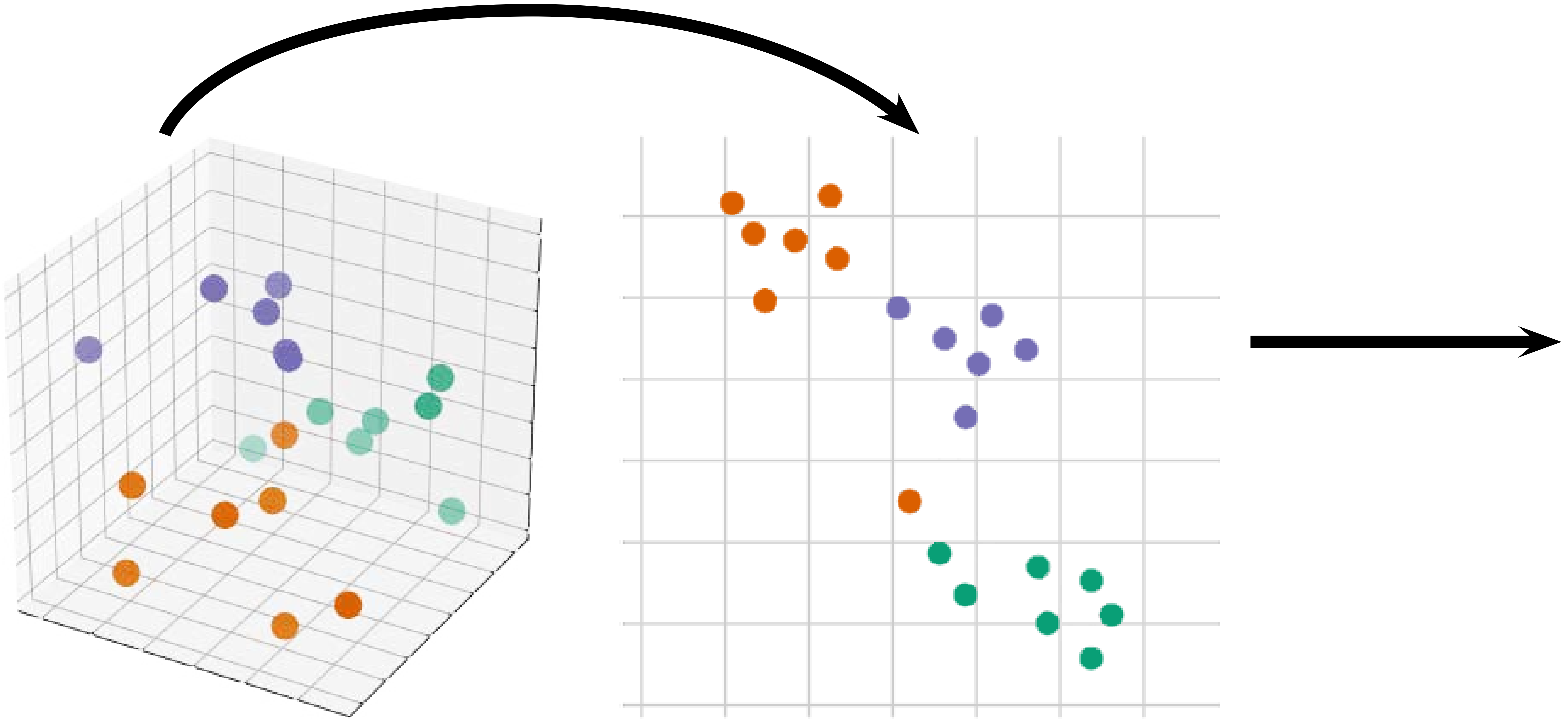
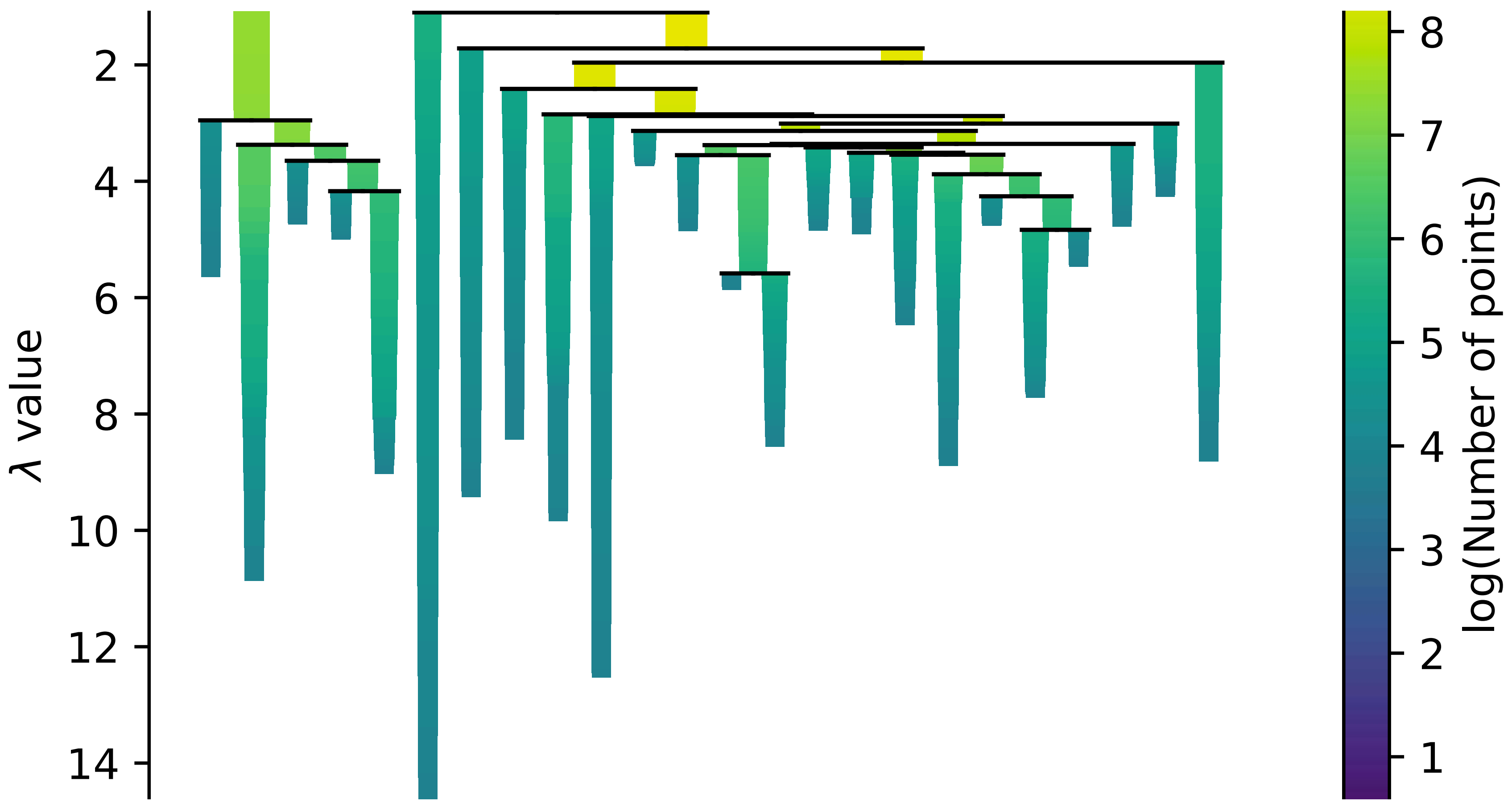


- Non-linear relationship
- Robust against noise and outliers
- Cluster of variable shapes & density

Clustering

HDBSCAN (*McInnes and Healy*, 2017)



- Identification of representative members of each cluster

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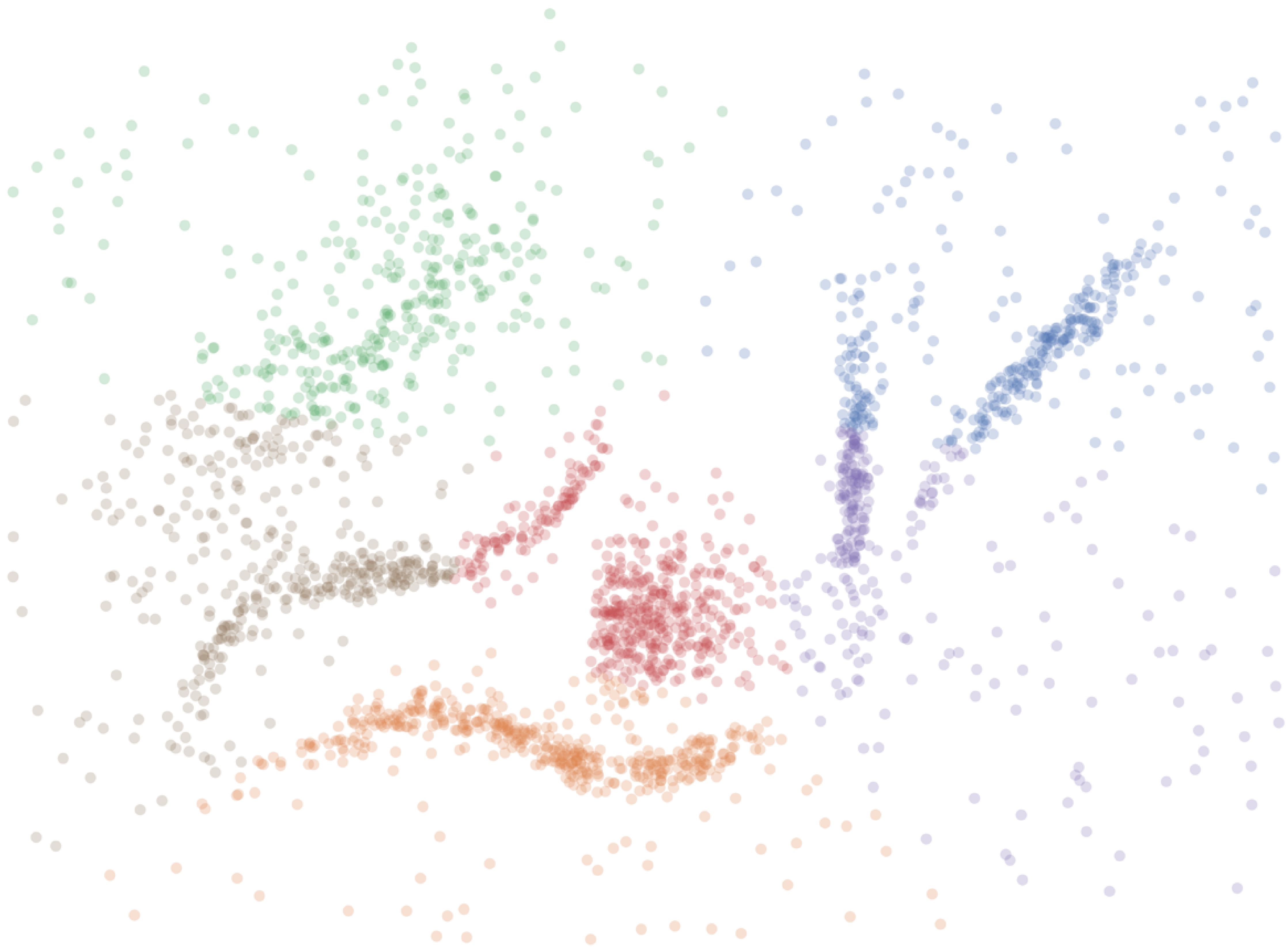
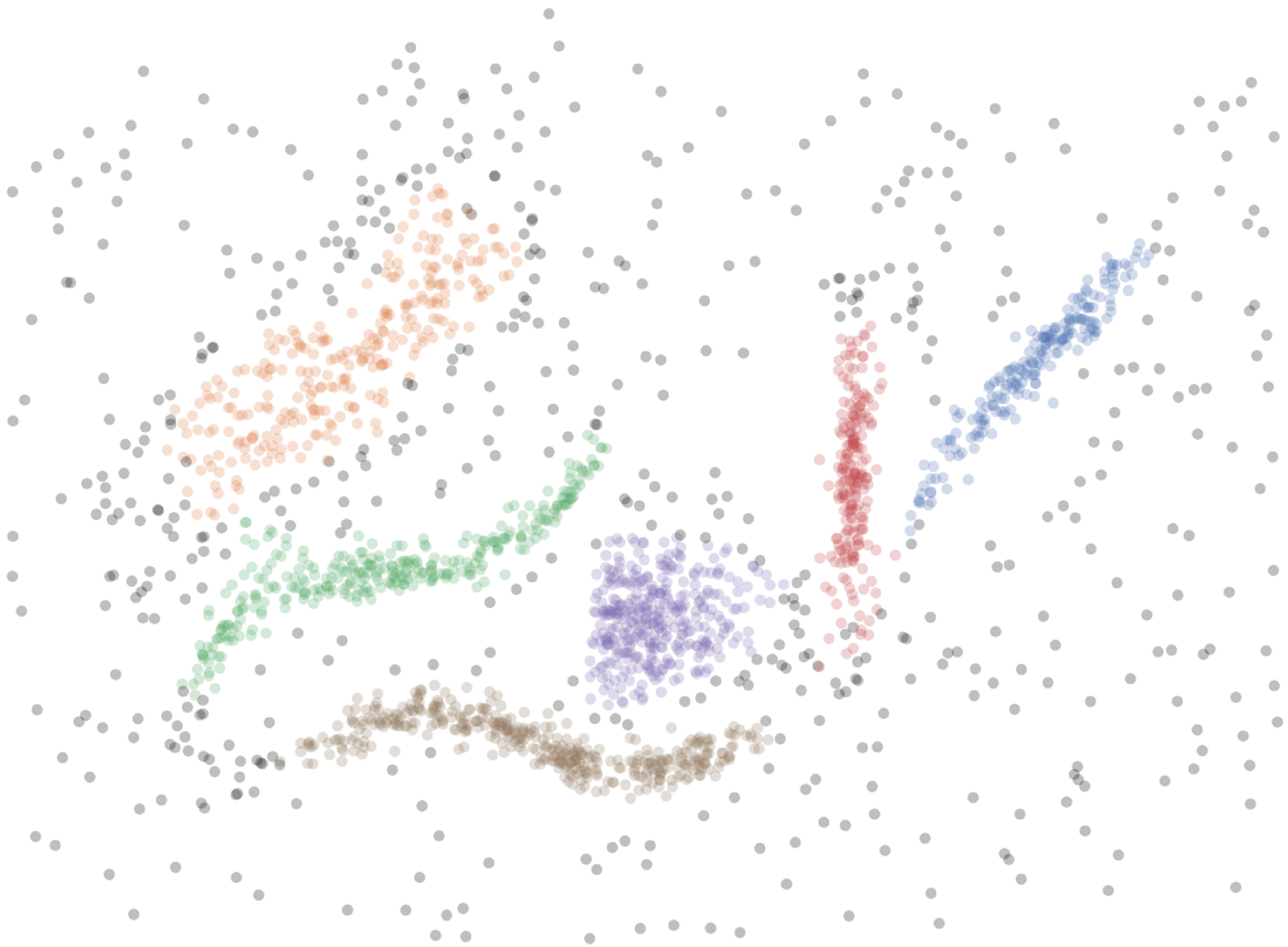
Comparison of clustering techniques on an example dataset

K-means



HDBSCAN

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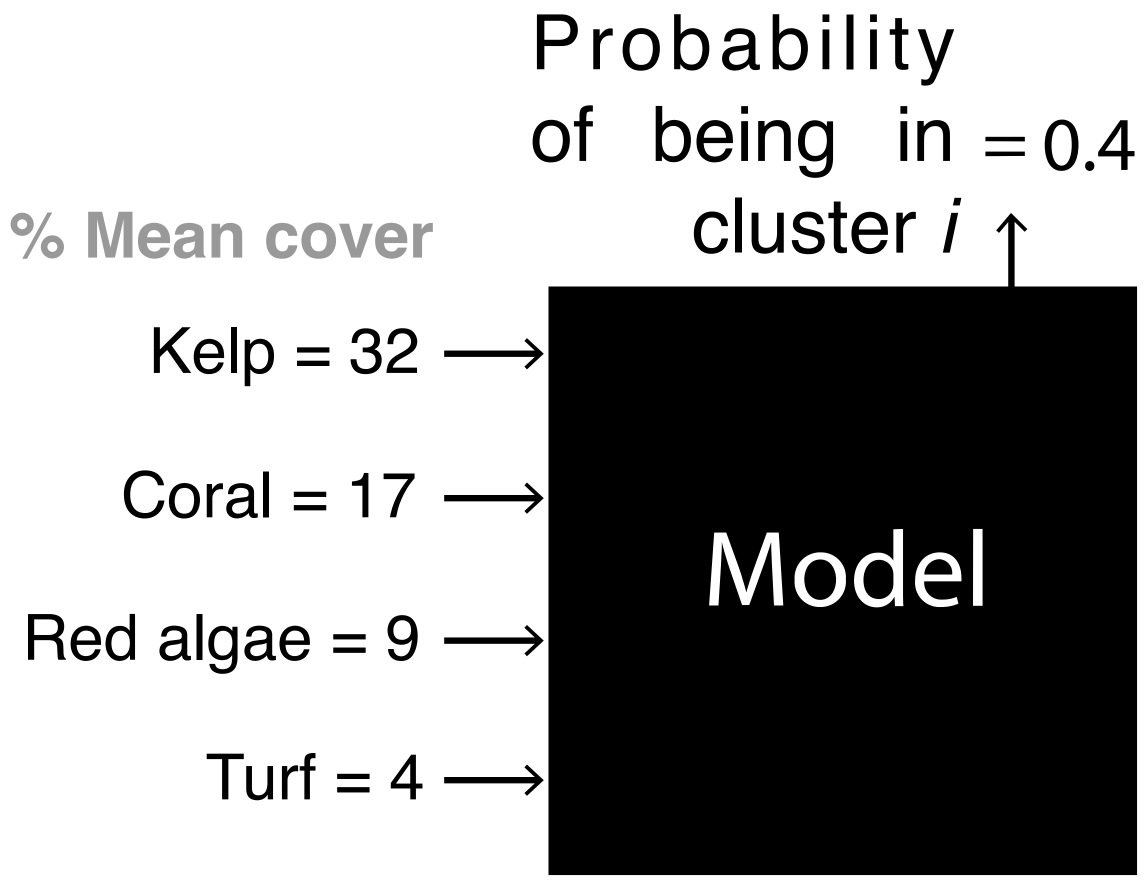
Interpretation of clustering results

- Complex pipeline can act as ‘black-boxes’
  - SHAP framework to understand probabilities of belonging to clusters *(Lunderberg et al.*, 2017)

SHAP

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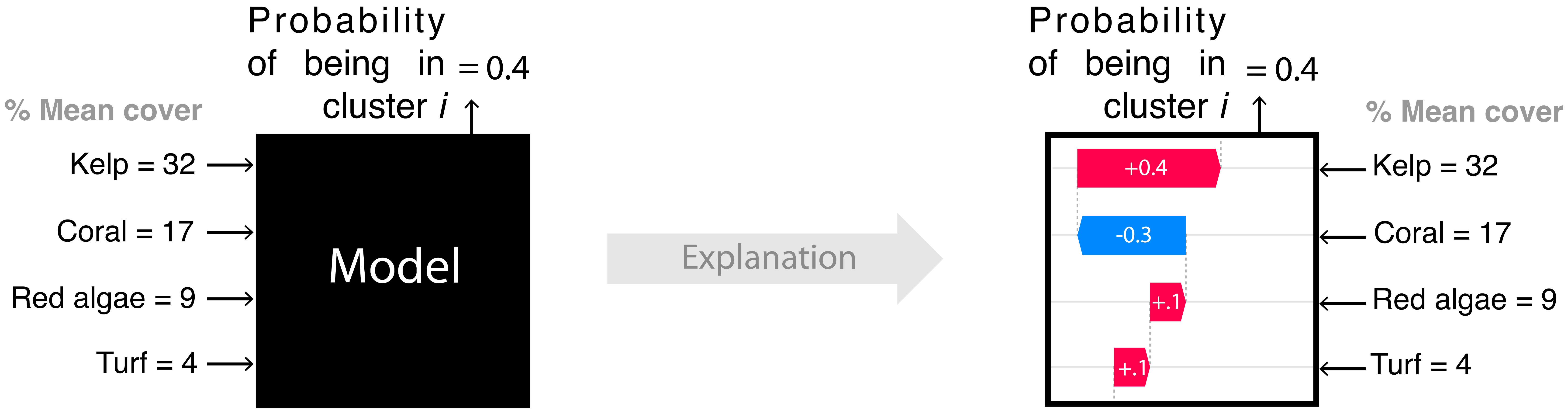
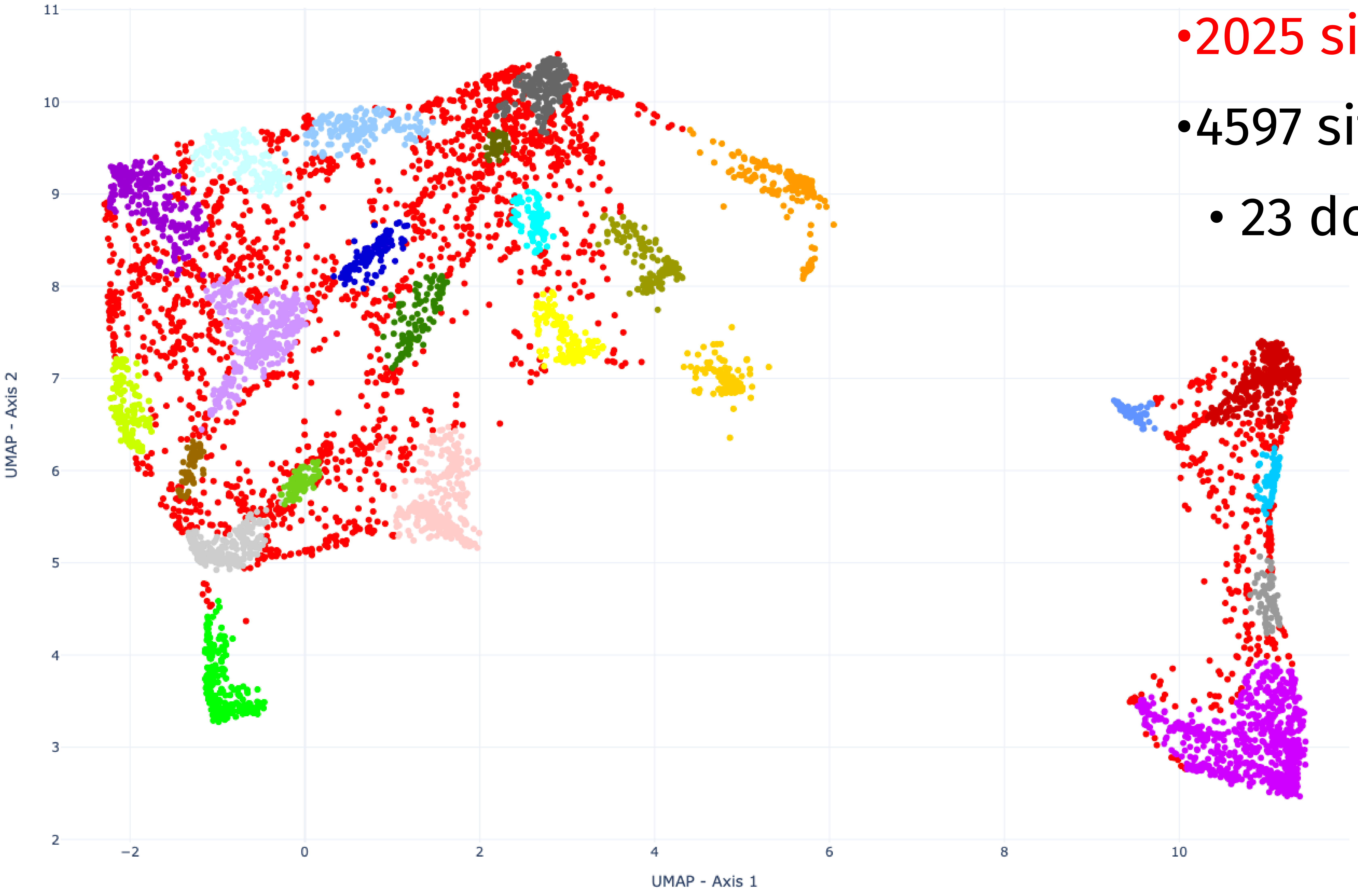
SHAP



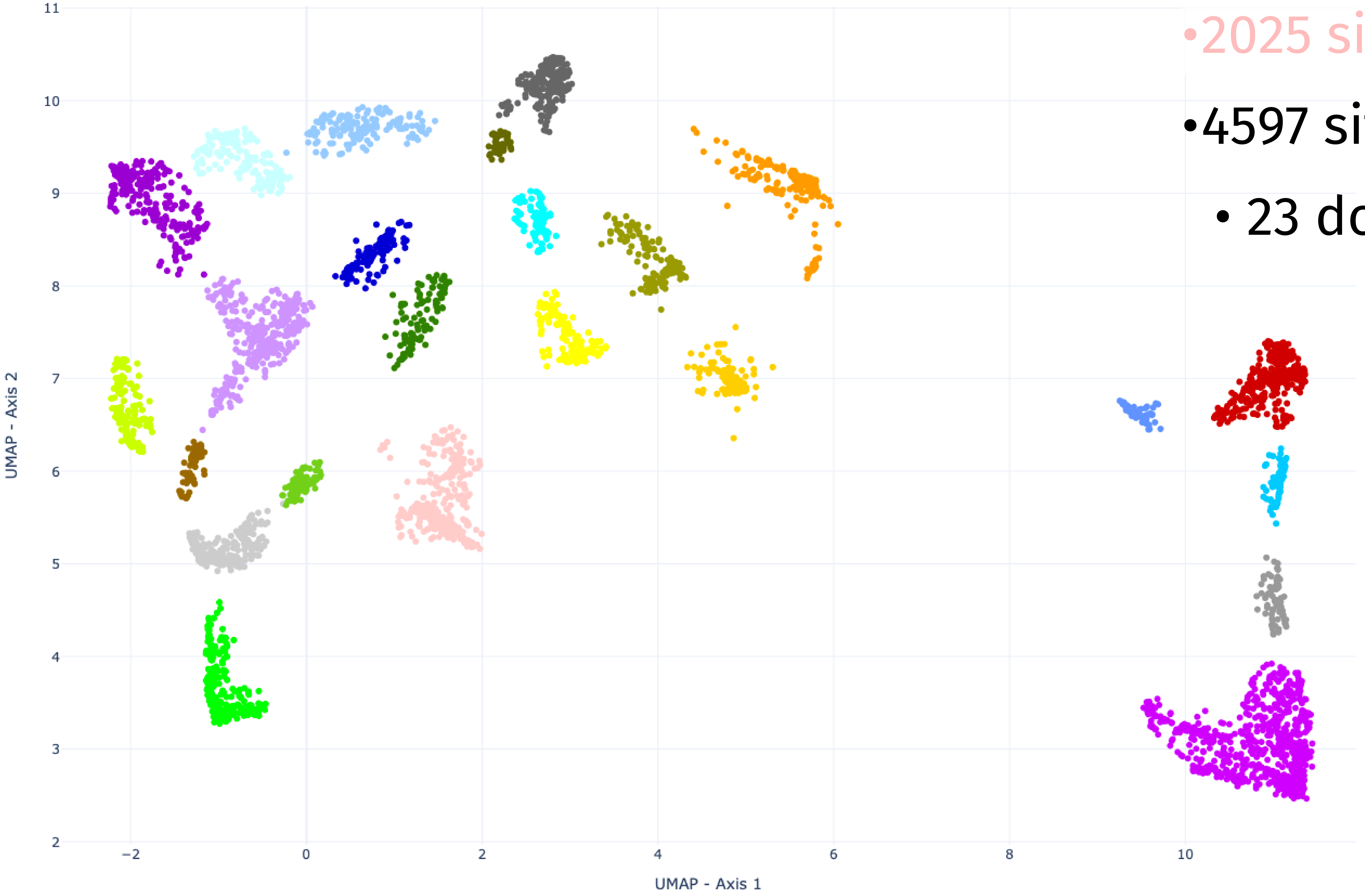
Results

Clustering *RLS* transects



- 2025 sites classified as noise
- 4597 sites classified
  - 23 dominant habitat types

Clustering *RLS* transects



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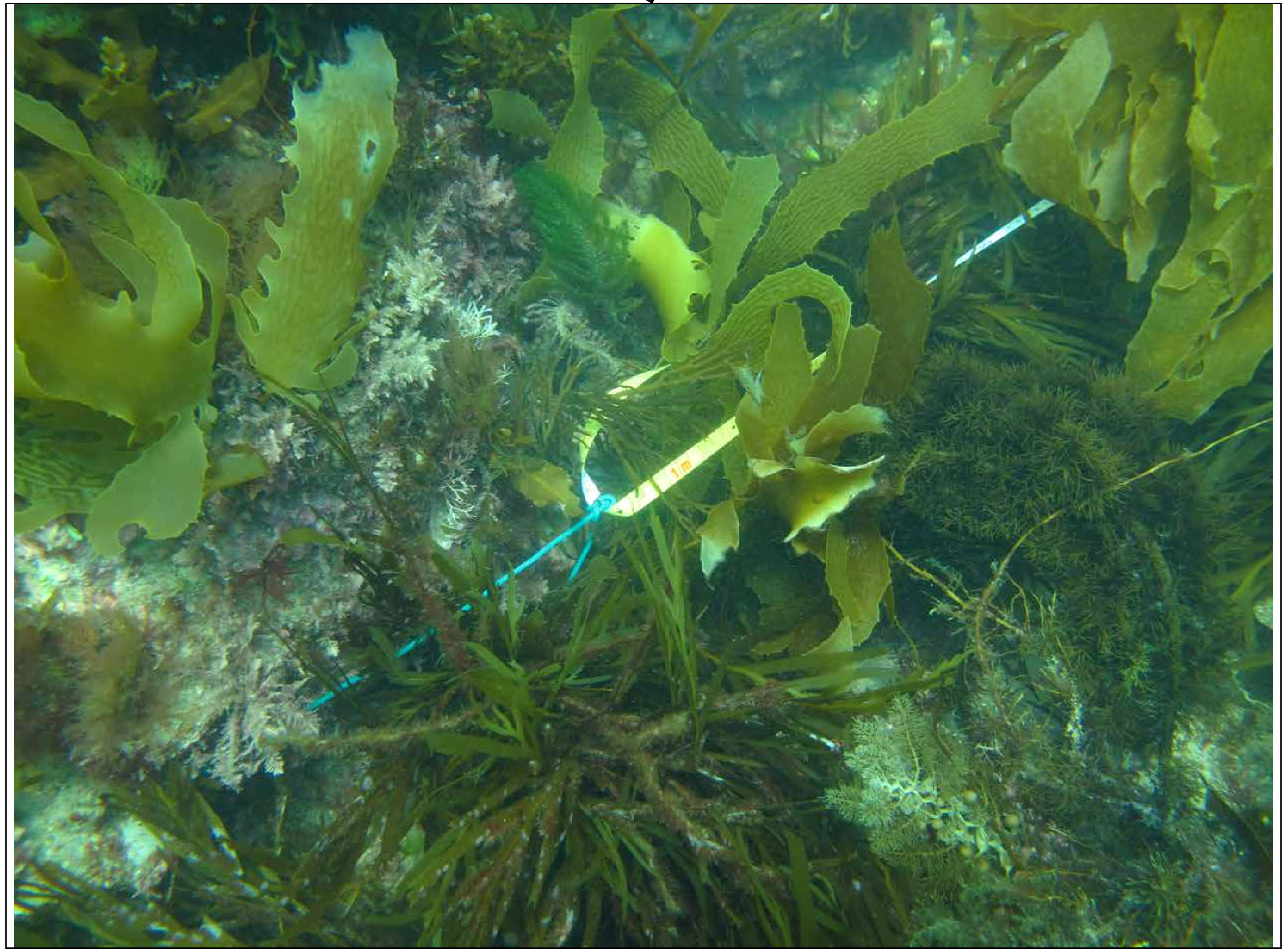
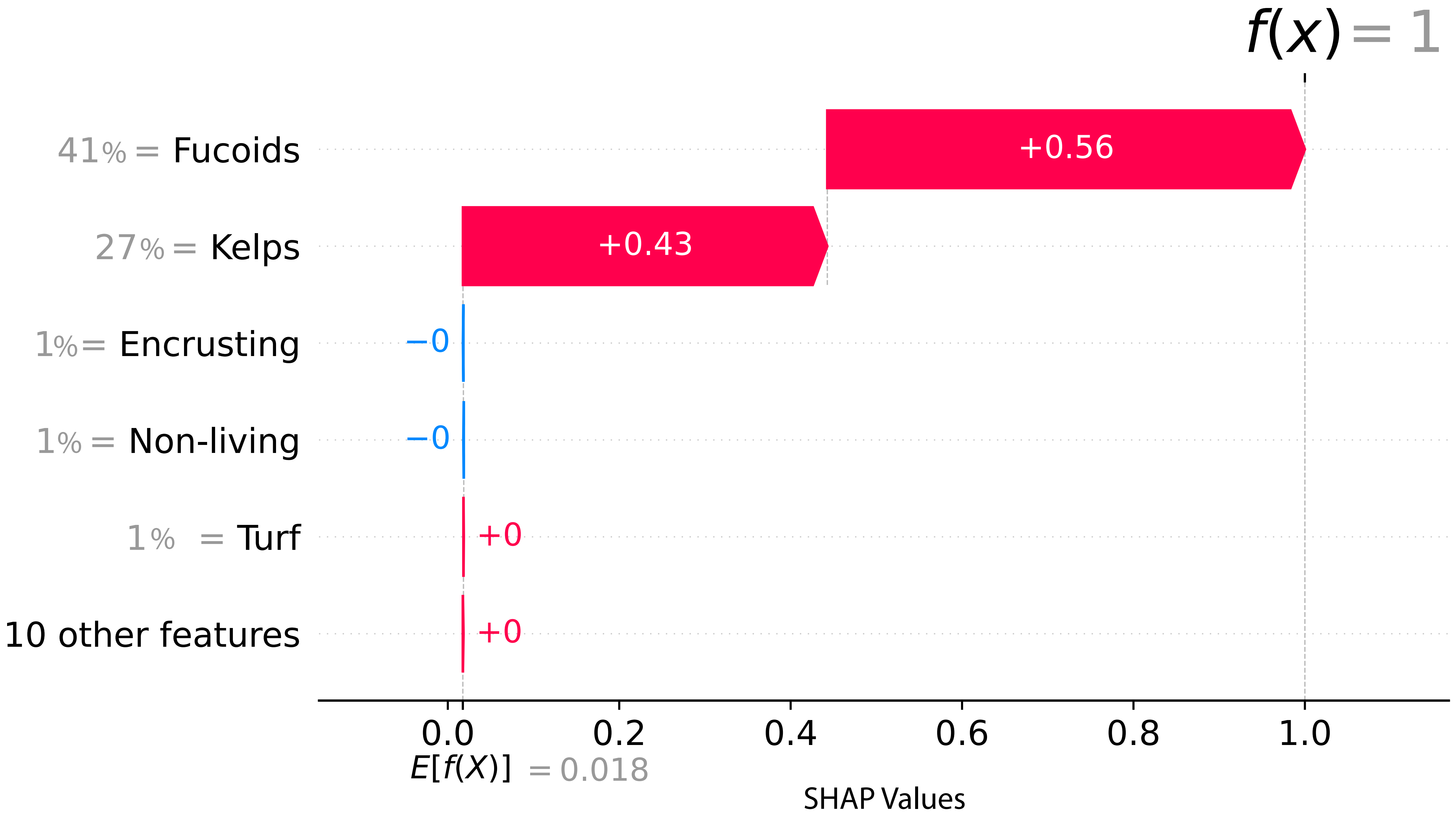
Explaining one member of a cluster



Relative contribution of each variable to this cluster



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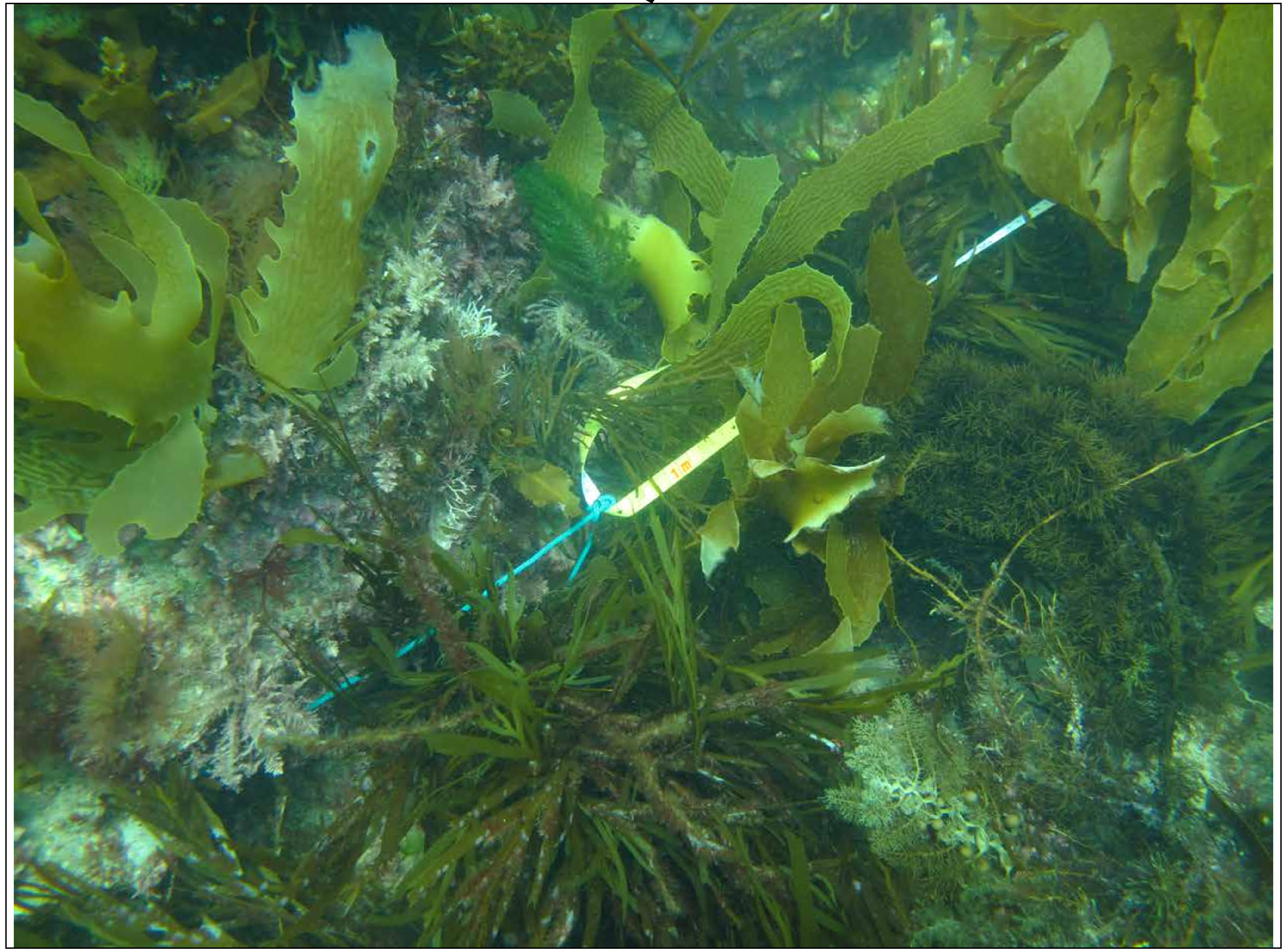

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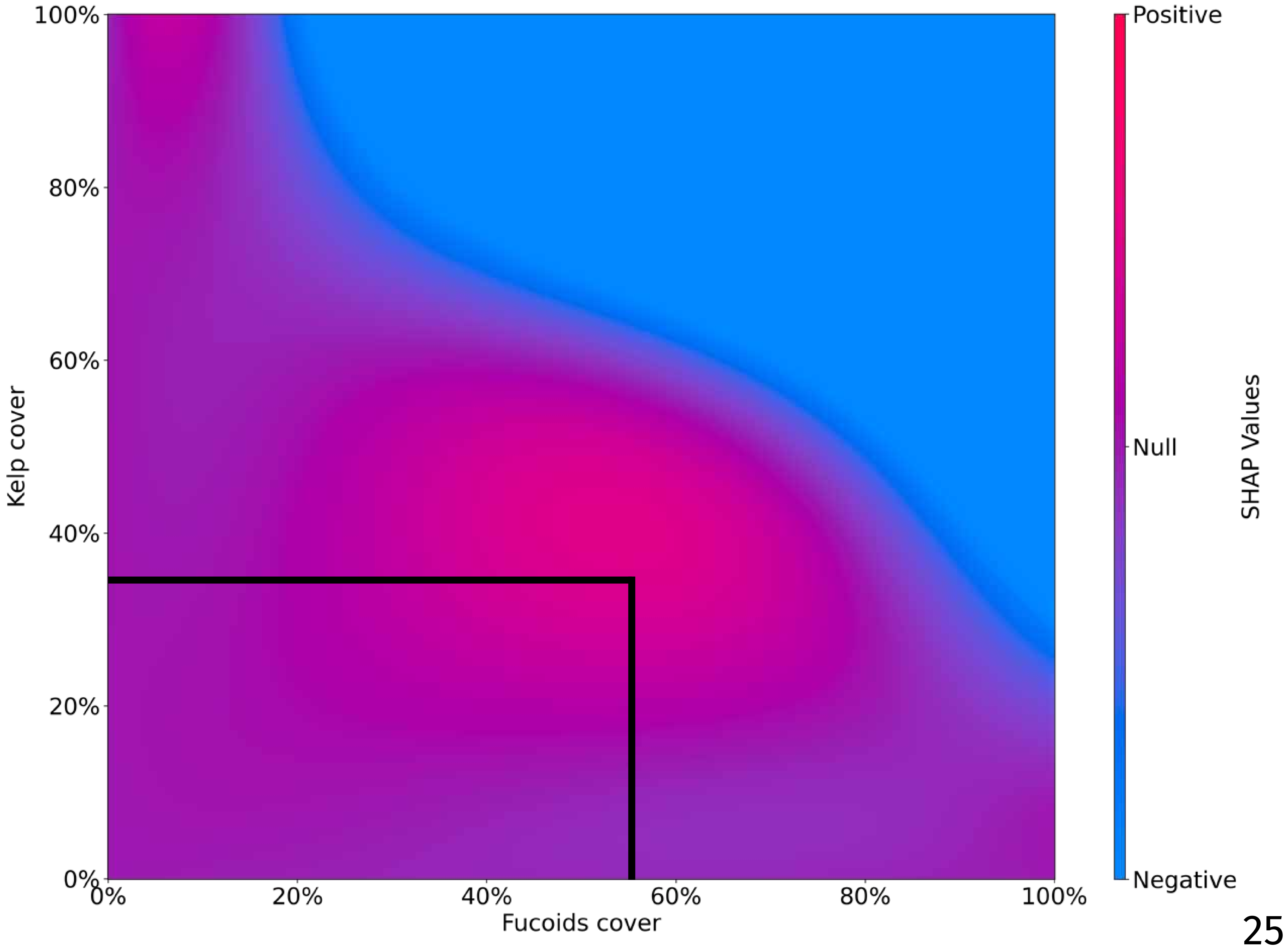
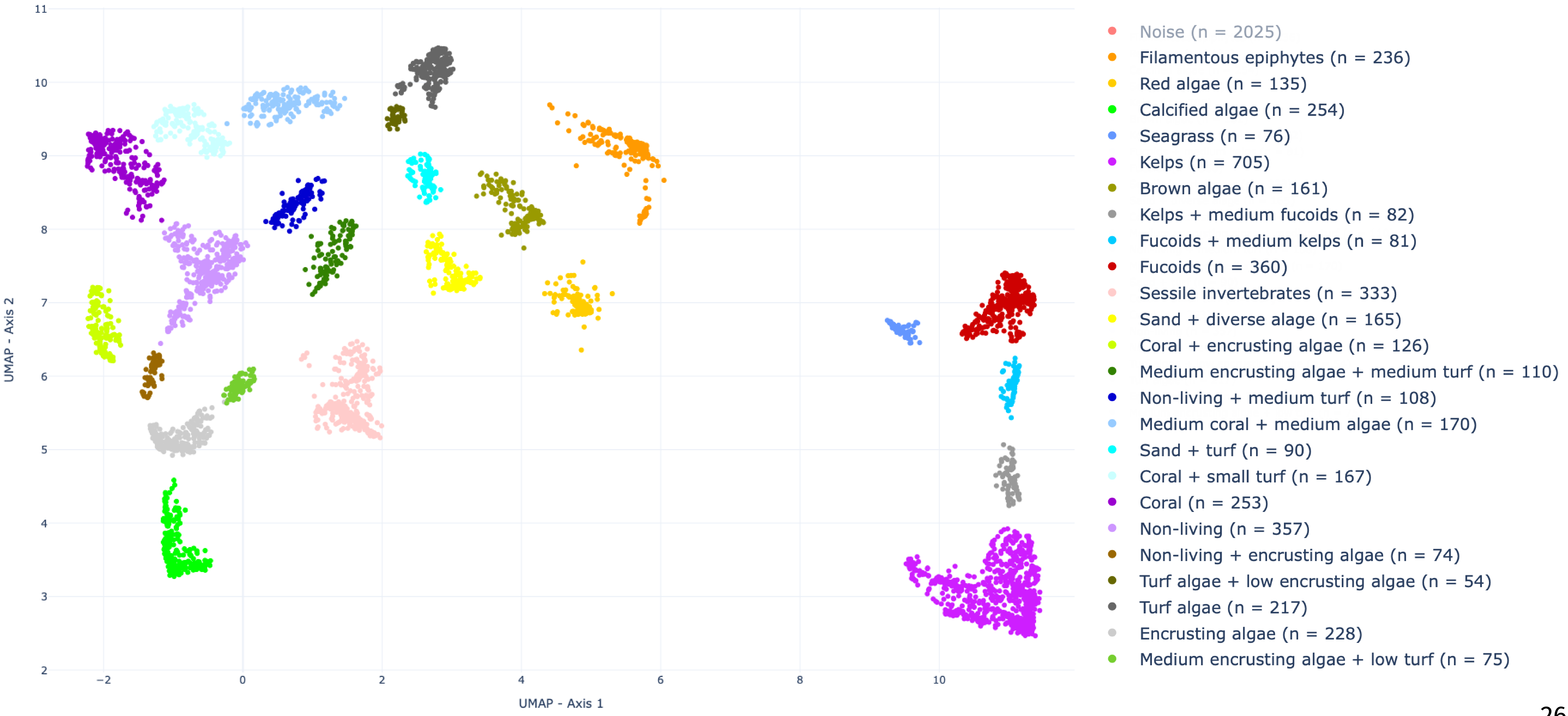


Interpreting overall results & identity of 23 clusters



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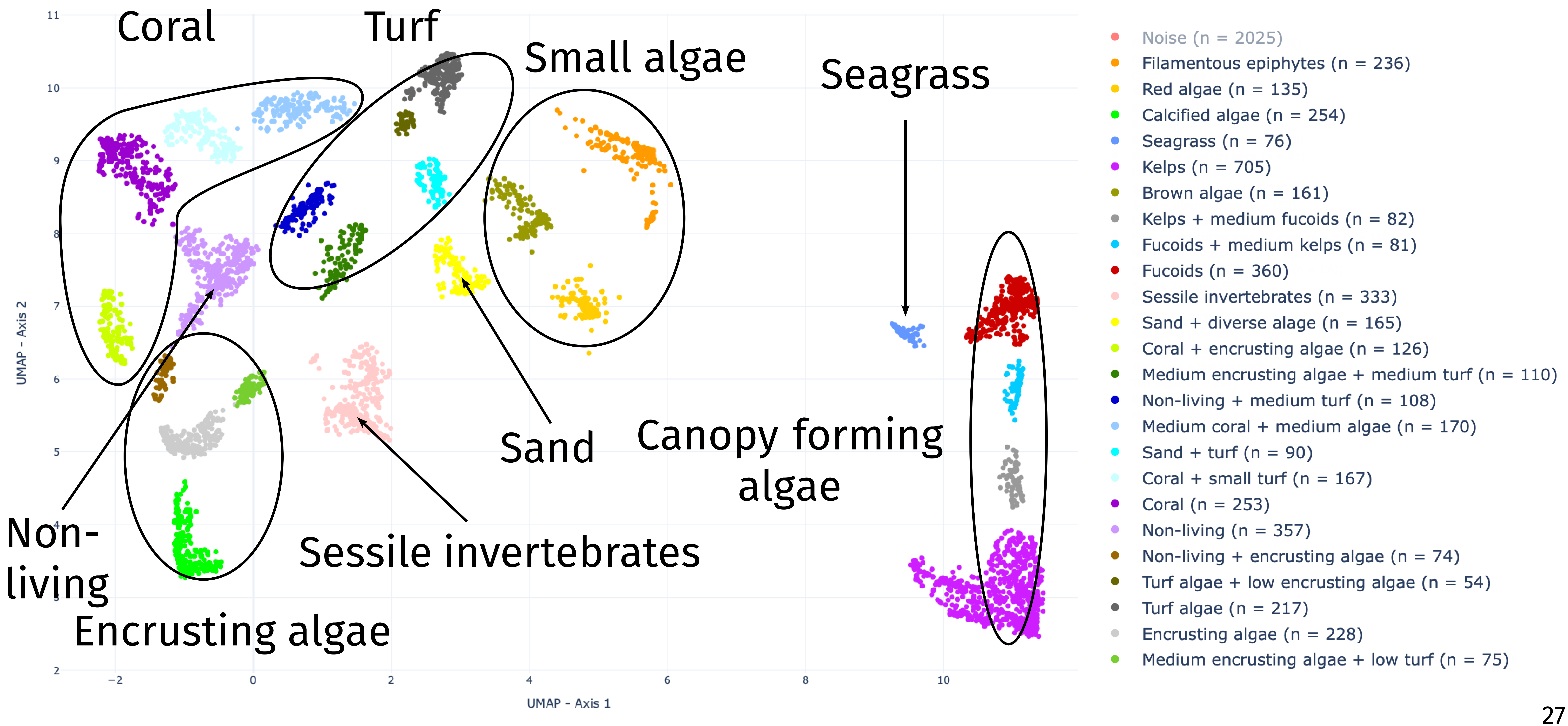
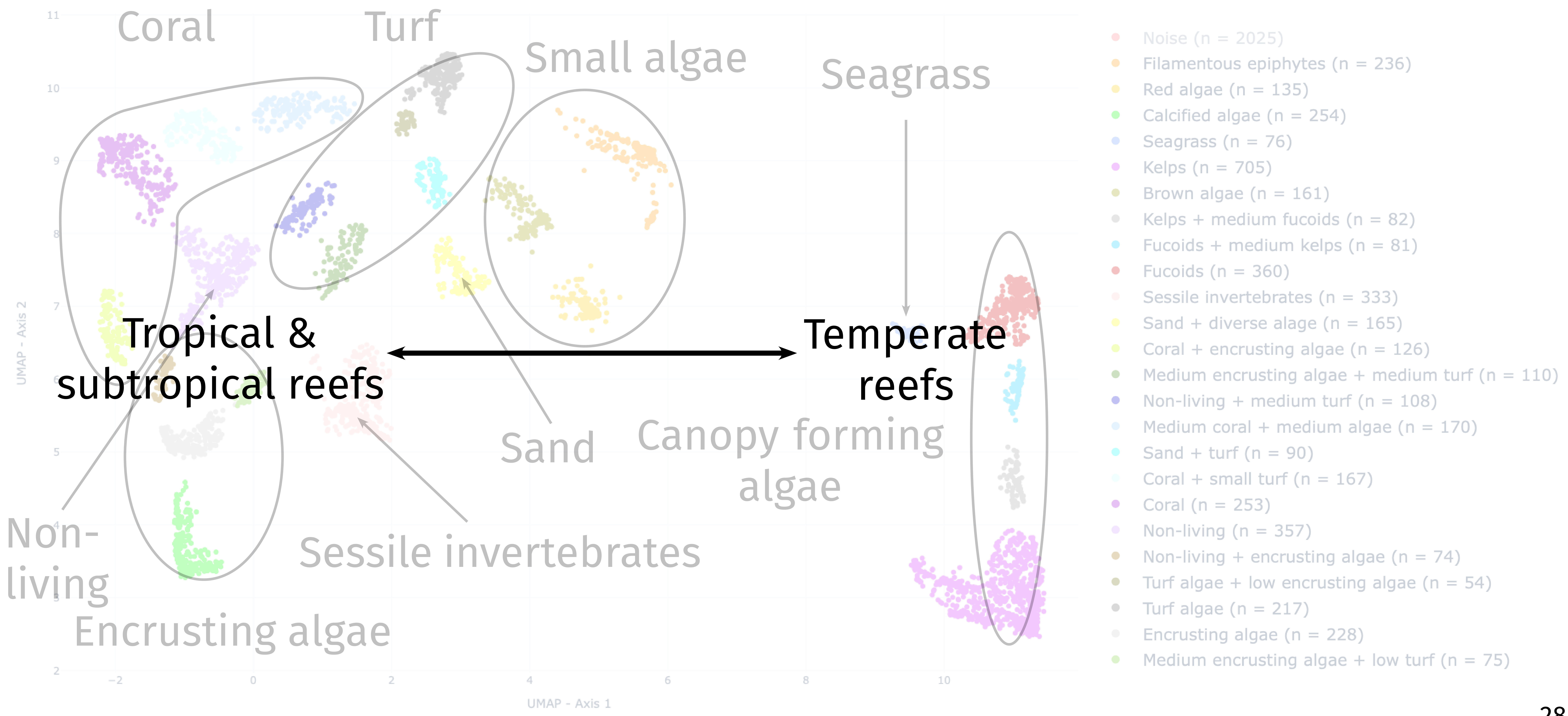
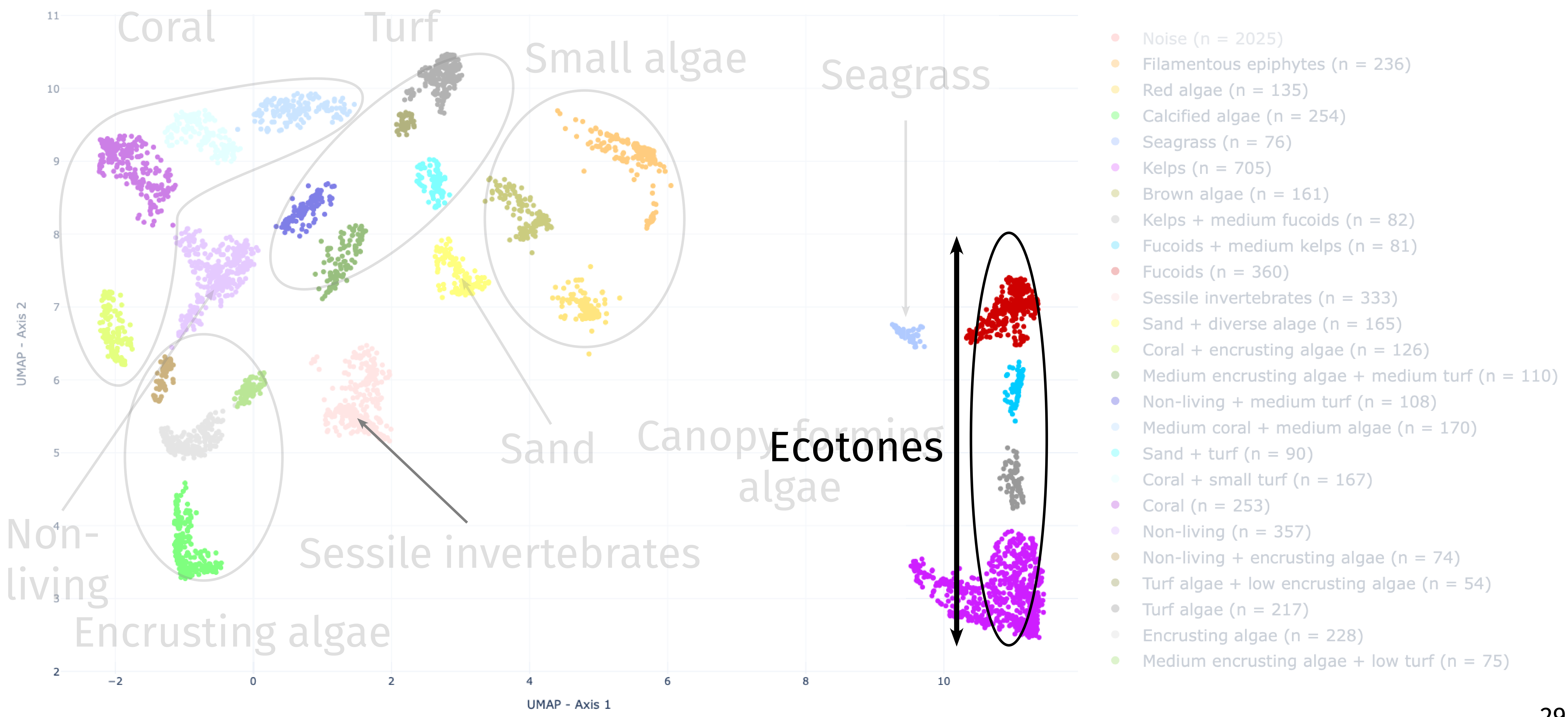


Interpreting overall results & identity of 23 clusters



Tropical & subtropical reefs ↔ Temperate reefs

Interpreting overall results & identity of 23 clusters



4 examples of temperate ecotones identified

Kelp forest

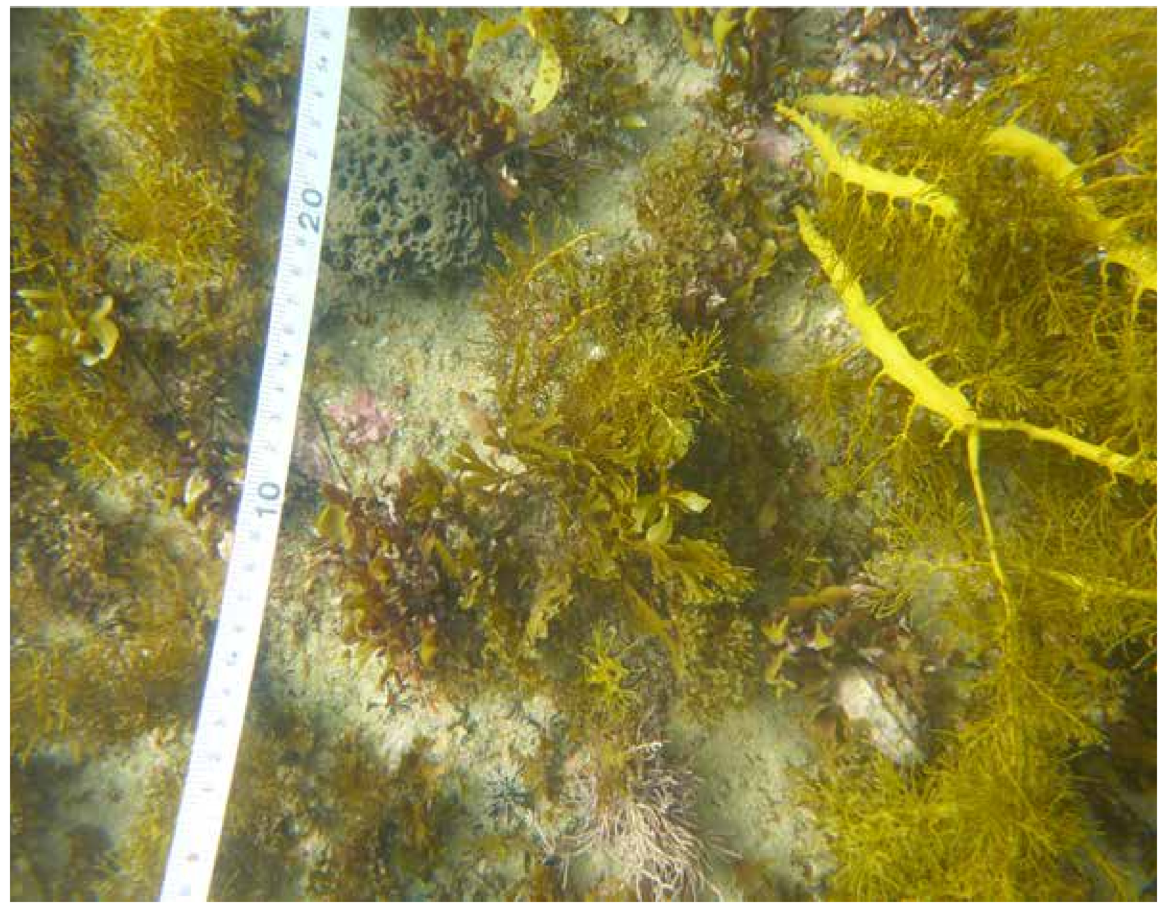
N = 705

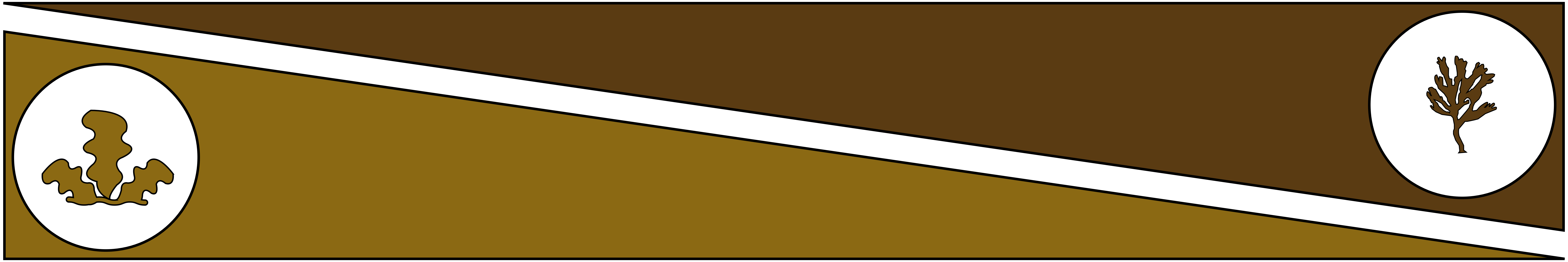
N = 82

N = 81

Fucoid forest

N = 360





Conclusion

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1. Development of an effective interpretable clustering pipeline

- Robust against noise
- Scalable to large datasets

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Conclusion

1. **Development of an effective interpretable clustering pipeline**
    - Robust against noise
    - Scalable to large datasets
2. **Succesful identification of 23 meaningful clusters based on RLS transects**
    - Large biogeographical patterns across latitudinal gradients
    - Alternative dominant habitat types and ecotones within bioregions

©Picture by John Turnbull

Conclusion

1. **Development of an effective interpretable clustering pipeline**
   - Robust against noise
   - Scalable to large datasets
2. **Succesful identification of 23 meaningful clusters based on RLS transects**
   - Large biogeographical patterns across latitudinal gradients
   - Alternative dominant habitat types and ecotones within bioregions
3. **Work-in-progress:**
   - Quantifying drivers of dominant habitat types occurrence
   - Inclusion of other RLS datasets to define ecological states

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Thank you for listening!

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References

Bernal-Ibáñez, *et al*. 2021. "The Role of Sea-Urchins in Marine Forests from Azores, Webbnesia, and Cabo Verde: Human Pressures, Climate-Change Effects and Restoration Opportunities." *Frontiers in Marine Science* 8.

Lundberg, Scott M, and Su-In Lee. 2017. "A Unified Approach to Interpreting Model Predictions." In *Advances in Neural Information Processing Systems* 30, edited by I. Guyon, U. V. Luxburg, S. Bengio, H. Wallach, R. Fergus, S. Vishwanathan, and R. Garnett, 4765–74. Curran Associates, Inc.

McInnes, Leland, John Healy, and Steve Astels. 2017. "Hdbscan: Hierarchical Density Based Clustering." *The Journal of Open Source Software* 2 (11).

McInnes, Leland, John Healy, and James Melville. 2020. "UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction." *arXiv*.