

# Atlantic cod individual spatial behaviour and isotope associations in a no-take marine reserve

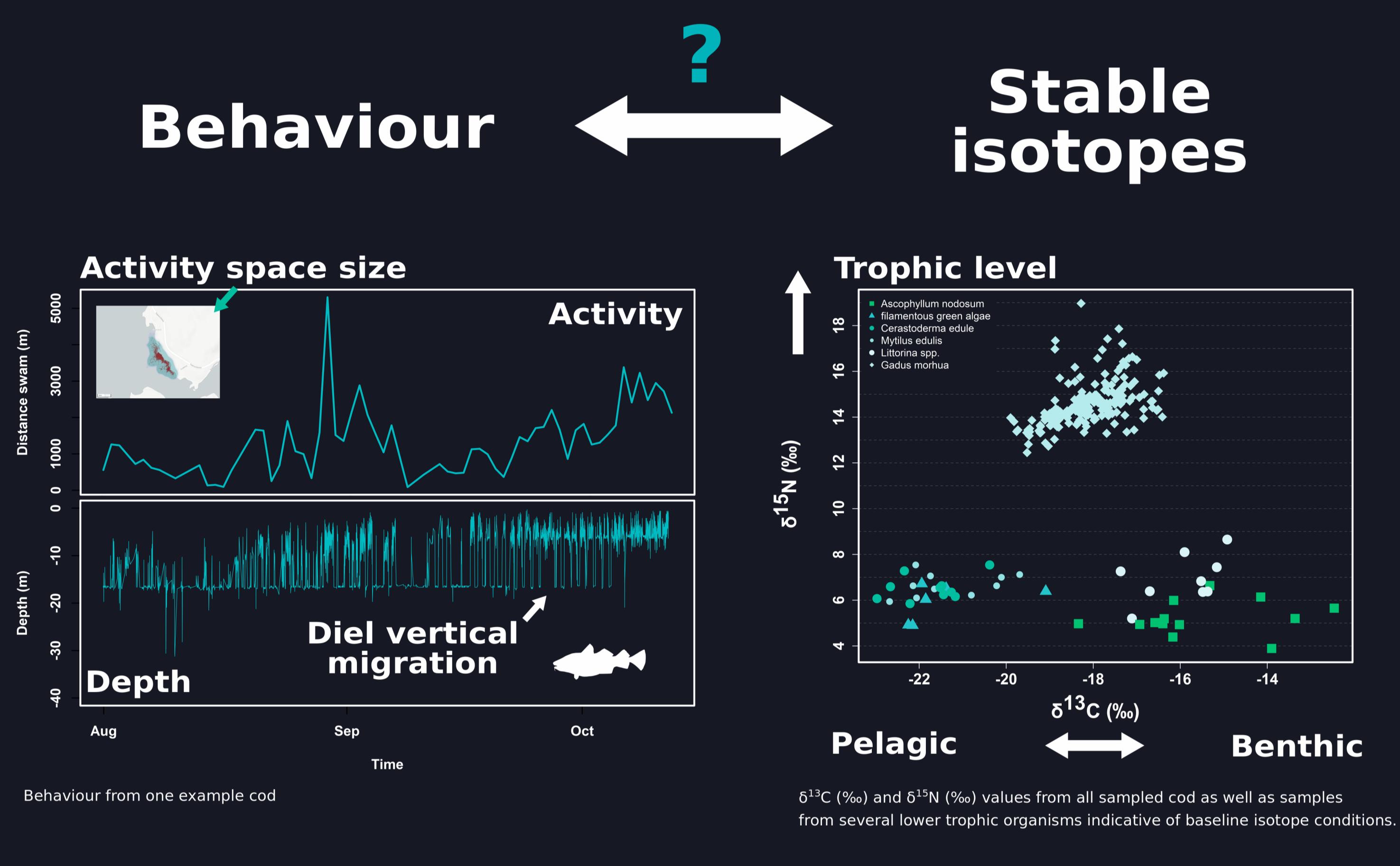
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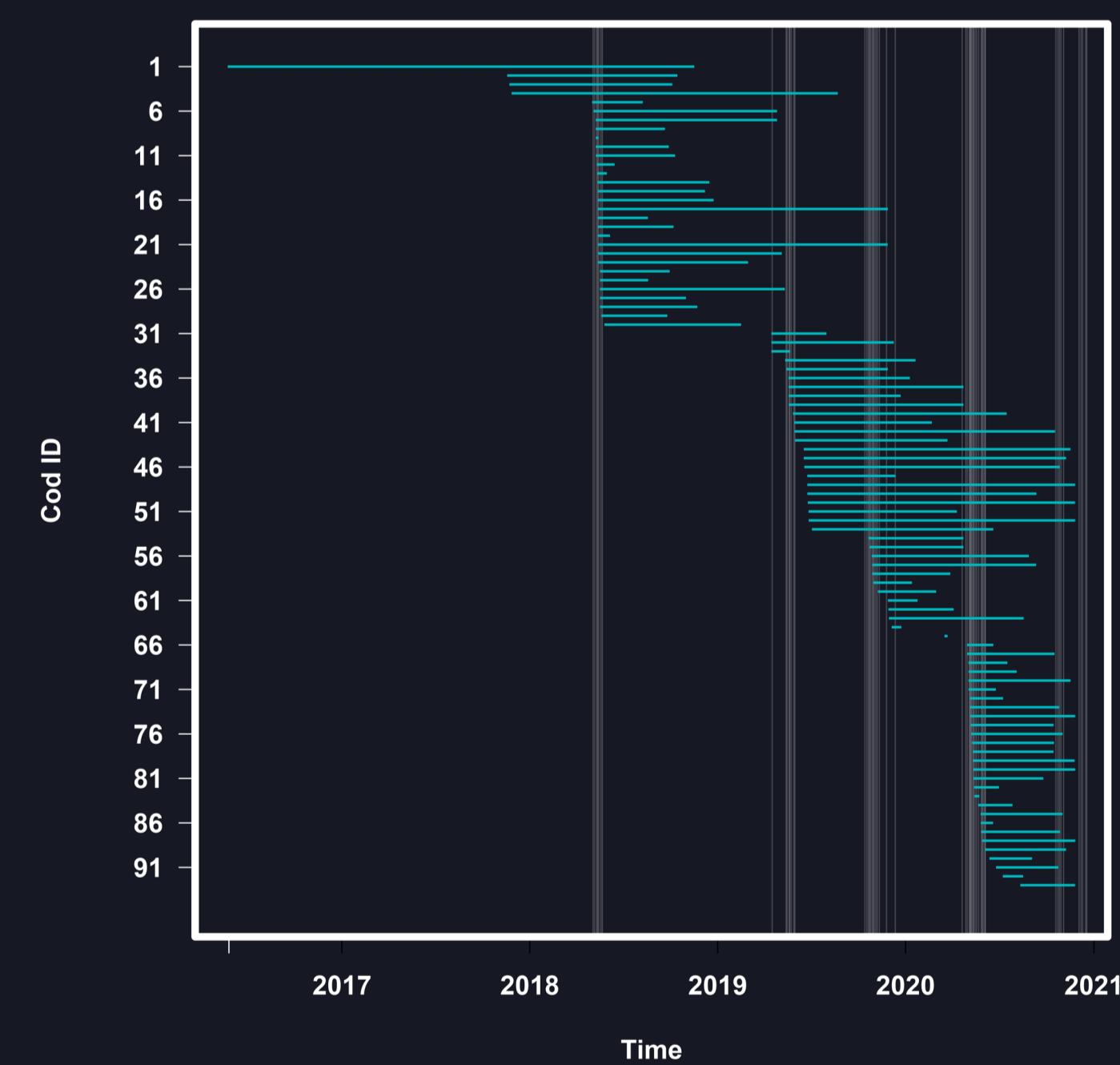
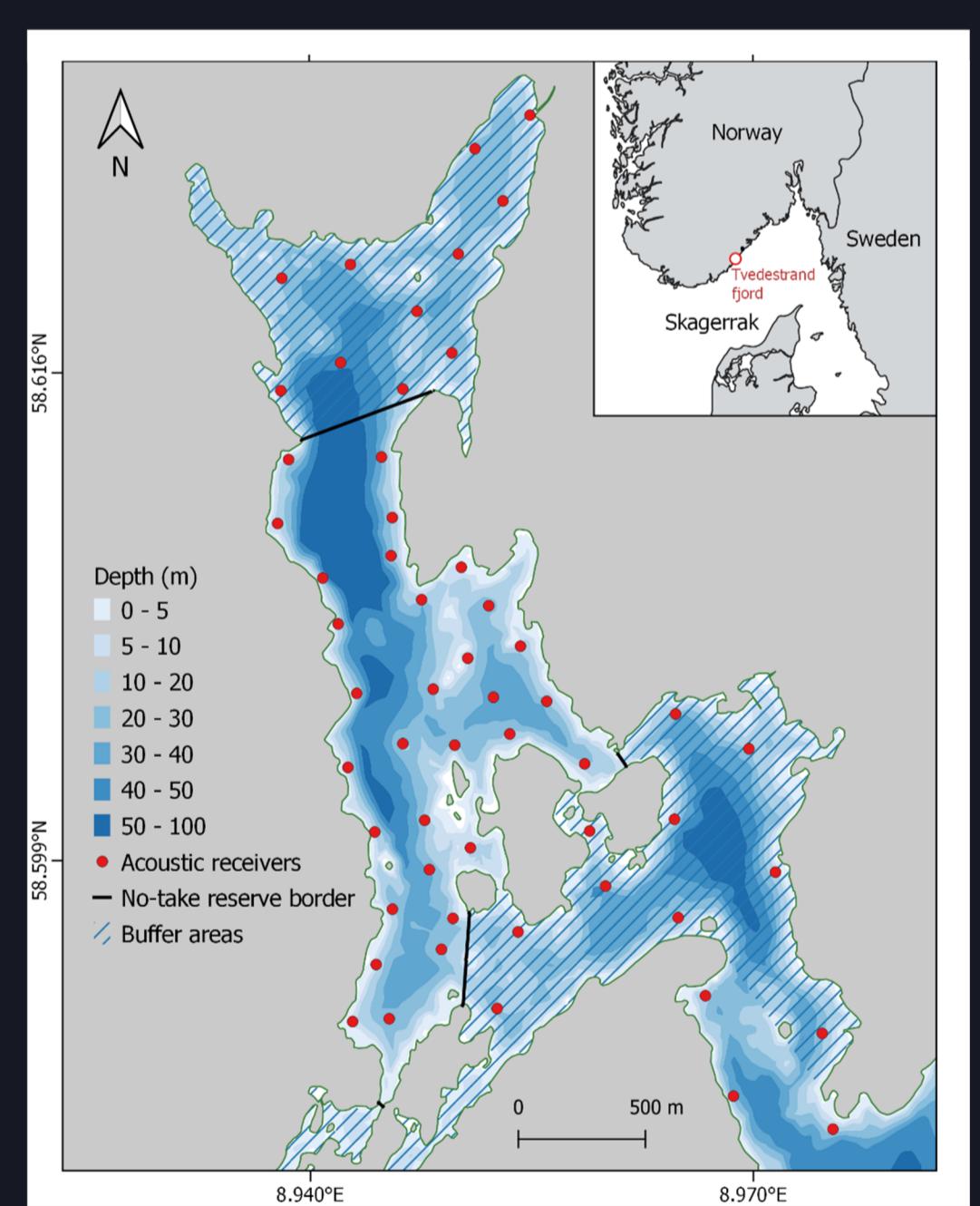
## Introduction

Foraging is a behavioural process, therefore consistent individual differences in behaviour are expected to correlate with individual differences in diet. We tested whether behaviour type and diet covary in a population of Atlantic cod, *Gadus morhua*, in a no-take marine reserve. We inferred behaviour using acoustic telemetry and diet from stable isotope compositions (expressed as  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ). We also tested whether behaviour and diet have survival costs.



## Methods

We sampled 184 cod (16–72 cm FL) between May 2018 and December 2020 in the Tvedstrand Fjord, a no-take MPA established June 2012. Muscle biopsies were taken from all cod for stable isotope analysis. Tissue samples were dehydrated and pulverized and isotopes were measured using a Delta Plus Continuous Flow Stable Isotope Ratio Mass Spectrometer coupled to a 4010 Elemental Analyzer. A subset of 97 cod were tracked with a 55 receiver Innovasea VPS telemetry array for 5 to 901 days (median 179). Mean transmitter delay was 180 s (130–230 s). The behaviour of 78 cod could be quantified. Behaviours were quantified daily from sunrise. We considered activity (cumulative distance travelled), activity space size (95% kernel utilization distribution), mean depth, and diel vertical migration (difference in mean depth before and after sunrise). Survival was assessed from cod movement patterns.



We used cox proportional hazards models to assess whether behaviour or diet predict fate. For the relationship between behaviour and isotope values we used a single multivariate mixed effects model to carry through the uncertainty from daily variation in behaviour. We fit the model with Bayesian inference using the MCMCglmm package in R. We assessed the 95% credible intervals of the correlations within the multivariate posterior distribution for significance.

(activity, act. space, depth, d.v.m., d15N, d13C) ~ length + quarter + solar elevation, random = ~ ID

repeated measures      single measures      for isotopes only to control for sampling event      for behaviours only to control for seasonal effects

## Results

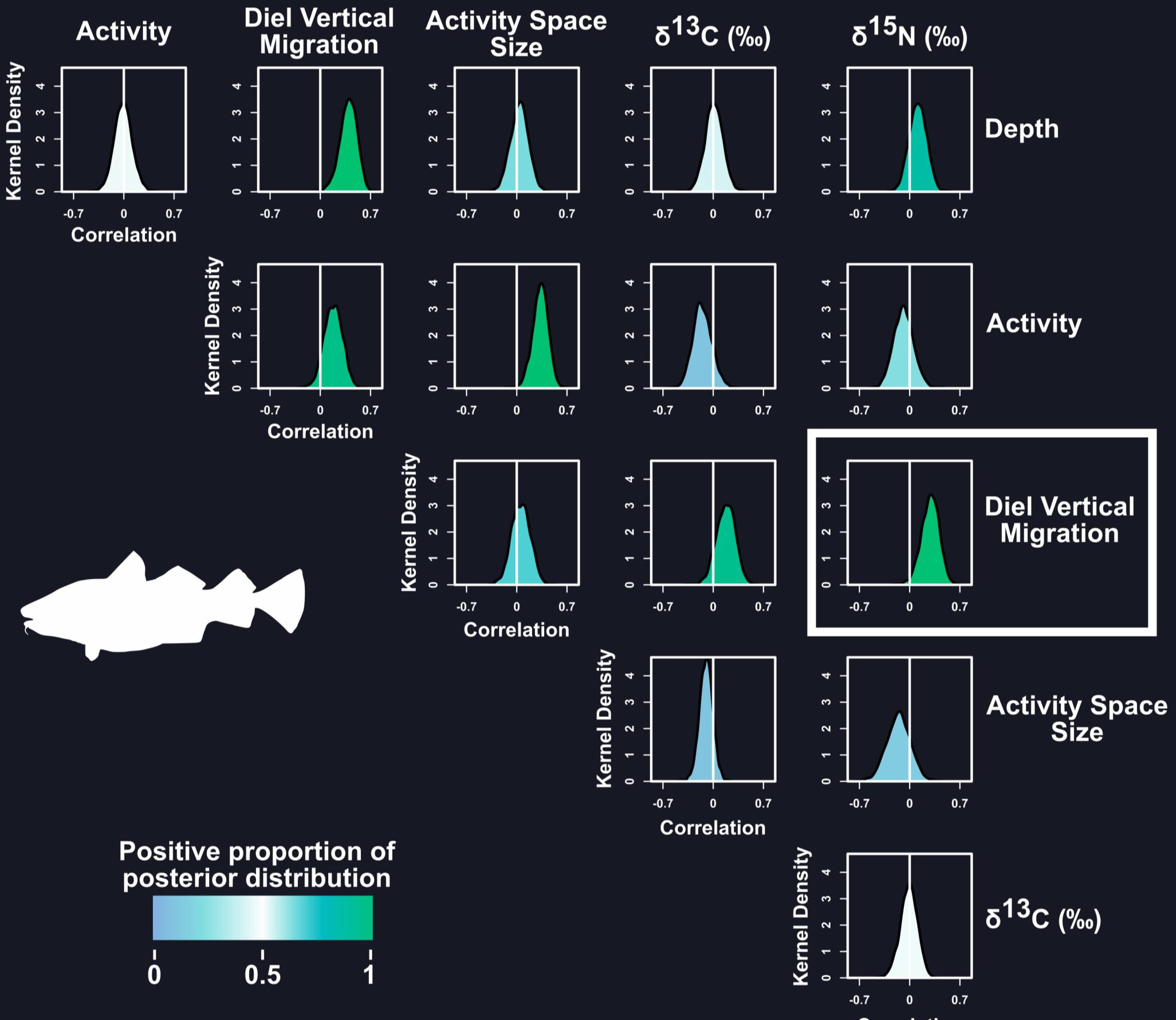
Neither behaviour nor diet were related to cod survival.

	Coefficient	Hazard ratio	SE (coeff)	z value	p value
$\delta^{13}\text{C} \text{\textperthousand}$	-0.088	0.916	0.153	-0.578	0.563
$\delta^{15}\text{N} \text{\textperthousand}$	-0.176	0.838	0.159	-1.108	0.268
Activity	0.281	1.325	0.167	1.680	0.093
Activity Space Size	0.206	1.228	0.147	1.400	0.161
Depth	0.203	1.225	0.130	1.553	0.120
Diel Vertical Migration Distance	0.085	1.088	0.171	0.495	0.621

dispersed: 6, natural mortality: 23, consumed by predators: 25, harvested: 15, survived: 26, tagging mortality: 1, undetermined: 1

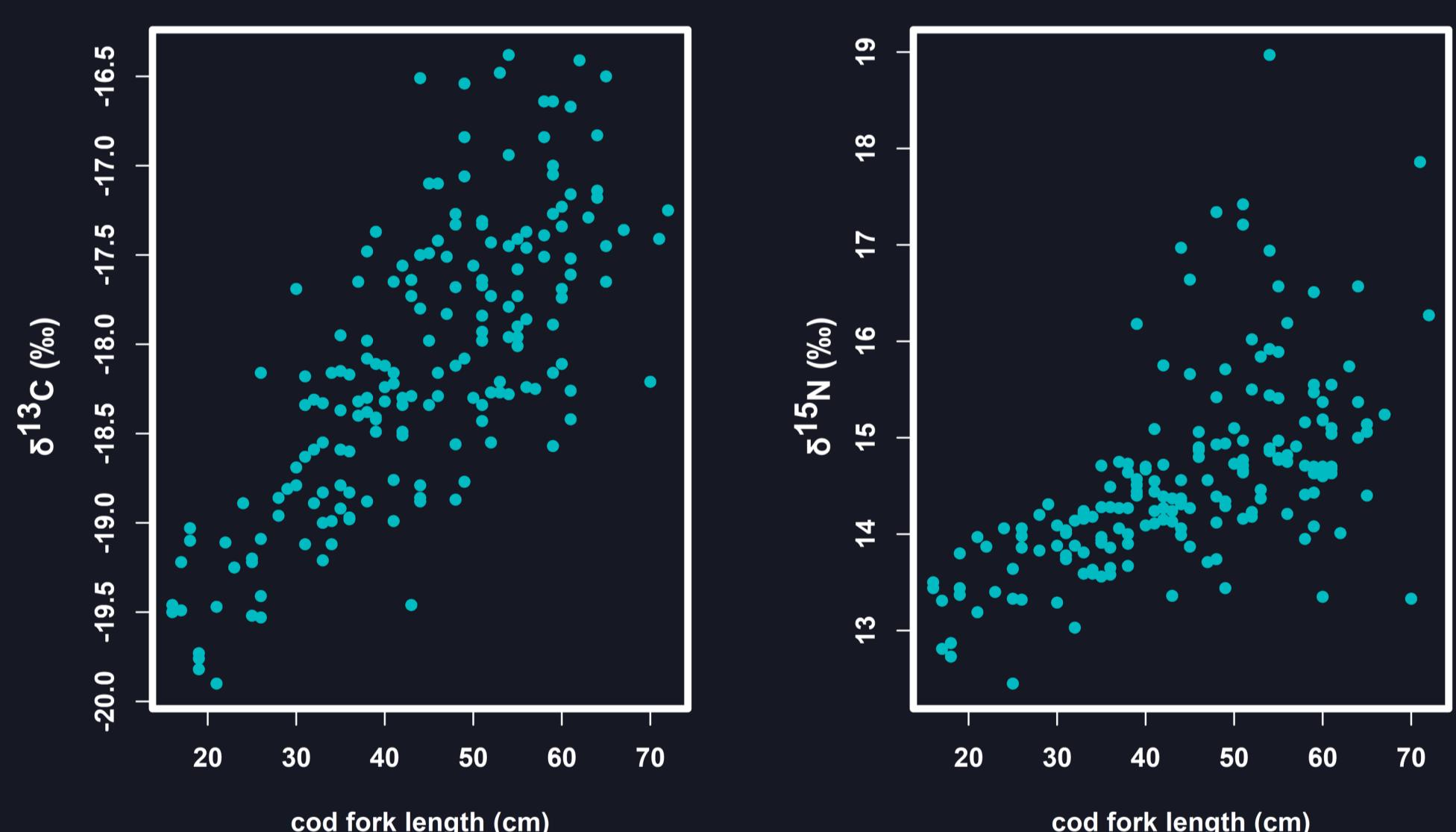
Diel vertical migration distance was correlated with  $\delta^{15}\text{N}$ , where cod with lesser diel vertical migrations\* consumed food at a higher trophic level.

\*more negative = greater diel vertical migration distance



Repeatability (mode, 95% CI): Activity ( $r = 0.66$ , 0.58 - 0.72), Activity space size ( $r = 0.67$ , 0.59 - 0.74), depth ( $r = 0.53$ , 0.45 - 0.62), diel vertical migration ( $r = 0.17$ , 0.12 - 0.24).

Cod body size and isotope signatures were highly correlated



## Conclusion

- Diel vertical migration distance was related to diet, implying consistent individual differences in cod behaviour can have community level impacts. Future work is needed to understand whether shifts in diel vertical migration during environmental change (e.g. fishing or climate related impacts) could lead to trophic cascades.
- Animal personality and diet specialization should be better integrated. Acoustic telemetry is well suited for measuring personality in the wild.
- Lack of mortality risks may allow multiple combinations of behaviour and foraging tactics to coexist.
- Trophic cascades from behaviourally selective fishing based on space-use or depth appear unlikely in coastal populations of cod in southern Norway.

## Acknowledgements

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