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Characterisation of stratification regimes and implications of these regimes on biochemical properties across a Pacific shelf system

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1. Background and Motivation

- Regional setting: Queen Charlotte Sound (QCS) on the Pacific coast of Canada (Fig 1&2)
- QCS is a dynamic region where large-scale forcings interact with local processes
- It is highly biologically productive & is a vital fishing ground.
- It hosts several Marine Protected Areas
- QCS has human communities that rely on marine ecosystems inhabiting along its coastline
- Ecosystems in QCS are becoming increasingly susceptible to marine heatwaves, ocean acidification and deoxygenation
- Stratification plays an important role in setting the physical and chemical environment, thus impacting how climate affects the region, including its biochemical cycles and ecosystems
- In this study, we investigate how variability in stratification between the coast and open ocean influence the physical and biochemical properties

2. Study goal

- Characterise the variability in stratification regimes
- Investigate the implications of variability in stratification regimes on biogeochemical properties

3. Methods and observations

3a. A Sustained glider monitoring program

- 10 glider surveys; 8,050 profiles were collected over one annual cycle: (July 2020 – August 2021) despite struggles
- Coast-to-open ocean transects along Goose Trough (Fig 1&2)
- Measured physical, chemical, biological and optical properties at high spatiotemporal resolution (Fig 4)

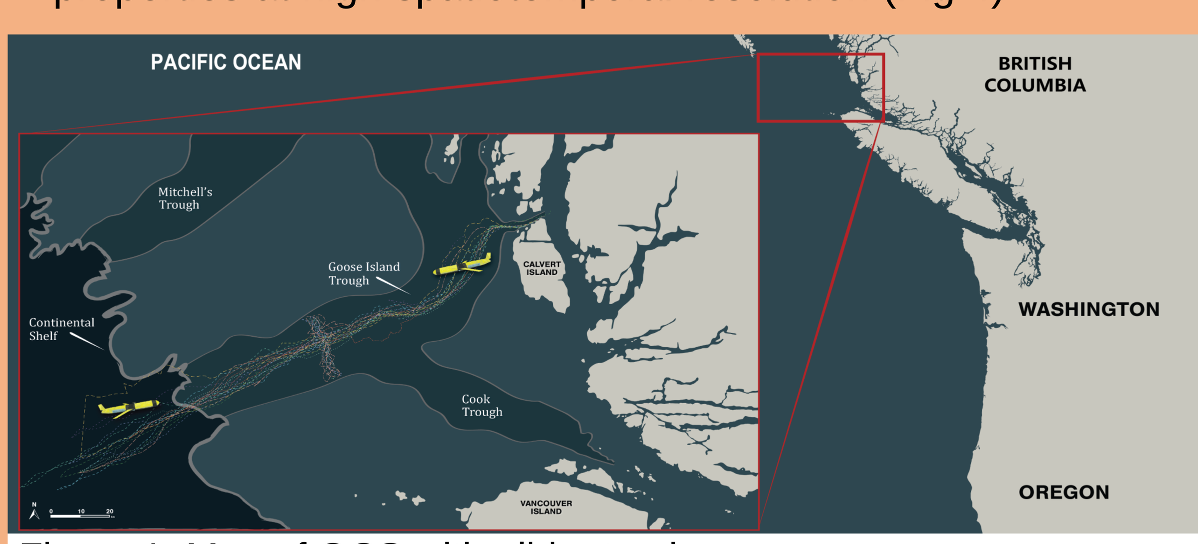

Figure 1: Map of QCS with glider tracks.

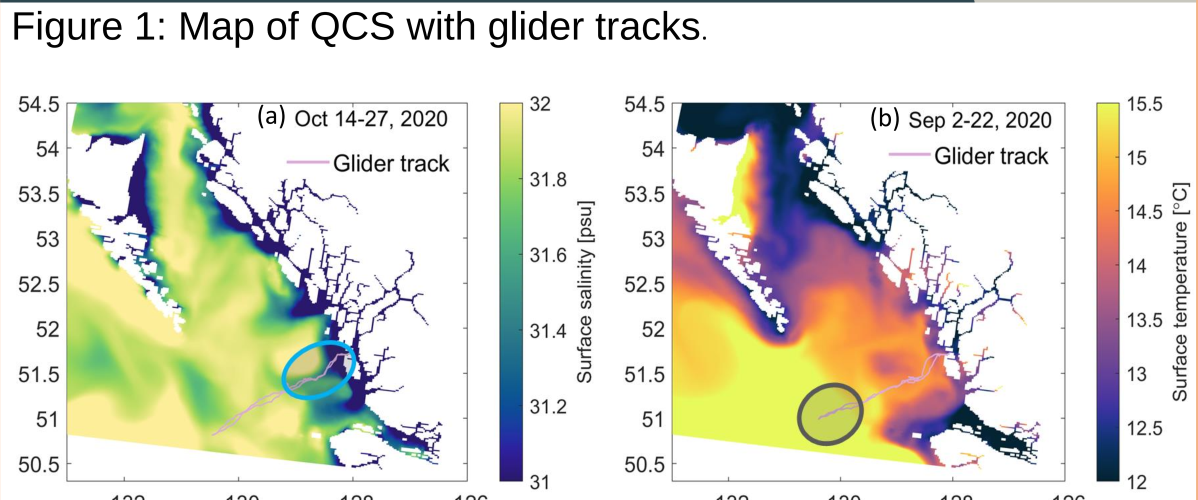

Figure 2: Surface (a) salinity and (b) temperature from the CIOPS-W pseudoanalysis model. Circles mark examples where (a) beta and (b) alpha regimes can be found.

3b. Defining stratification Regimes

- Defined three stratification regimes (Alpha, Beta and Transition Regimes) based on temperature and salinity contributions to density stratification (Fig 3)
- Seas strongly stratified by temperature: alpha oceans
- Seas strongly stratified by salinity: beta oceans
- Calculated salinity and temperature contributions to density stratification for the upper 50 m, and used a criteria of Δ0.003 between N^2_T ($N^2_T = g\alpha dT/dz$) and N^2_S ($N^2_S = g\beta dS/dz$) to identify significant spatial boundaries of each regime

$$-0.003 \quad < \quad N^2_T - N^2_S \quad < \quad 0.003$$

Beta Regime	Transition Regime	Alpha Regime

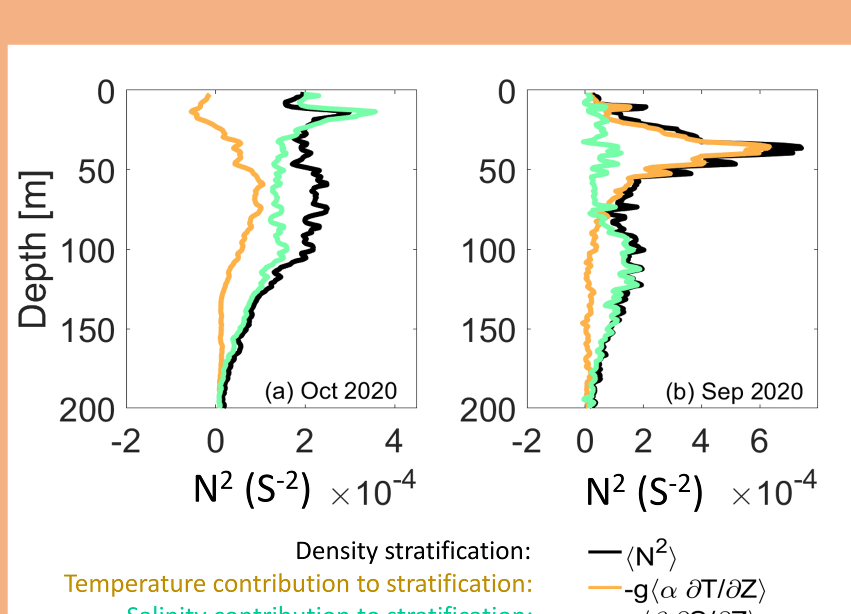

Figure 3: Vertical stratification N^2 (s^{-2}, in black), with contributions from temperature (orange), and salinity (green) for (a) a Beta Regime in Oct 2020 and (b) an Alpha Regime in Sept 2020.

4. Results

	Beta Regime	Alpha Regime	Transition Regime
Characterisation of stratification regime	• Low salinity near surface due to influence of freshwater (Fig 2a) • Lower temperatures and high CDOM (Fig 4), indicating a riverine and coastal source • Observed in coastal and nearshore regions, and sometimes where Goose Trough and Cook Trough intersect • Strongest signals in autumn and spring (increased rainfall, snow melt)	• Higher temperatures than the rest of the shelf (Fig 2b) • Usually has a more defined mixed layer • Observed in the open ocean and farshore end of the transect • Present mostly in summer and autumn when there is seasonal warming	• Exists between alpha and beta regimes and are regions where the stratification is seasonally or intermittently set by heat or salt • Influenced by estuarine exchange influence in the on the nearshore side and open ocean exchanges on the farshore side • Observed between the coastal and open ocean • Present year-round but its spatial extent varies
Implications for biochemical properties	• Low chl-a in autumn, but high chl-a in spring (Fig 4&5a,c) • Low oxygen concentrations in autumn, but high dissolved oxygen concentrations in spring (Fig 4&5a,c)	• Layer of subsurface chl-a maximum past shelf break (Fig 4&5b,c), beneath the temperature stratified layer. • Patches of high subsurface dissolved oxy. in summer, between two stratification maxima (4b,c)	• Biochemical implications not necessarily a direct consequence of observed stratification patterns (Fig 4&5)

Table 1: Characteristics of Beta, Alpha and Transition Regimes and their respective implications for biochemical properties.

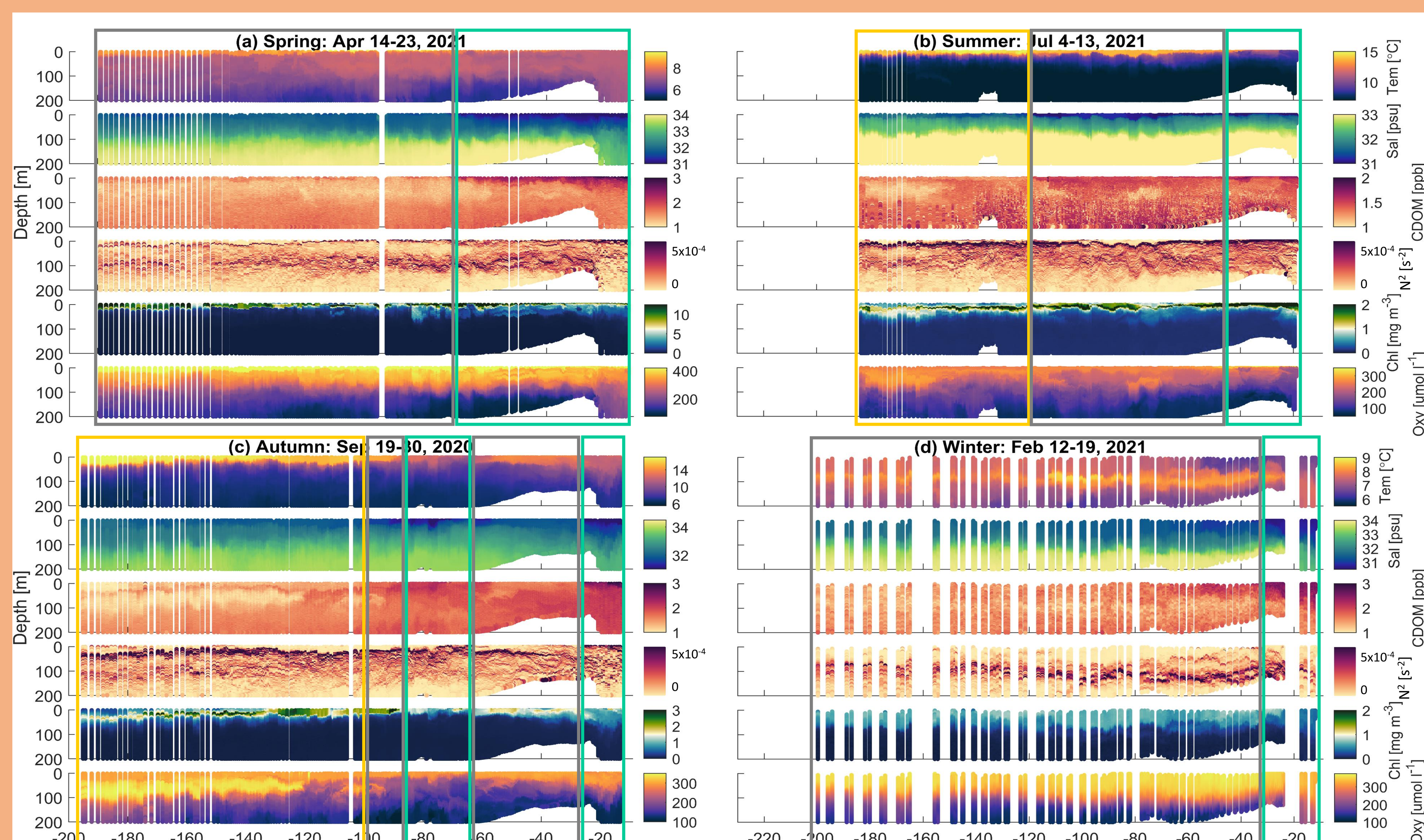

Figure 4: Glider transects of temperature, salinity, CDOM, chlorophyll-a concentration and dissolved oxygen concentration (from top to bottom) for the upper 200 m for four surveys conducted in (a) spring 2021: Apr 14-23, (b) summer 2021: Jul 4-13, (c) autumn 2020: Sep 19-30 and (d) winter 2021: Feb 12-19. Active regimes for these four surveys are highlighted in rectangular boxes; beta regimes in teal, alpha regimes in orange and transition regimes in grey.

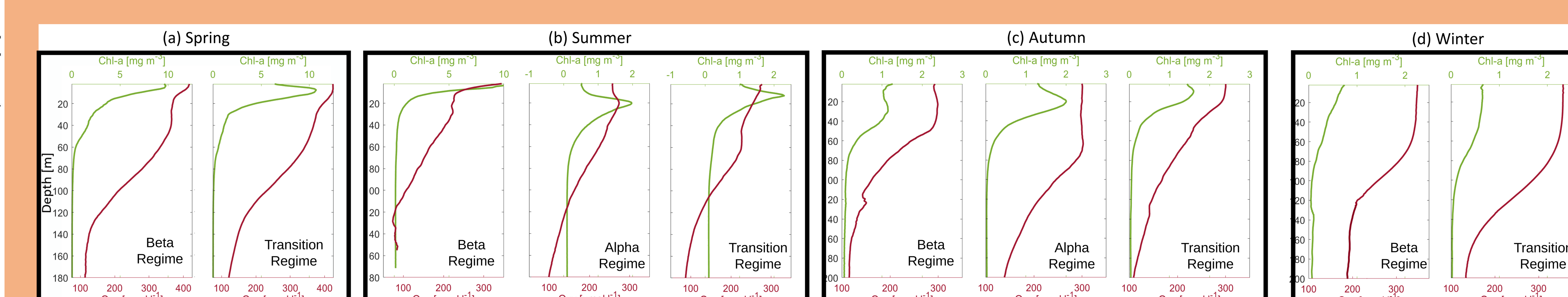

Figure 5: Implications of the distinct stratification regimes and seasonality for biochemical properties. Averaged Chl-a (in green) and dissolved oxygen (in red) profiles associated with active regimes in (a) spring 2021: Apr 14-23, (b) summer 2021: Jul 4-13, (c) autumn 2020: Sep 19-30 and (d) winter 2021: Feb 12-19.

5. Summary

- Stratification regimes co-exist (Fig 4), but number of active regimes and their spatial extent vary seasonally (Fig 6)
- It is useful to define different stratification regimes to understand the strength of the drivers of variability from coast to open ocean
- These regimes are sometimes important for biochemical properties (esp. Beta and Alpha Regimes)

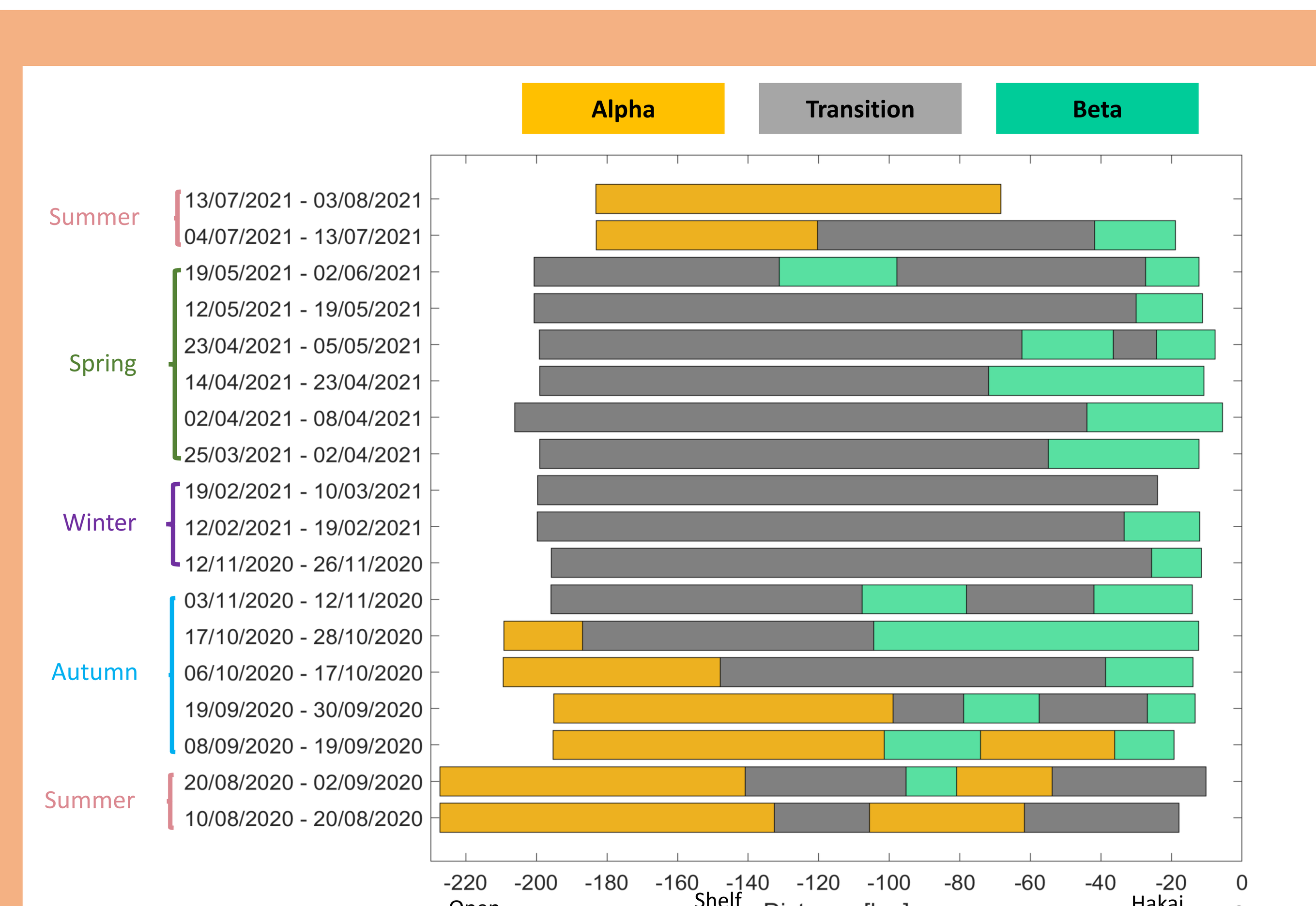

Figure 6: Bar graph showing spatial extent of active regimes as they vary over an annual cycle.

6. Climate change implications

- Stressors through increased riverine inputs, more melting glaciers, increased precipitation and warmer waters are expected.
- These will increase surface stratification, weaken ocean overturning and ventilation, reduce mixing between ocean layers, decrease vertical exchanges of heat, carbon, oxygen and nutrients.
- Understanding what causes the changes in stratification and their effects on biochemical properties is crucial to predict future extreme scenarios in shelf systems.

"Stratification is perhaps the most important attribute of oceans with regards to climate and biology."

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