Title: The Growth of Finfish in Global Open Ocean Aquaculture under Climate Change

Running Title: Open Ocean Aquaculture under Climate Change

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SUPPLEMENTARY INFORMATION

1.0 Data limitations – growth curves and physical oceanography

Temperature-dependent growth data are limited for most fish, and in order to project changes in other farmed species, further research is required to establish their TPCs for growth. For example, there are currently few controlled experiments on temperature-dependent growth in fish across the entire grow-out period. Conducting laboratory temperature and growth experiments with fish over several months or years is expensive and logistically difficult, meaning most studies focus on short-term temperature-growth relationships, reducing the accuracy of estimated TPCs. Further, environmental conditions in offshore grow-out operations differ from laboratory conditions and can alter growth rates and bias TPCs. Controlled temperature experiments in grow-out environments are logistically prohibitive but would be the most accurate method to estimate the temperature dependence of growth in open ocean aquaculture settings. Farms would be the most viable source of this type of data, but the industry currently has little incentive to share data (Callaway *et al.*, 2012). There is also evidence that fish health and growth rates may be higher offshore than in coastal operations (e.g. Kirchhoff *et al.*, 2011; Maricchiolo *et al.*, 2011). As such, the growth rates used in this study are likely conservative estimates. TPCs change with ontogeny, and although the change within the grow-out period is small relative to other lifestages, there are changes in the shape of the TPC and the optimum and extreme temperatures (Handeland *et al.*, 2008). An improved understanding of the relationship between growth and temperature and growth and other environmental variables (e.g. current and salinity) would allow for the use of more robust growth models with additional dynamic parameters.

Future studies would benefit from additional oceanographic data concerning the depth of thermocline. Open ocean aquaculture technology is improving rapidly, making it possible to establish operations further from shore and in deeper waters. In addition, pens can also be submerged further from the surface to avoid unfavorable surface conditions (Lekang, 2013). A shallow thermocline may mean that farms have to balance surface threats with potentially unfavorable ambient water temperatures at submerged depths below the thermocline. Knowledge of thermocline depth and temperature throughout the water column would allow farmers to balance these trade-offs and target or avoid specific water temperatures. Incorporating thermocline information could also allow the model to exclude areas with seasonally low dissolved oxygen concentrations associated with upwelling.

Daily temperature fluctuations have been shown to be physiologically important to TPC parameters (Kern *et al.*, 2015). Use of higher frequency temperature data (e.g. hourly), coupled with an improved understanding of the physiological mechanisms that govern TPCs, would allow for better predictions of how species respond to temperature change, as the monthly means used in this study can obscure variation and extremes that could alter growth or lead to mortality (Schulte *et al.*, 2011; Sheldon & Dillon, 2016).

Table S1. Values and references for temperature-growth components of each species, Atlantic salmon (*Salmo salar*), gilthead seabream (*Sparus aurata*), and cobia (*Rachycentron canadum*). Extensive literature searches were conducted using both traditional academic sources (e.g. Web of Science and Google Scholar) and industry and gray literature available online. Temperature values (Tmin, Topt, and Tmax) are determined based on laboratory and field studies. Growth values (monthly growth rate) are determined based on reports from laboratory and field studies and industry reports.

Species	**T_{min}**	**T_{opt}**	**T_{max}**	**Monthly Growth Rate grams month^{-1}**	**References**
Salmo salar	1.5	14	19	0.33	(FAO, 2015a; Handeland *et al.*, 2008; Marine Harvest, 2015)
Sparus aurata	12	25	32.9	0.03	(FAO, 2015b; Hernández *et al.*, 2003; Lupatsch & Kissil, 1998; Seginer, 2016; Silva *et al.*, 2014; Tort *et al.*, 2004)
Rachycentron canadum	22	29	32	0.5	(Benetti *et al.*, 2010; Fraser & Davies, 2009; Kaiser & Holt, 2005; Liao *et al.*, 2004; Miao *et al.*, 2009; Nhu *et al.*, 2011; Schwarz *et al.*, 2007)

Table S2. Values of linear function constants for each species, Atlantic salmon (*Salmo salar*), gilthead seabream (*Sparus aurata*), and cobia (*Rachycentron canadum*).

Species	**a_1**	**a_2**	**b_1**	**b_2**
Salmo salar	0.0264	-0.066	-0.0396	1.254
Sparus aurata	0.026	-0.0042	-0.0308	0.1388
Rachycentron canadum	0.0714	-0.1667	-1.5714	5.3333

Figure S1. Summary of sea surface temperatures increase in Earth System Model CM2.6: The difference between the 2016-2020 and 2046-2050 average monthly temperatures.

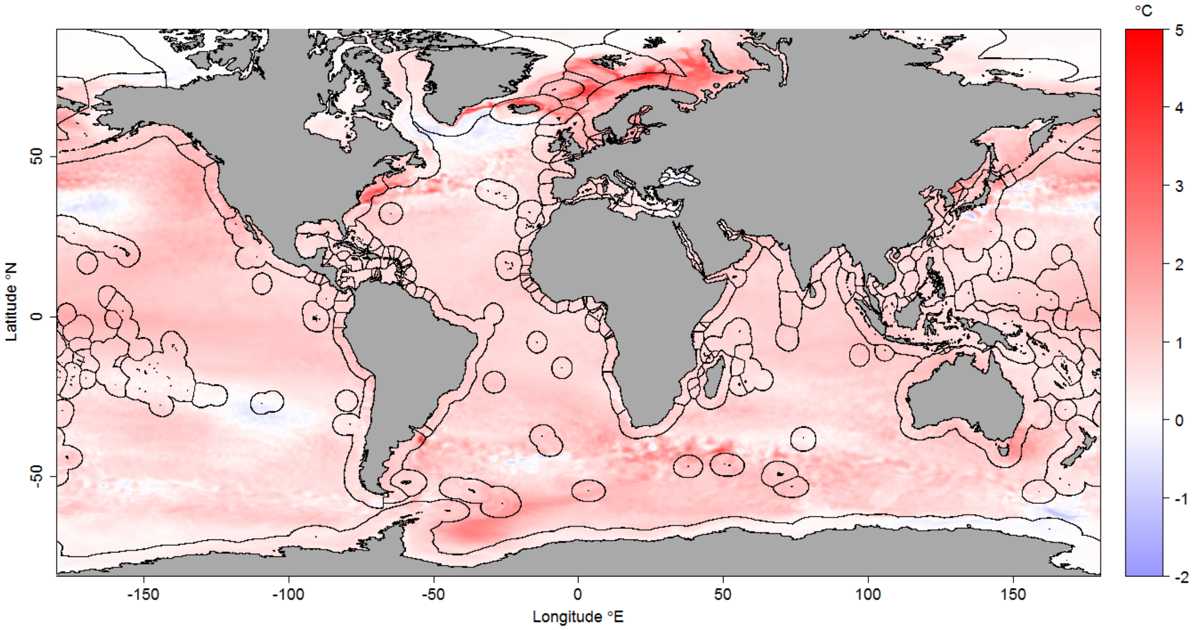


Figure S2. Area available (square kilometers) for salmon growth with application of no constraints (a, red), current (b, purple), eez (c, blue), depth (d, green), and all constraints (e, orange), over 5 year average from 2016-2020.

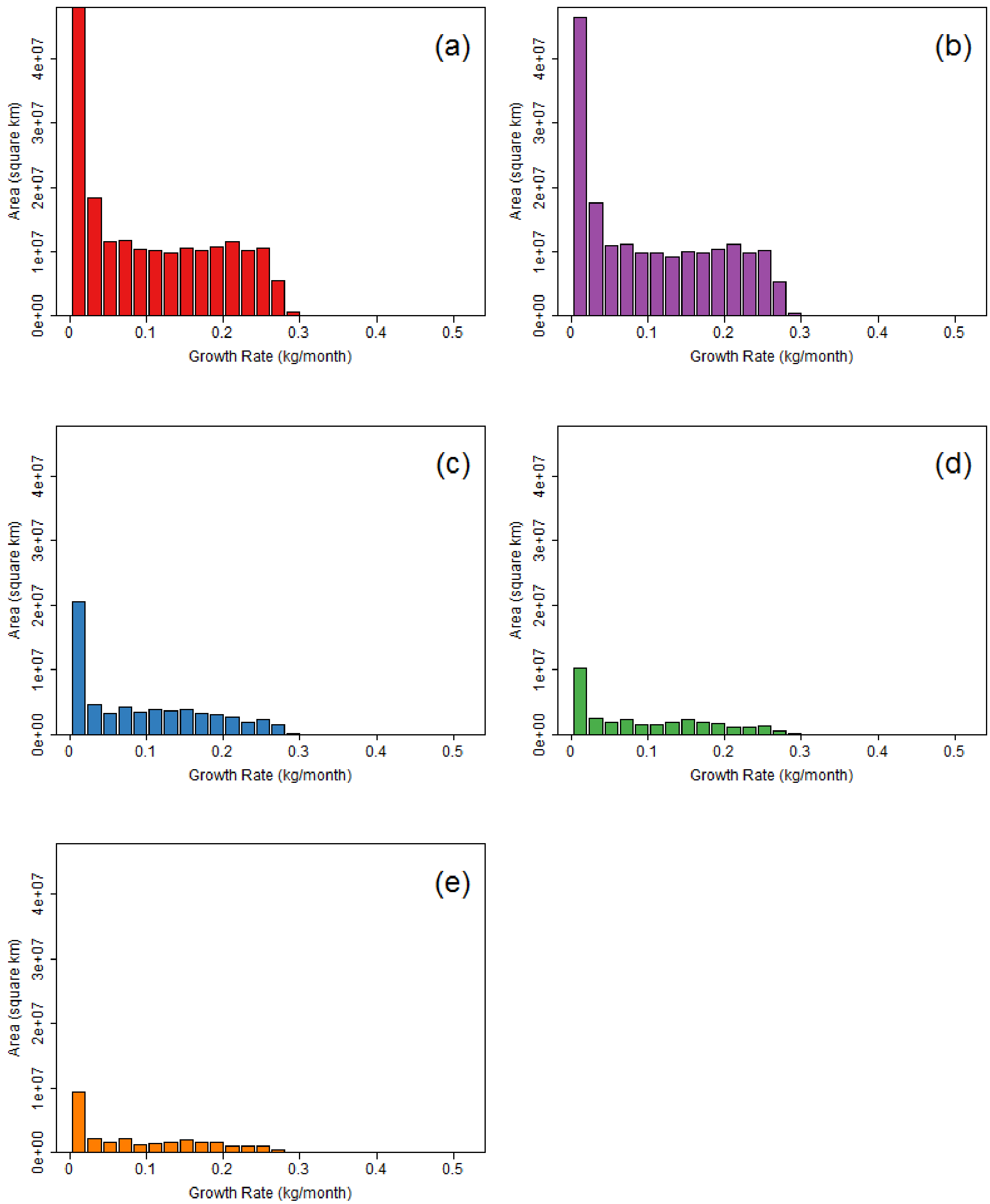


Figure S3. Area available (square kilometers) for seabream growth with application of no constraints (a, red), current (b, purple), eez (c, blue), depth (d, green), and all constraints (e, orange), over 5 year average from 2016-2020.

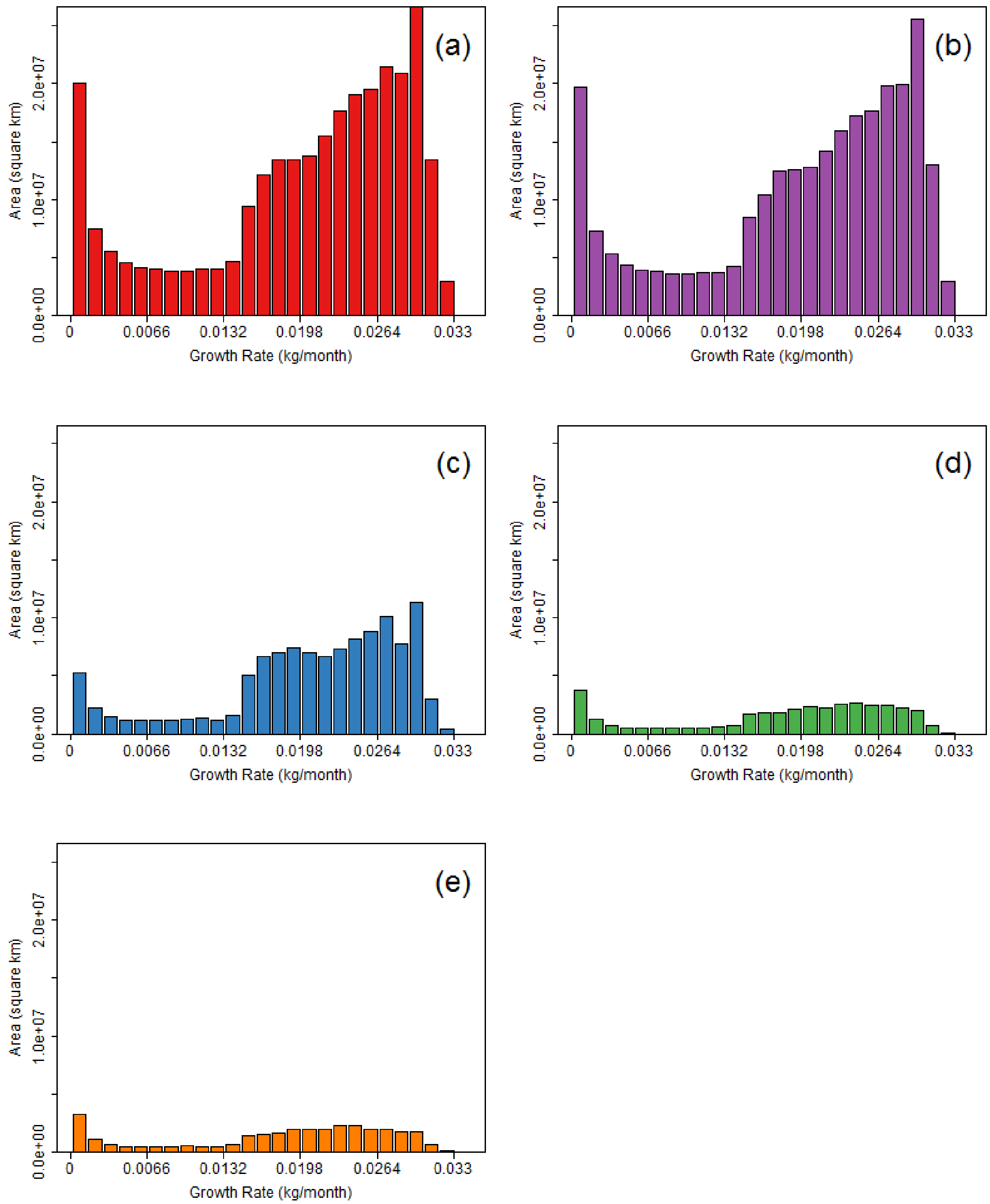
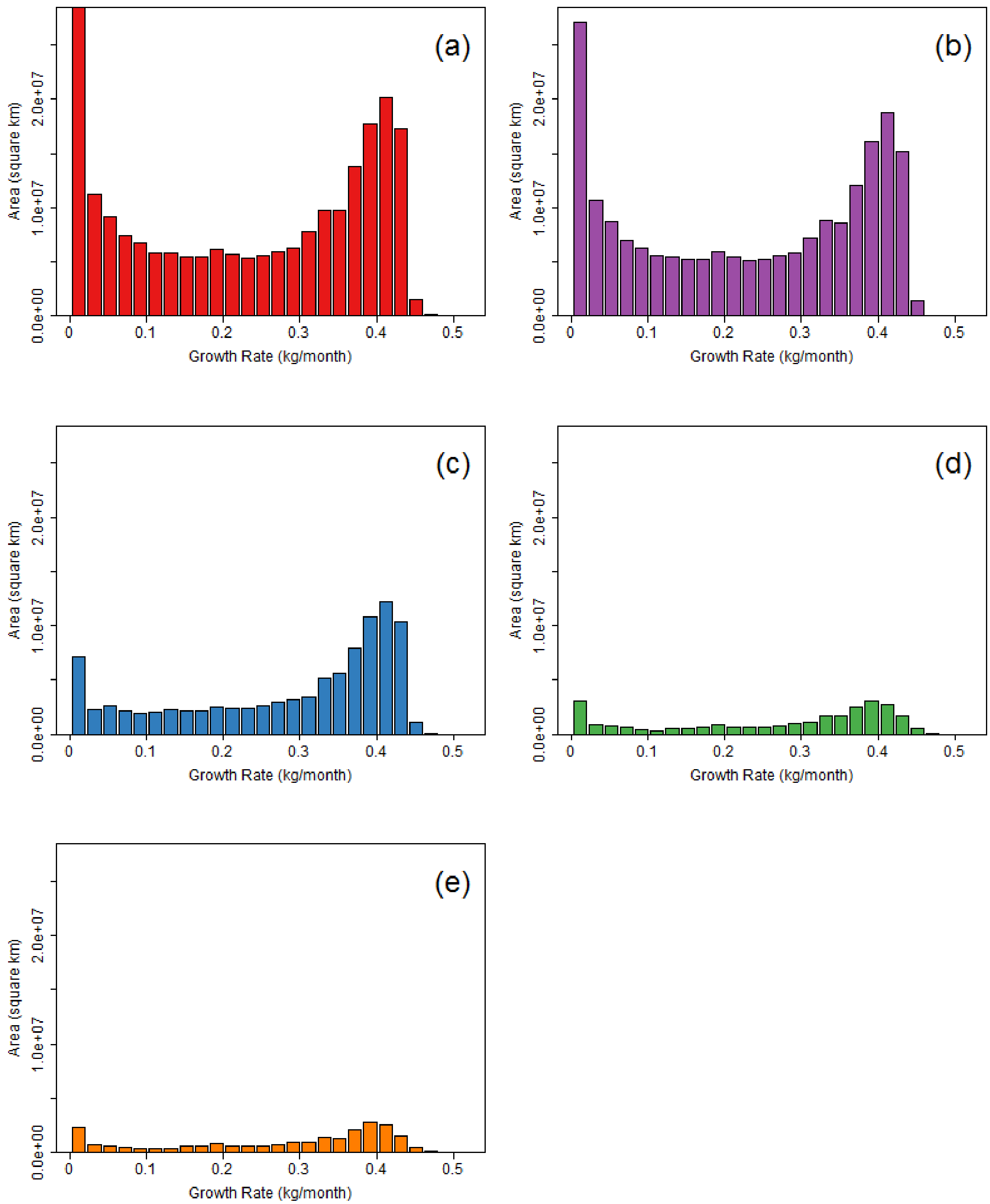


Figure S4. Area available (square kilometers) for cobia growth with application of no constraints (a, red), current (b, purple), eez (c, blue), depth (d, green), and all constraints (e, orange), over 5 year average from 2016-2020.



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