Appendix – Details of the Individual-Based Model (IBM)

This Appendix describes the equations and assumptions used to generate the length-at-age datasets used in the simulation testing component of this study. The first section describes the generation of the observed data, and the second component details further how spatial variation in fish size at age is introduced. Table A1 provides parameter values used in the study.

# A.1 Generation of age-length data

The IBM is designed to mimic individual variation in growth for an exploited fishery. The model runs for 100 years. Generally, all fish within each simulation are subject to the same baseline life history parameters, with three different growth “Regimes” (defined by distinct parameters of the growth equation, see below) assigned spatial ranges accordingly (see Assigning Spatio-temporal Variation, below).

## A.1.1. Growth

The growth module of the IBM is a von Bertalanffy growth function parameterized in terms of *L*1 and *L*2:

= App. Equation

where represents the lengths of a fish at ages , and *K* is the growth coefficient. The size of n individual *i* at age *a* is defined by its length in the previous year and a growth increment *I* that is lognormal:

App. Equation 2

where ) and = 0.025 for all ages and simulation Regimes.

## A.1.2 Survival

The composition of the fishery during year *y* includes all surviving fish from recruitment to a maximum age (represented here as a plus group ). After recruitment, all fish are subject to natural mortality *M*, which in our simulation consists only of natural mortality (set to 0.25 for all ages for all years) as there is no fishery, thus fishing mortality (typically denoted *F*) and selectivity can be ignored.

App. Equation 3

## A.1.3 Recruitment

Recruitment in the IBM is governed by a Beverton-Holt stock-recruitment function (Beverton and Holt, 1957), and a size-based maturity ogive which determines the probability of individual *i’*smaturity at age *a*, . Recruitment in a given year *Ry*is the sum of the product of the maturity ogive and empirical weights of each individual in that year, which is governed by a deterministic exponential length-weight relationship (Equation 3). The parameters of this relationship were the same in all Regimes. The maturity ogives were also fixed for all regimes, with (the length at 50% maturity) 143.68cm, and the slope of the ogive at -0.1034. Because no fishing pressure nor selectivity acted upon the simulated population, we are unconcerned about variation in productivity…

happens at a midway point, and is subject to variation via a bias-corrected lognormal recruitment deviation

App. Equation 4

App. Equation 5

App. Equation 6

App. Equation 7

App. Equation 8

# Assigning Spatio-temporal Variation

The simulation testing component required generation of datasets that comprised variation in fish size-at-age across space and/or time. To obtain spatial variation in length-at-age, we conducted simulations using one of three growth “regimes” (see Table 1). Parameters for Regime 1 are similar to Pacific billfish; values for Regimes 2 and 3 were chosen to present either high or low contrast (respectively) in the size at maximum age compared to Regime 1. Other parameters were held constant across regimes. Spatial scenarios tested are described in the main manuscript, Table 1. In all except the final (break-at-edge) and non-spatial scenarios, the latitude and longitude of fish grown under Regime 1 are sampled independently and at random from a uniform distribution between 0° and 25°; for simulations with spatial variation, fish grown under Regimes 2 and 3 have latitude and longitude sampled the same way from 25° to 50°. In the final scenario, fish simulated under life history Regime 1 are assigned latitudes and longitudes sampled independently and at random from a uniform distribution from 1° to 49°, and those simulated under Regime 2 have coordinates sampled similarly with both latitude and longitude bounded from 49° to 50°.

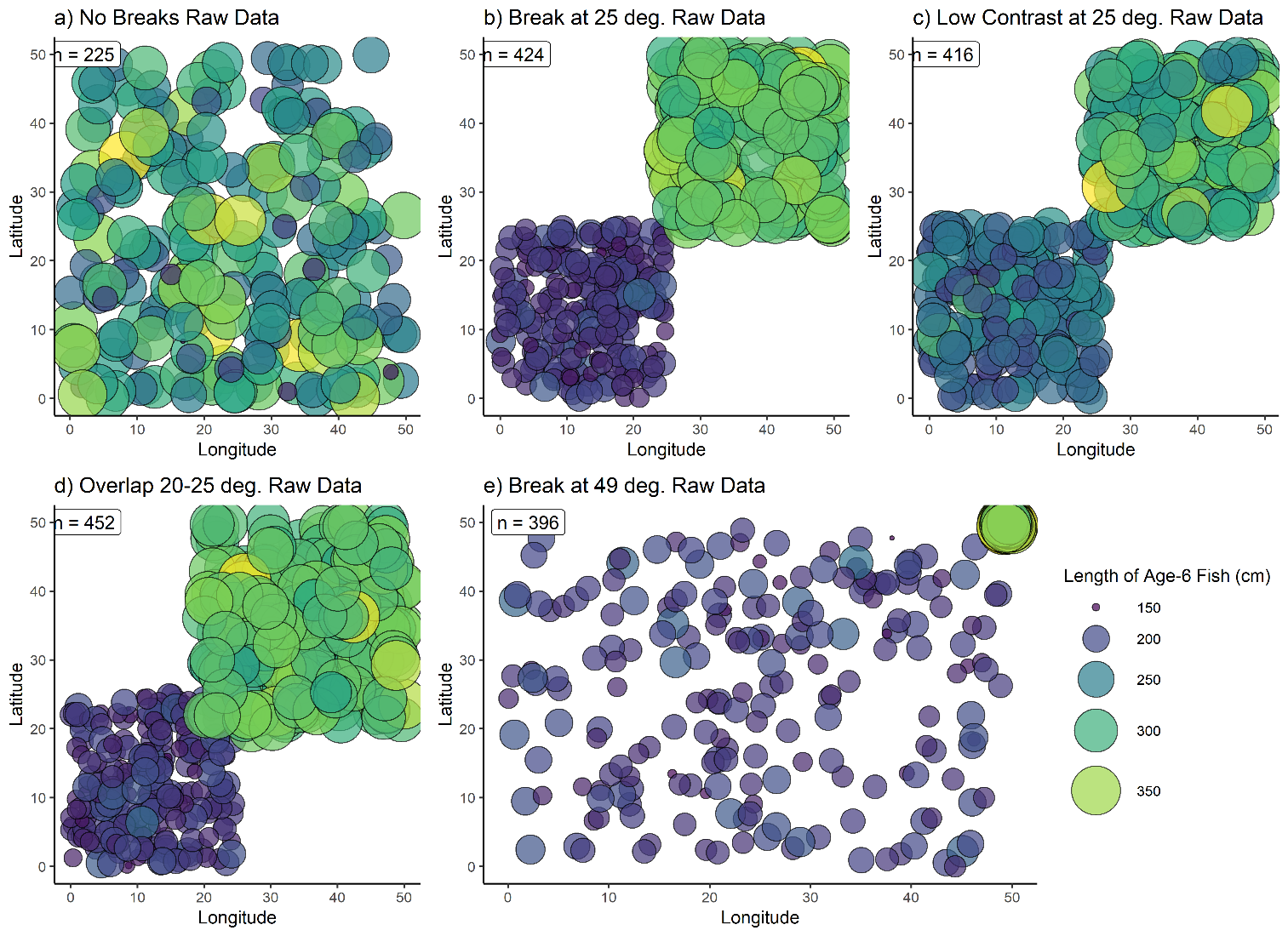


Figure A1. Example single dataset for each tested spatial scenario presented in Table 1, main manuscript.. For each scenario, points represent the length and location of a single simulated fish of age six, with the size of the individual fish indicated by the radius of the circle. Fish locations (latitudes and longitudes) were sampled from a uniform distribution of the boundaries indicated in above text. Text labels indicate the number of individual fish in the sample.

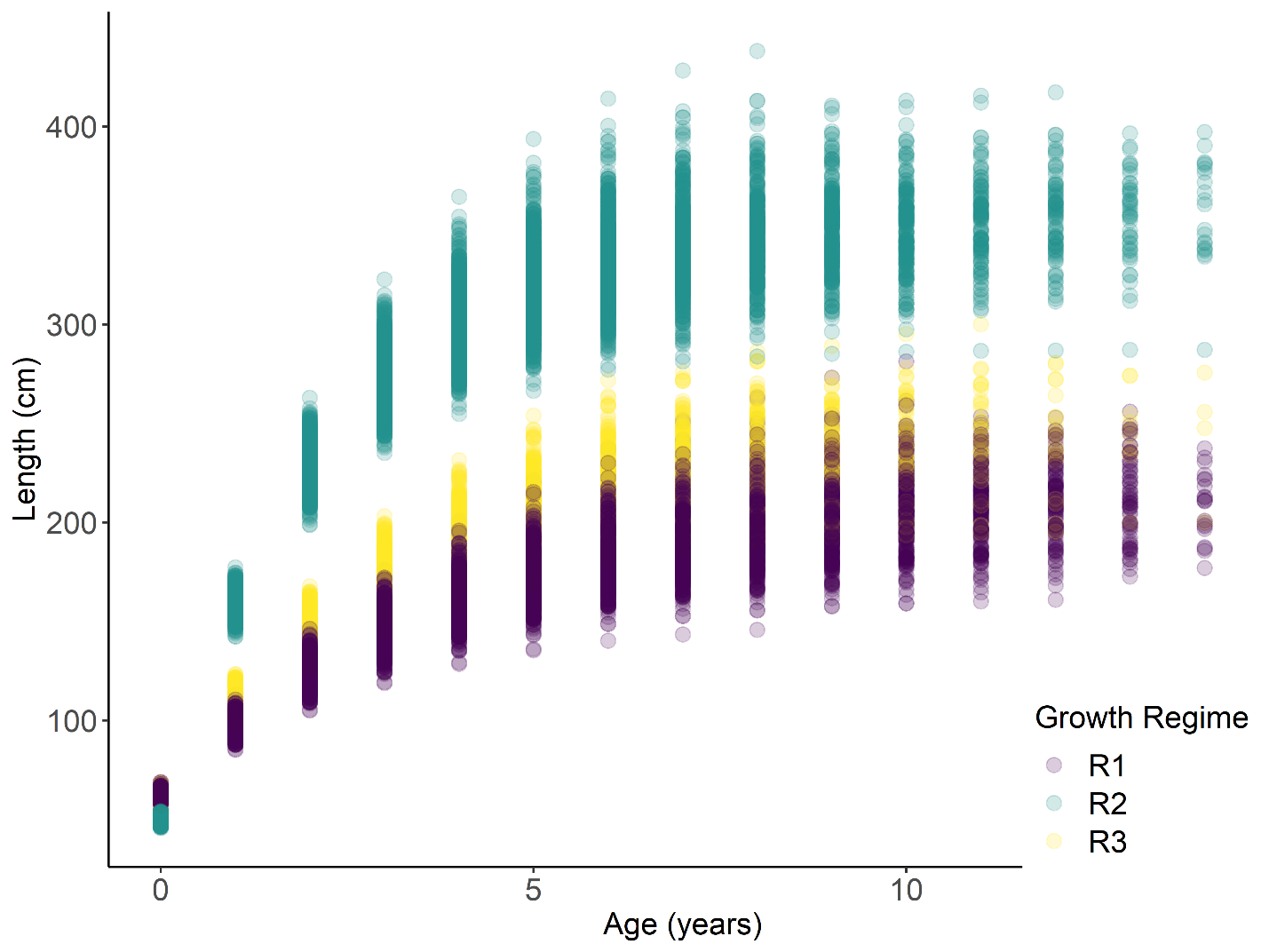


Figure A2. Example growth trajectories from simulated populations. Each circle represents a simulated individual fish’s length and age; colors correspond to the growth regime (i.e., growth curve) under which that fish was generated.

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| --- | --- | --- | --- |
| Module | Parameter | Definition | Value |
| Growth |  | Size at age (cm) | 62.7 (Regimes 1, 3)  50 (Regime 2) |
| Growth |  | Size at age (cm) | 216.7 (Regime 1)  350 (Regime 2)  248 (Regime 3) |
| Growth | K | Growth coefficient | 0.258 (Regime 1)  0.45 (Regime 2) |
| Growth |  | Age at (years) | 0 |
| Growth |  | Age at (years) | 15 |
| Growth |  | Lognormal growth error term | 0.025 |
| Growth | *a* | Multiplier of length-weight function | 1.35e-6 |
| Growth | *b* | Exponent of length-weight function | 3.427 |
| Survival | *M* | Natural mortality | 0.25 |
| Recruitment | *r* | Slope of maturity ogive | -0.1034 |
| Recruitment | L50 | Length at 50% maturity | 143.68 |
| Recruitment | *h* | Steepness of Beverton-Holt SRR | 0.9 |
| Recruitment | *R0* | Maximum number of recruits per year | 12 |
| Recruitment |  | Variation in recruitment | 0.1 |

Table A1. Parameter symbols, definitions and values used in the simulation study.

# References

Beverton, R.J.H., Holt, S.J., 1957. On the Dynamics of Exploited Fish Populations, Fisheries Investigations Series 2: Sea Fisheries. https://doi.org/10.1007/BF00044132

Methot, R.D., Wetzel, C.R., 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142, 86–99. https://doi.org/10.1016/j.fishres.2012.10.012