Spawning migration in fish: A case study of sockeye salmon from the Fraser River in British Columbia

by

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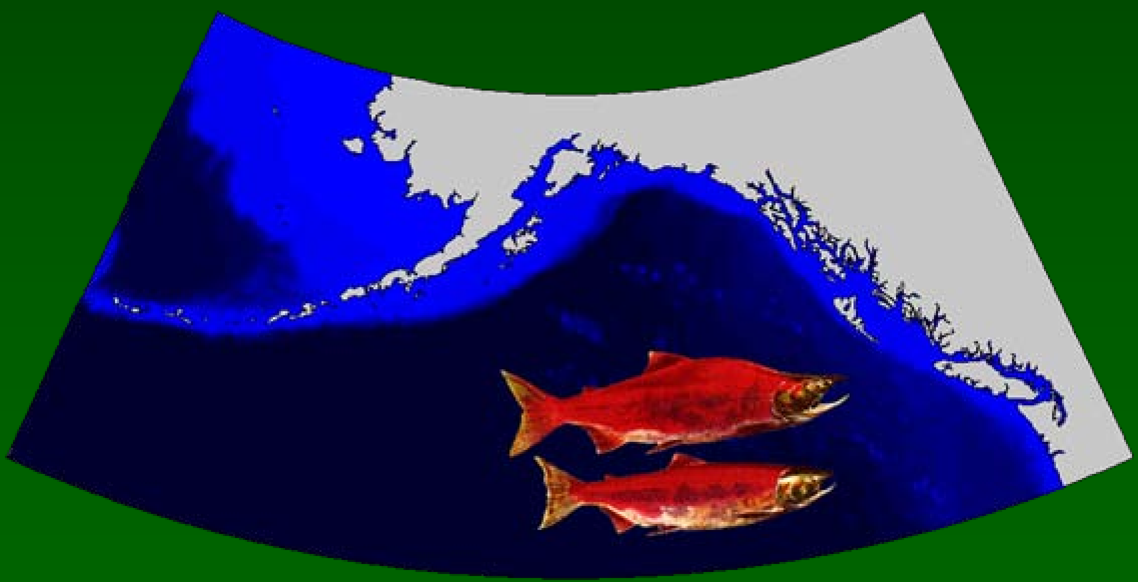

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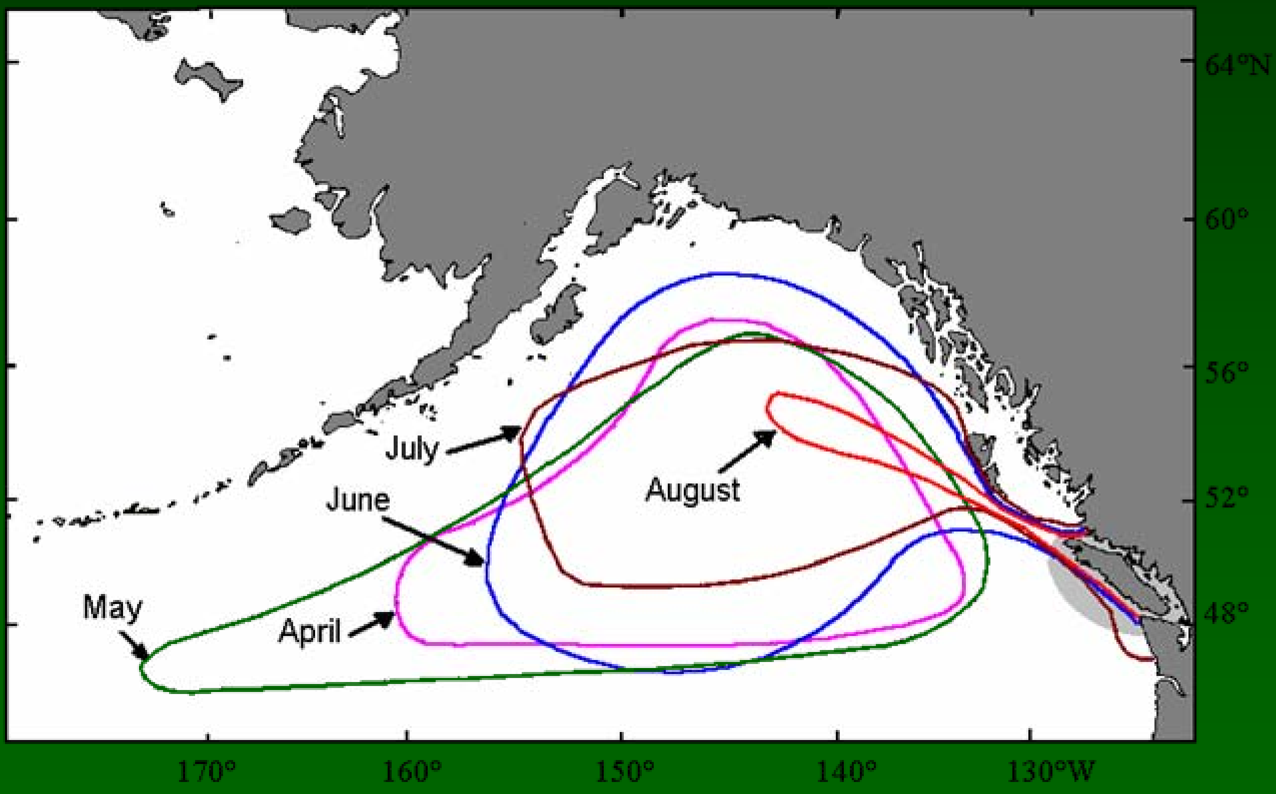
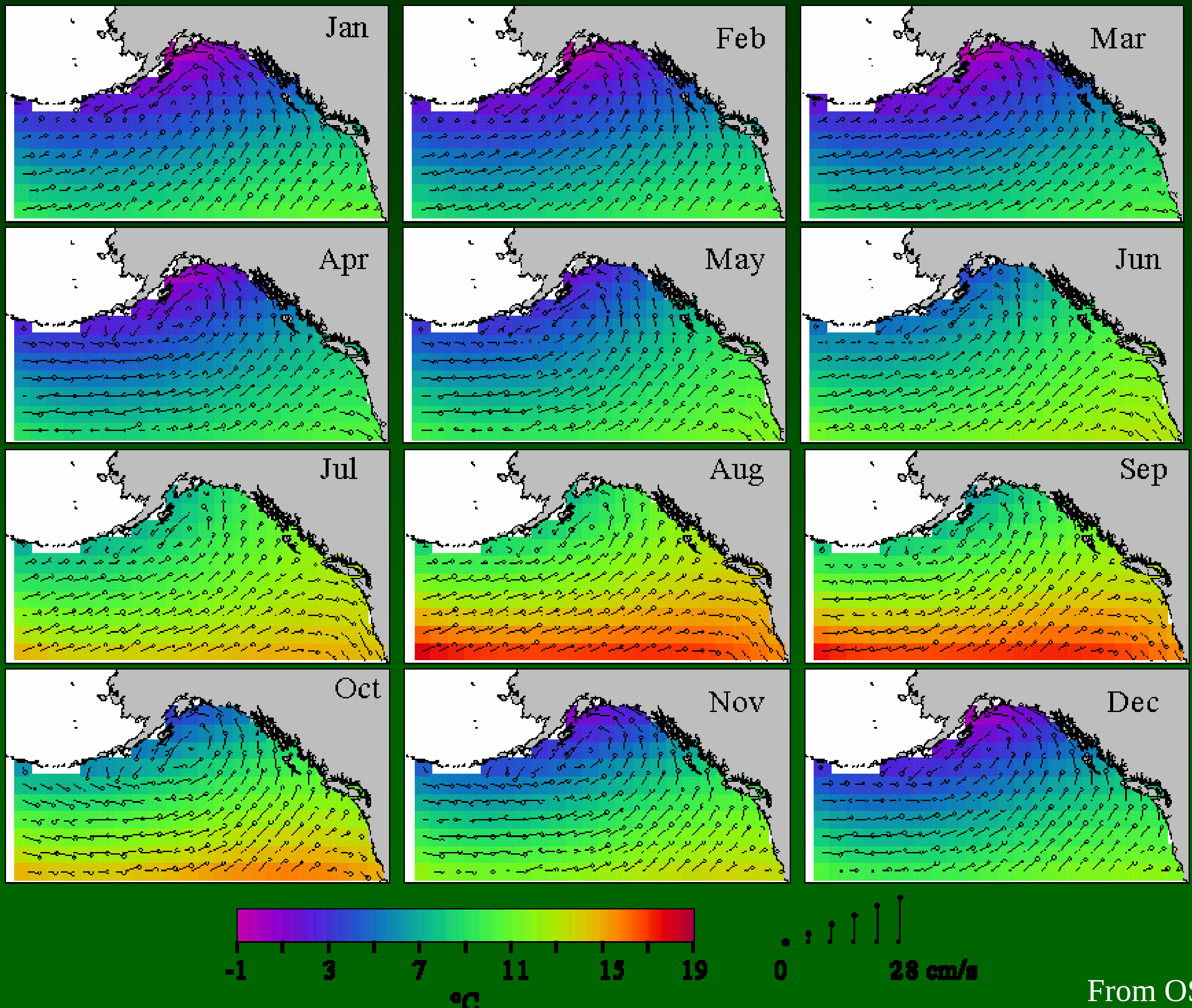
Migration pattern of Fraser River sockeye salmon



Sea surface temperature and currents



From OSCURS model

Reproductive migrations

Common characteristics of long range migrants

1) Streamlined bodies and high metabolic efficiency during swimming

2) Shoaling behavior

3) Good orientation and navigation abilities

Reproductive migrations (cont.)

Hypothesis

The migratory behavior of mature adults returning to spawn minimizes an expectation of the total costs of migration, defined by the metabolic cost of swimming and the risk of predation.

Reproductive migrations (cont.)

So...

The swimming speed and orientation of migrants are an optimal response to the spatial and temporal distribution of mortality risk, and to environmental variables known to affect the metabolic cost of swimming.

An energy allocation model for reproductive migrations

$$E = E_s + E_r + E_o$$

Where

E = Total energy content in fish

E_s = Structural (somatic) energy

E_r = Energy required for current reproduction

E_o = Energy required for purposes other than current reproduction

An energy allocation model for reproductive migrations (cont.)

$E_s = a\,E$

$E_r = \alpha\,G_d\,N_e$

$N_e = E\,(1 - a) / (\alpha\,G_d)$

α = Cost of producing and delivering one egg

G_d = Energy density of one egg

N_e = Number of eggs produced

Dynamic programming model for reproductive migrations

Terminal Condition

$$F(E, x, y, T) = \begin{cases} N_e & \text{if} \quad (x, y) = (X, Y), E \geq E_{crit} \\ 0 & \text{otherwise} \end{cases}$$

Dynamic programming model for reproductive migrations (cont.)

Dynamic programming equation

$$F(E, x, y, T) = \max_{\delta x,\, \delta y,\, \nu} \left[(1 - \mu_{x+\delta x,\, y+\delta y,\, t+\delta t})\, F(E_T - m_{x+\delta x,\, y+\delta y,\, t+\delta t},\; x+\delta x,\, y+\delta y, t+\delta t) \right]$$

δx, δy = Displacement in the x and y direction

ν = Swimming speed of fish

μ = Risk of mortality

m = Metabolic cost of swimming

Bioenergetics and swimming speed of sockeye salmon

$m = 77.28\ W^{0.6486}\ e^{(0.0306\tau\ +\ 0.027861\nu)}$ (in Joules)

$\nu_{opt} = 34.2\ W^{0.1642}\ (0.4 + 0.04\ \tau)$

τ = Temperature
ν = Swimming speed
w = Body weight

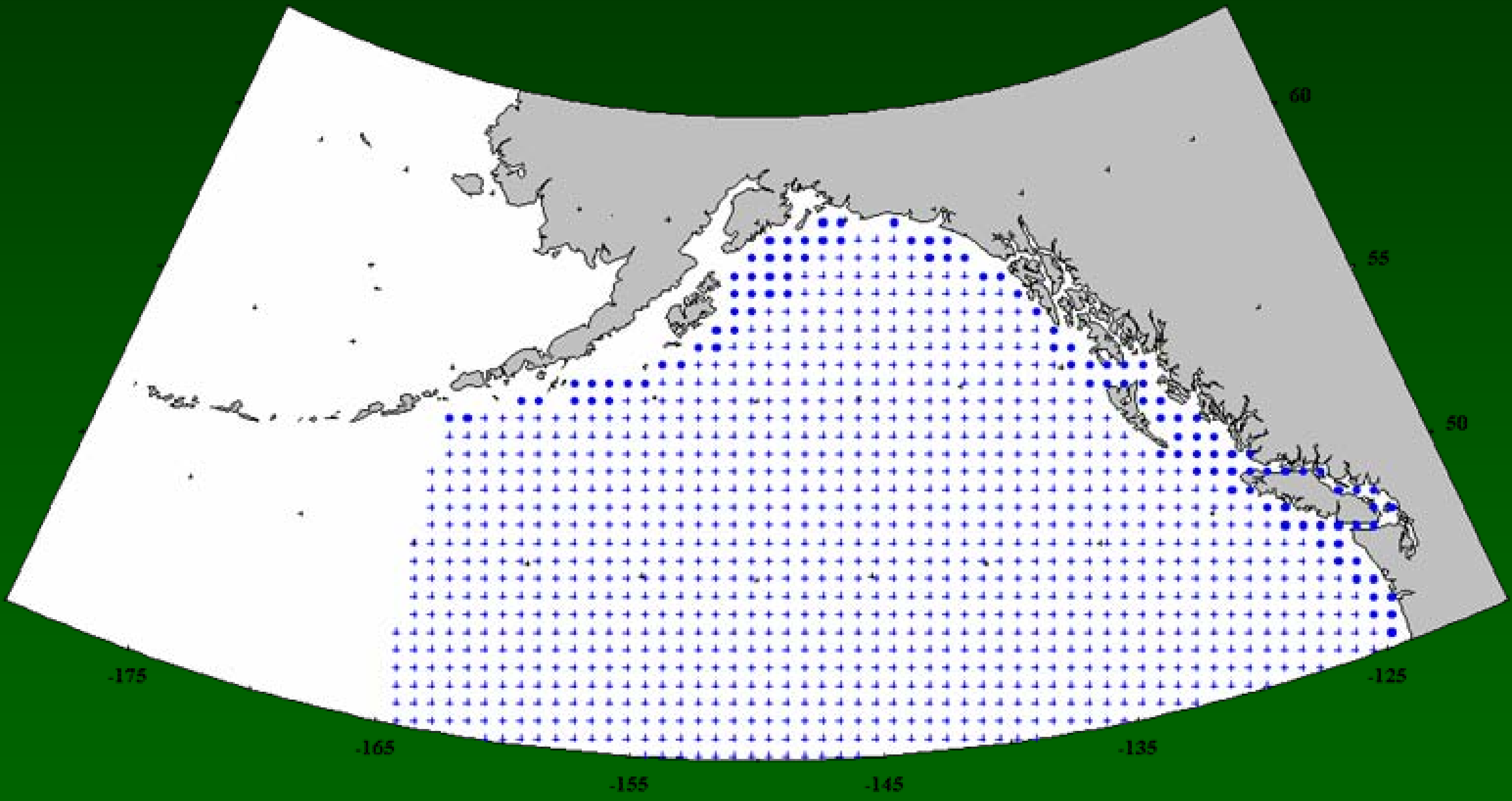
Migration characteristics of an Early Stuart female sockeye salmon

River entry = July 8th (Gilhousen, 1980)
Length = 53 cm (Gilhousen, 1980)
Weight = 2,400 g (Gilhousen, 1980)
Energy content at river entry = 20,264 kJ (Idler, 1959)
Energy content of a carcass = 4,382 kJ (21.6%) (Idler, 1959)
Energy content of an egg = 1.4 kJ (Dueñas, 1980)

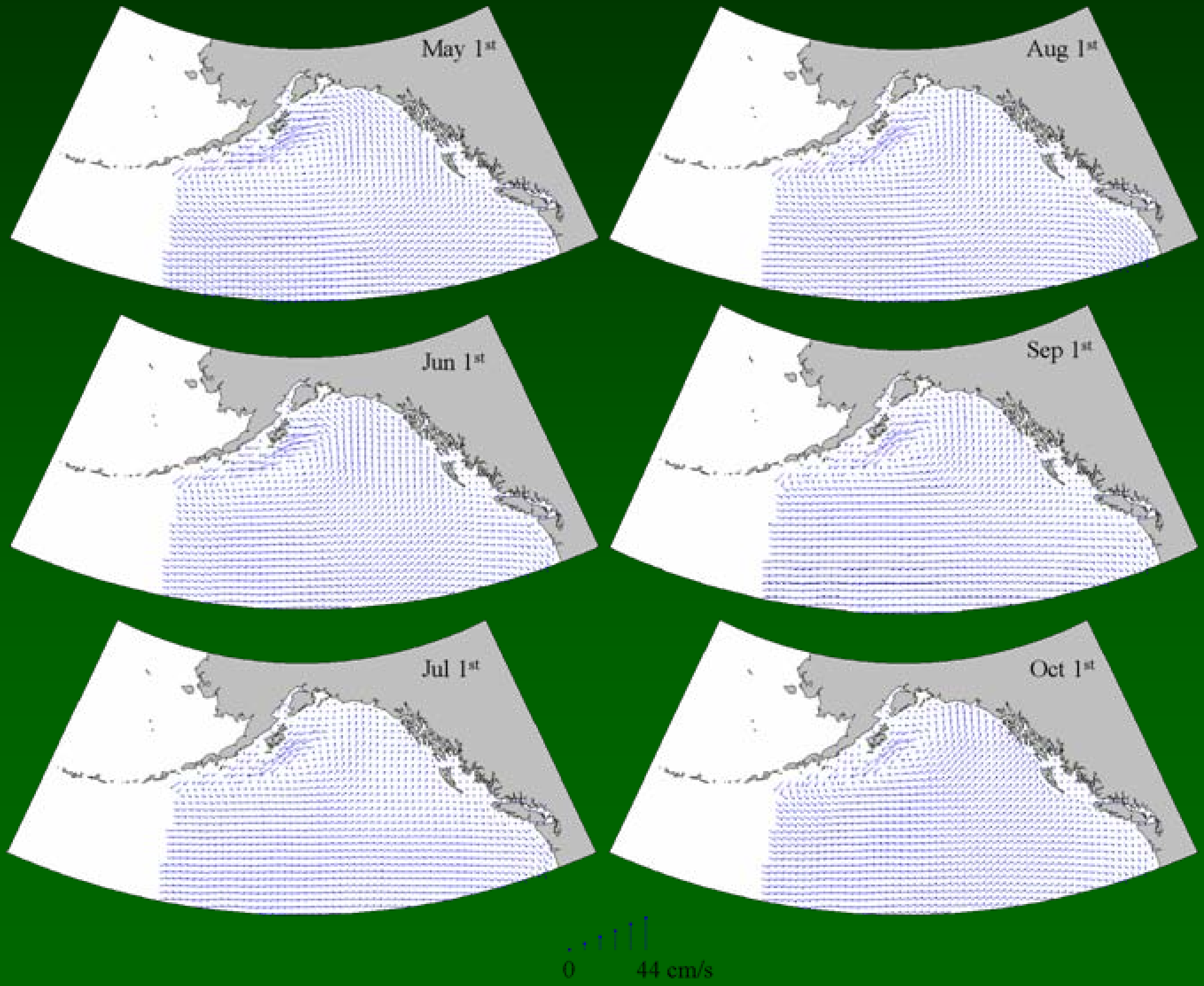
Swimming speed in the open ocean = 45 cm/s (Hartt, 1966)
Swimming speed in the coast = 57 cm/s (Hartt, 1966)

Monthly survival rate during the oceanic phase = 0.996 (Furnell, 1986)
Survival rate during coastal phase = 0.95 (Foerster, 1968)

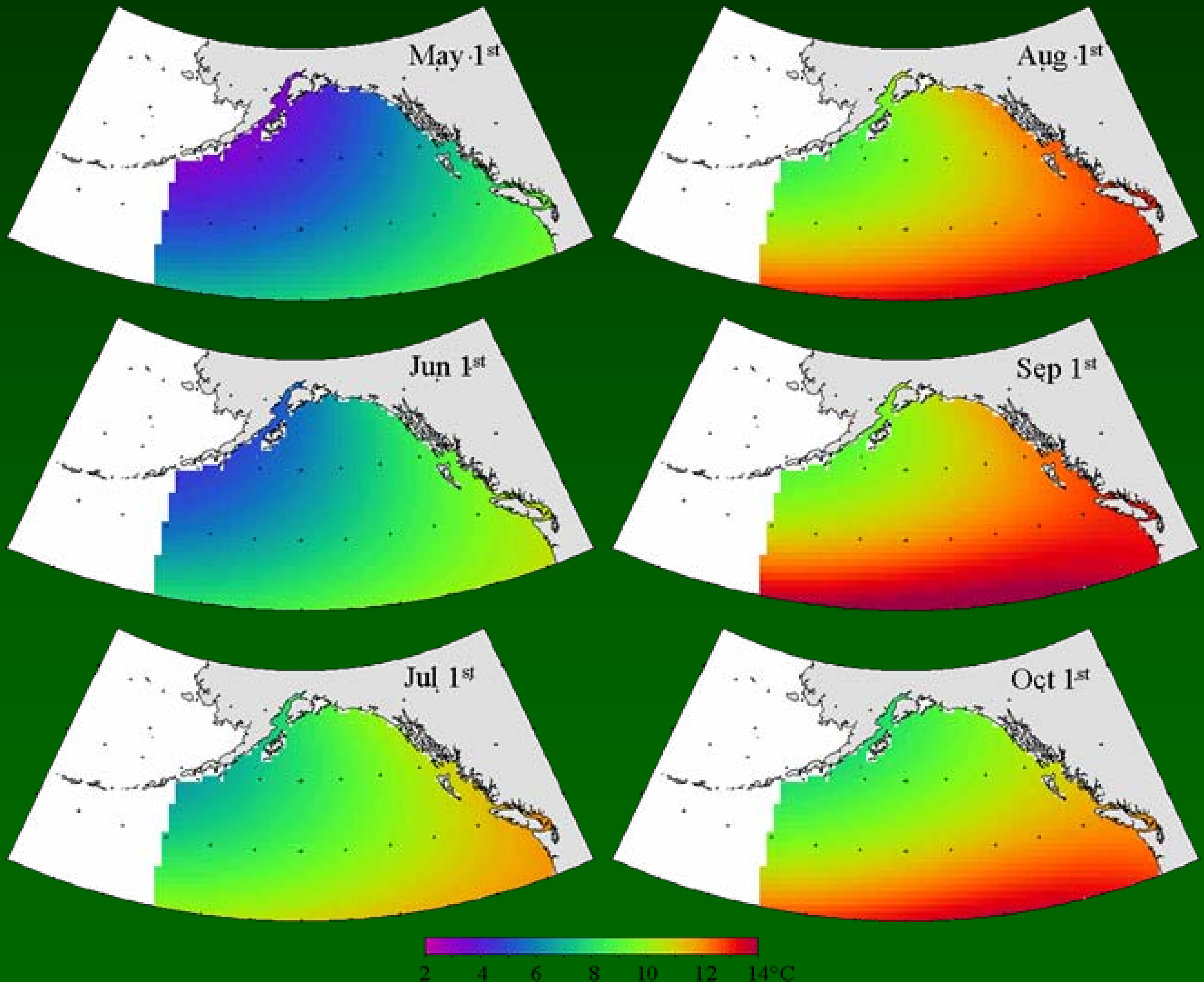
Grid Design



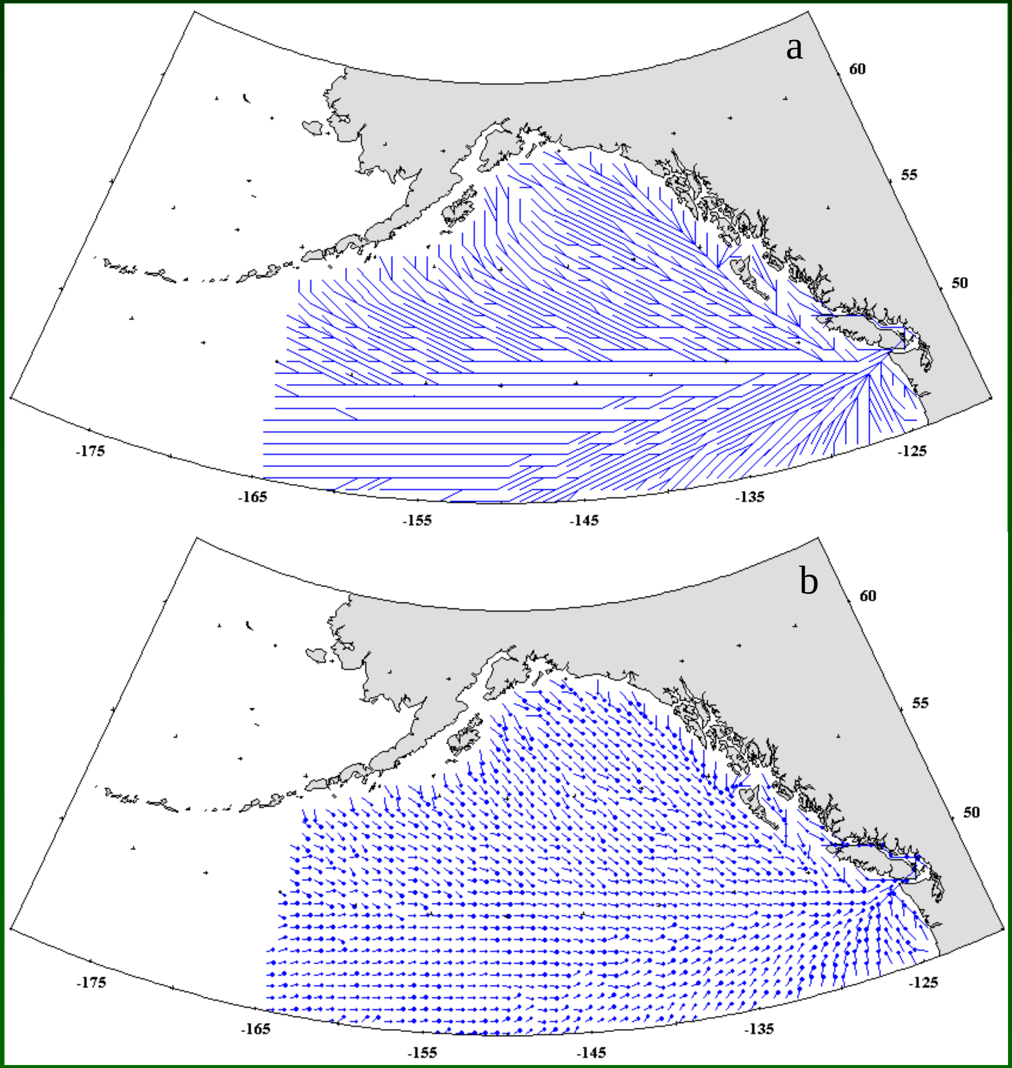
Environmental conditions
Mean daily surface currents



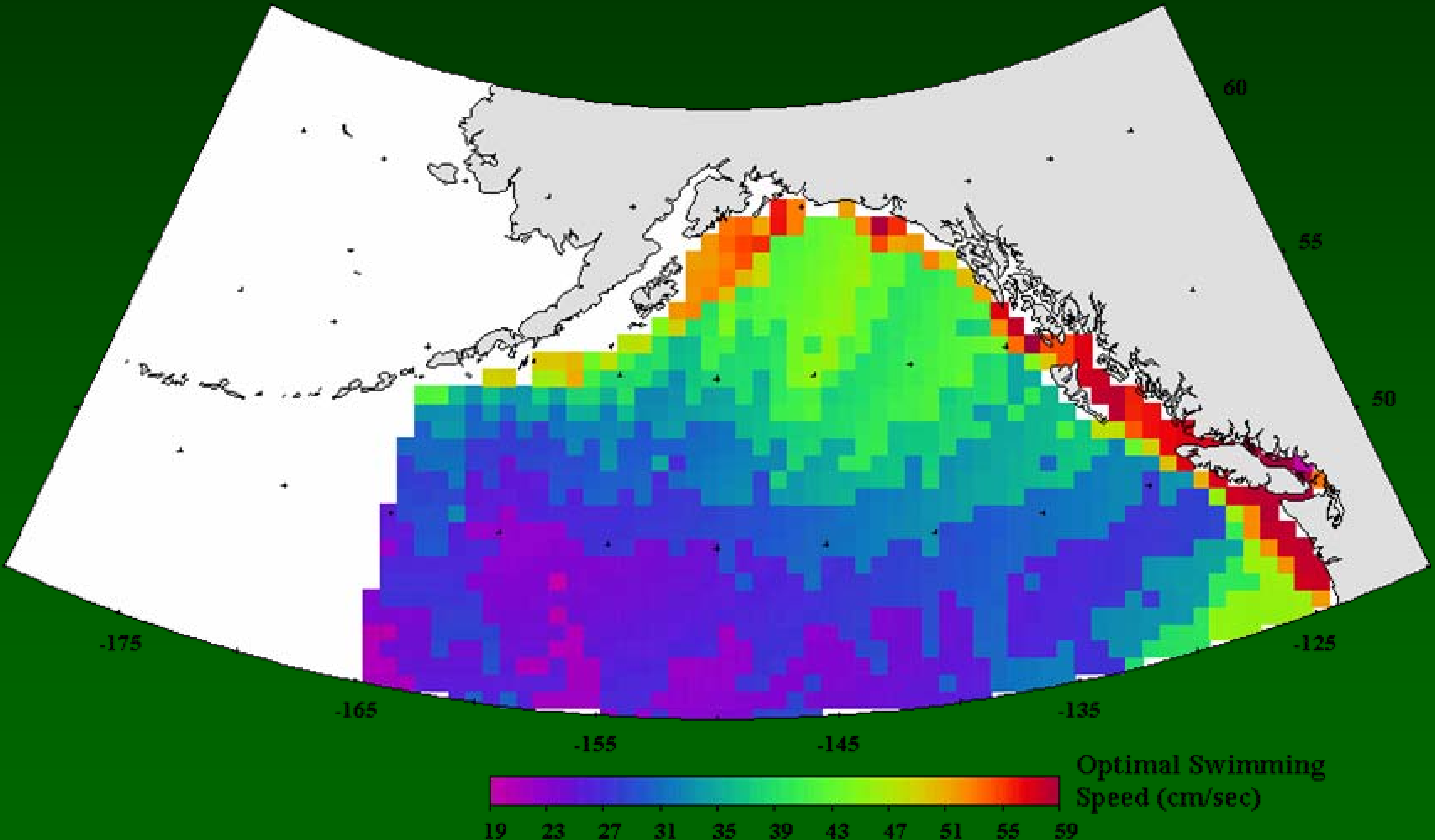
Environmental conditions
Mean daily surface temperature



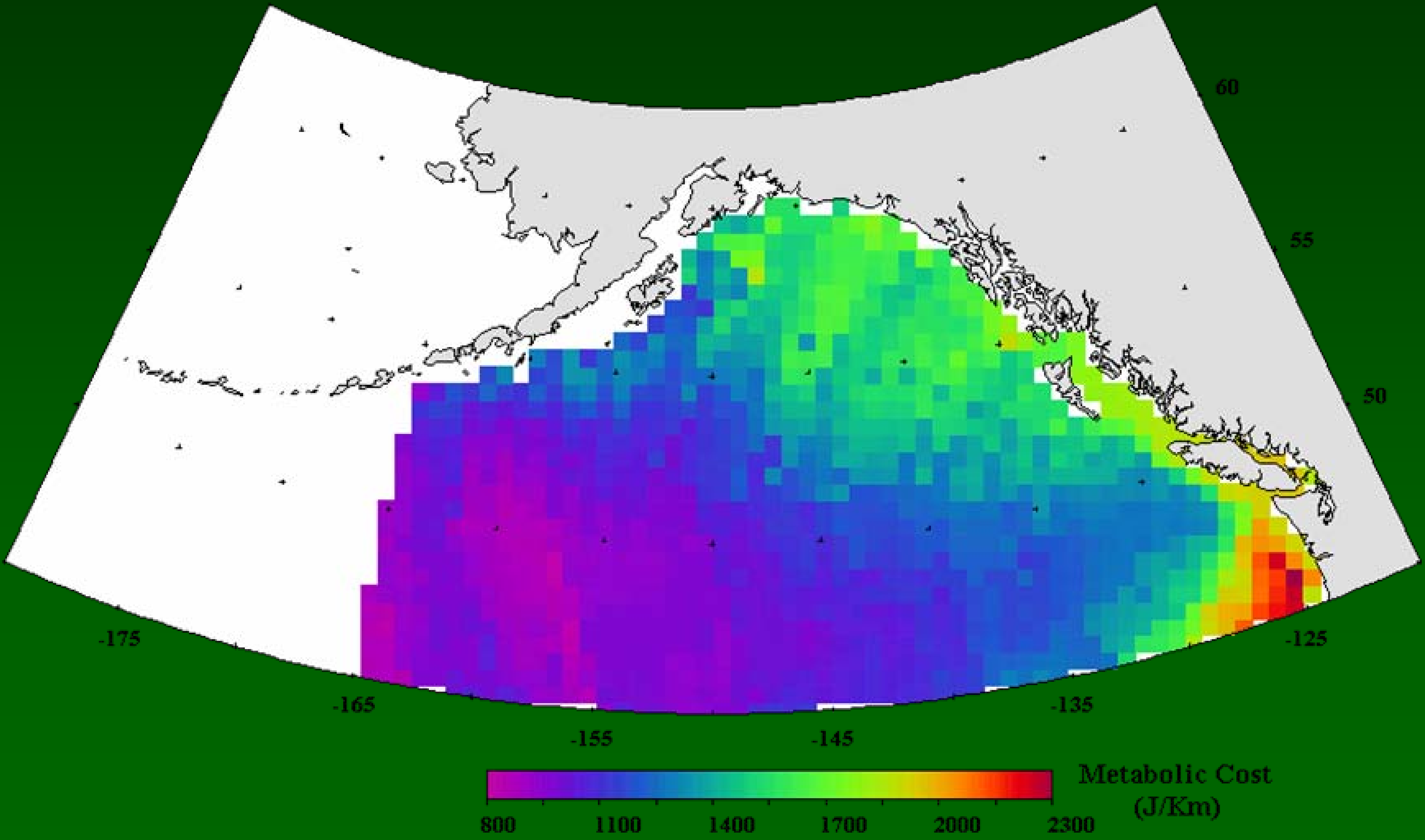
Optimal migration trajectories and swimming orientation. 5% coastal mortality



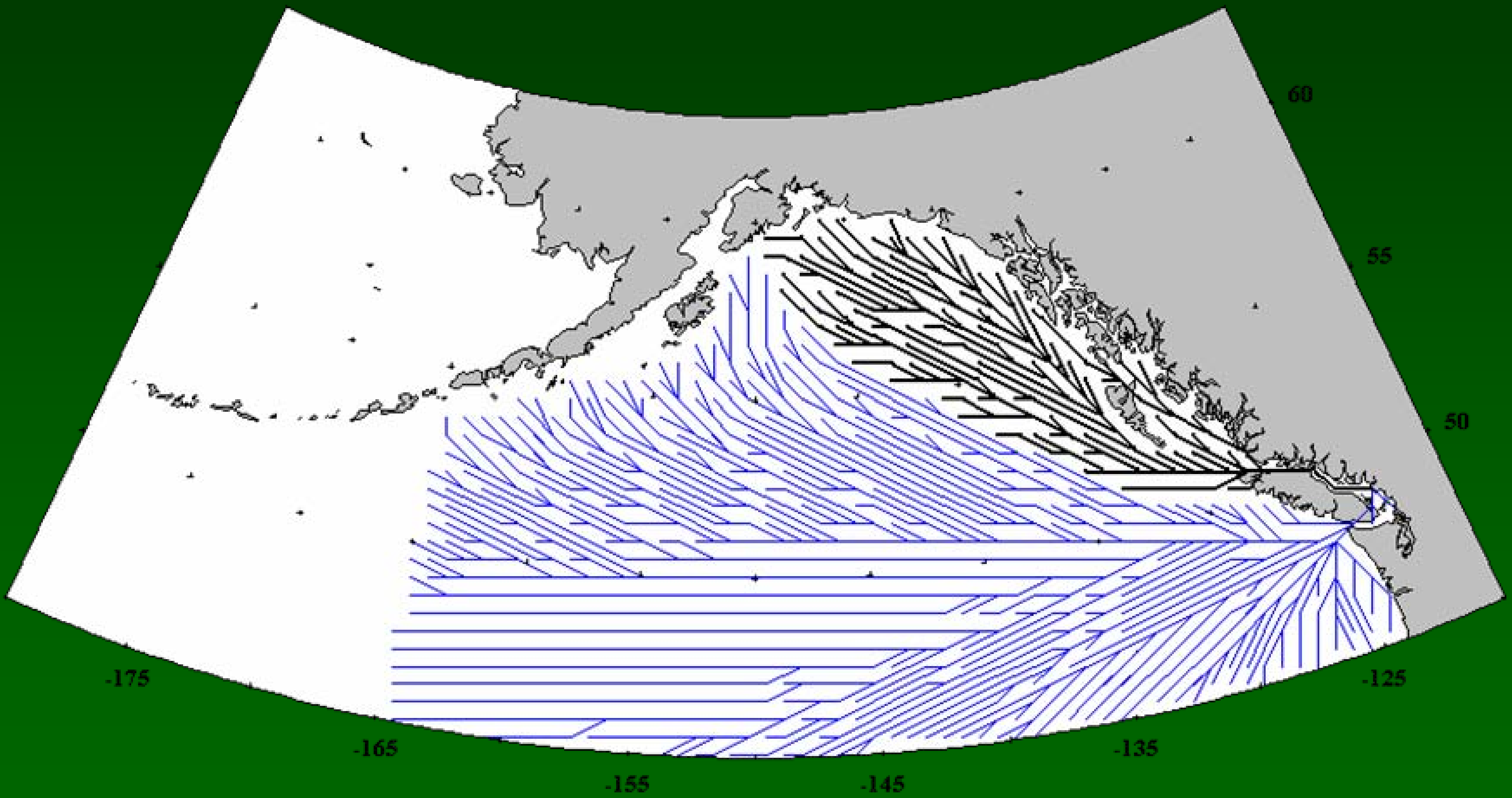
Optimal swimming speed 5% coastal mortality



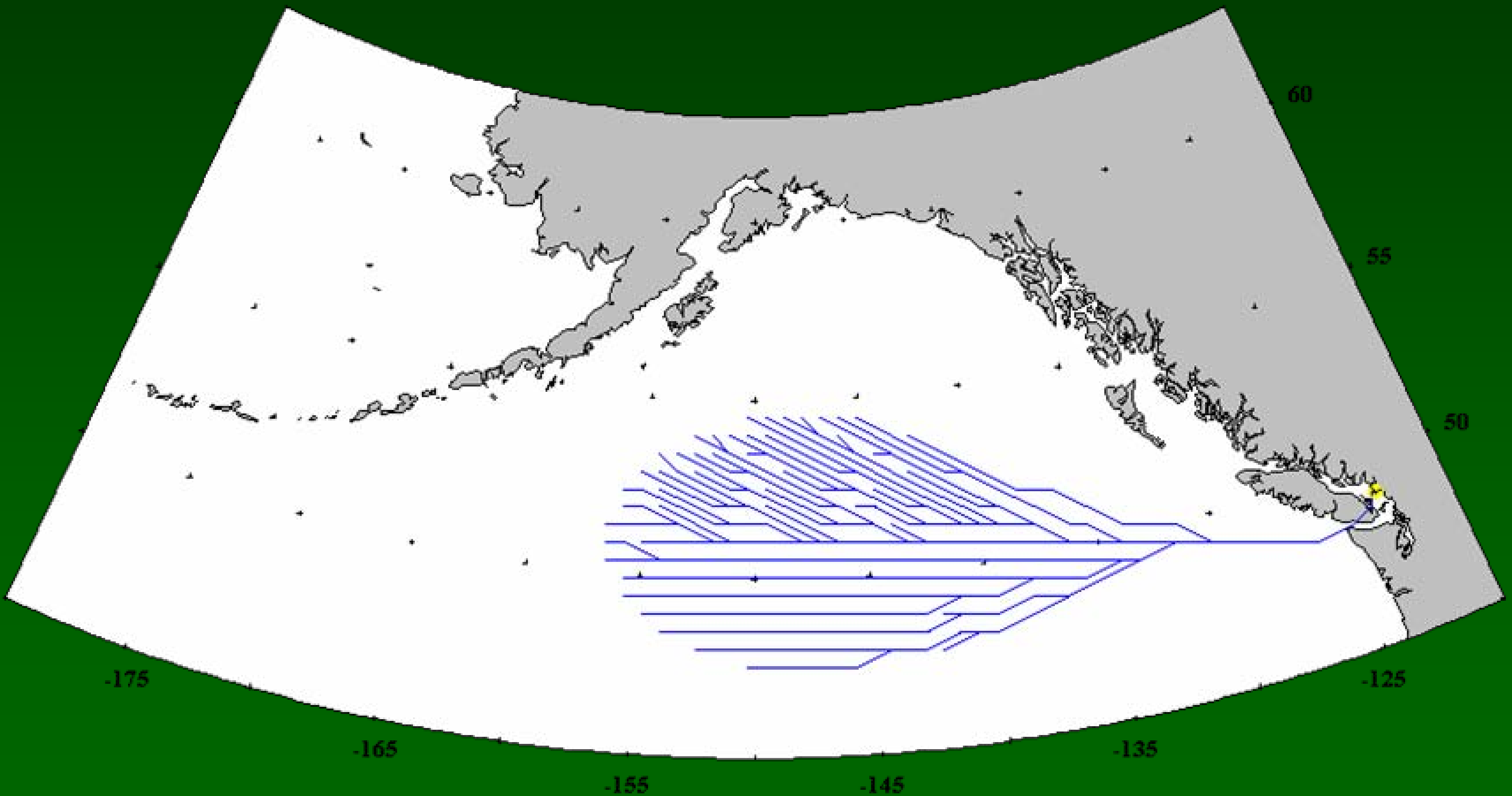
Predicted metabolic cost
5% coastal mortality



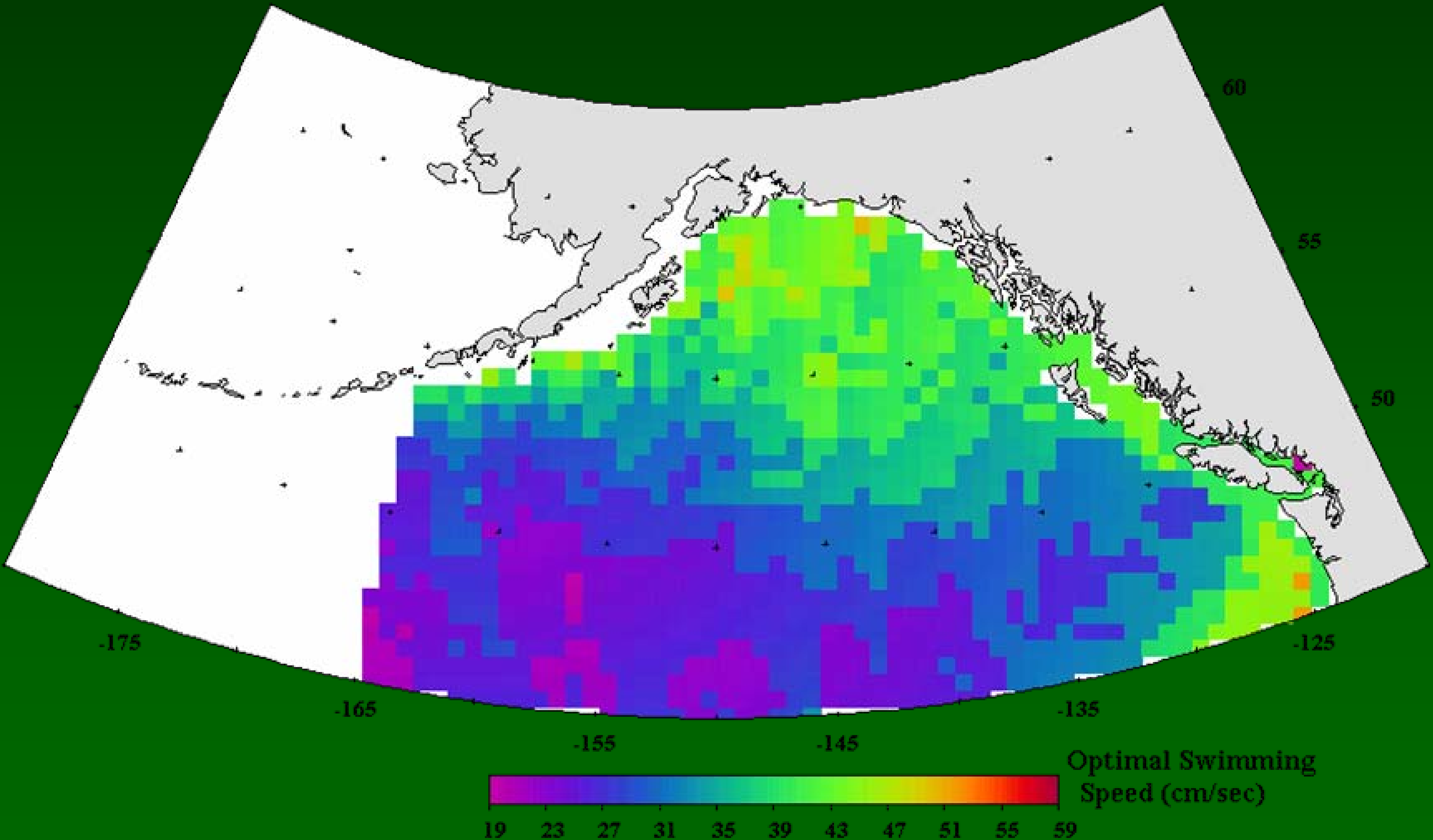
Optimal migration trajectory
1% coastal mortality



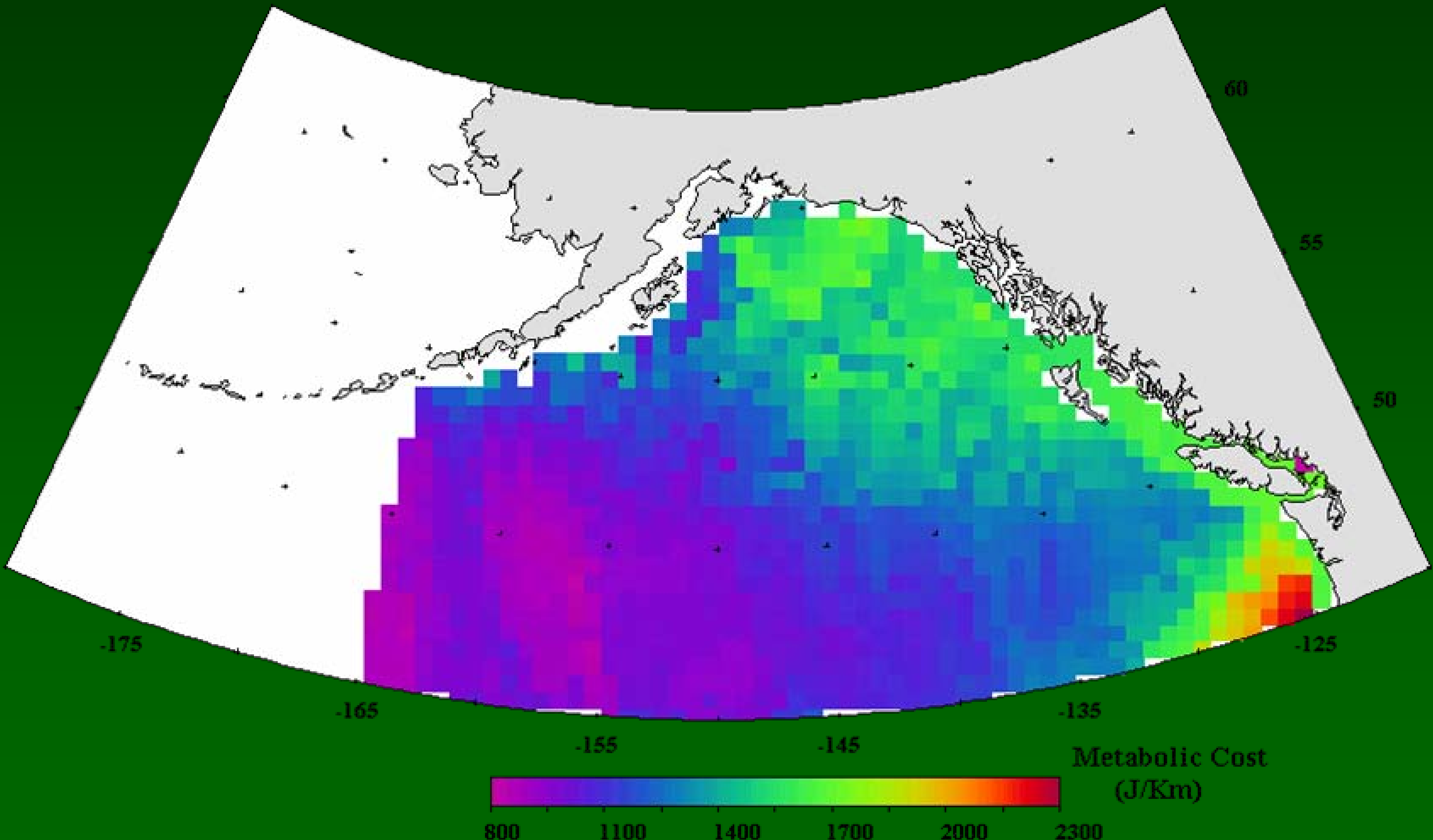
Optimal migration trajectory 1% coastal mortality



Optimal swimming speed 1% coastal mortality

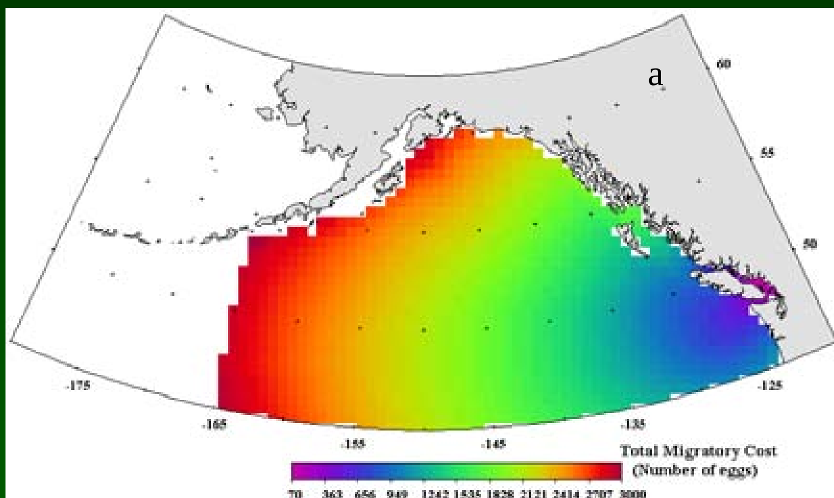


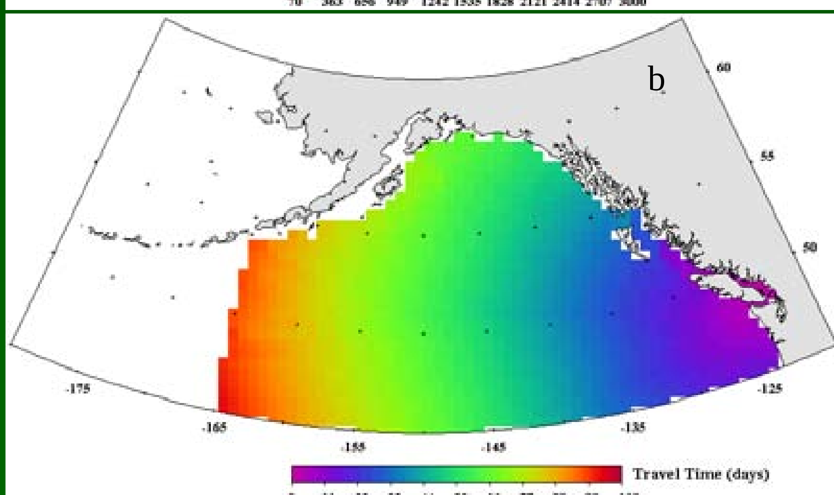
Predicted metabolic cost 1% coastal mortality



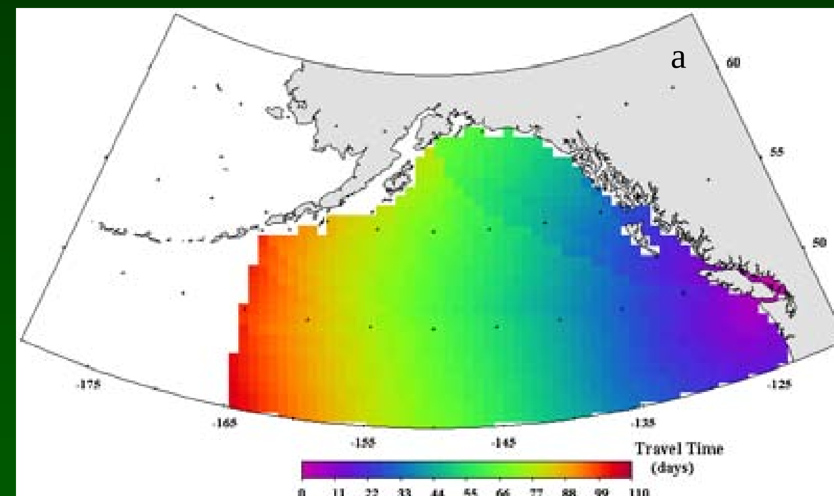
Total expected costs and migration time

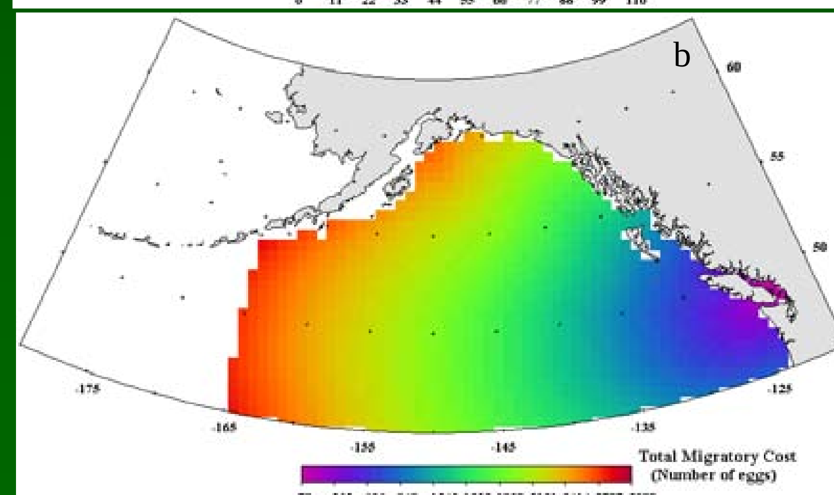
5 % coastal mortality





1 % coastal mortality





Conclusions

1) Maximum predicted travel time is 110 days

2) Maximum expected investment during migration is 3,000 egg-equivalent energy units

3) Juan de Fuca Strait is the optimal approach route to reach the Fraser River

4) Observed higher coastal swimming speeds likely arise as a response to a higher risk of predation on the coast

5) The hypothesis on which this model is based cannot explain the oceanic migration route nor the latitude of landfall

6) Other factor(s) are also involved in the decision process of sockeye migrants. Likely foraging is important during the migation

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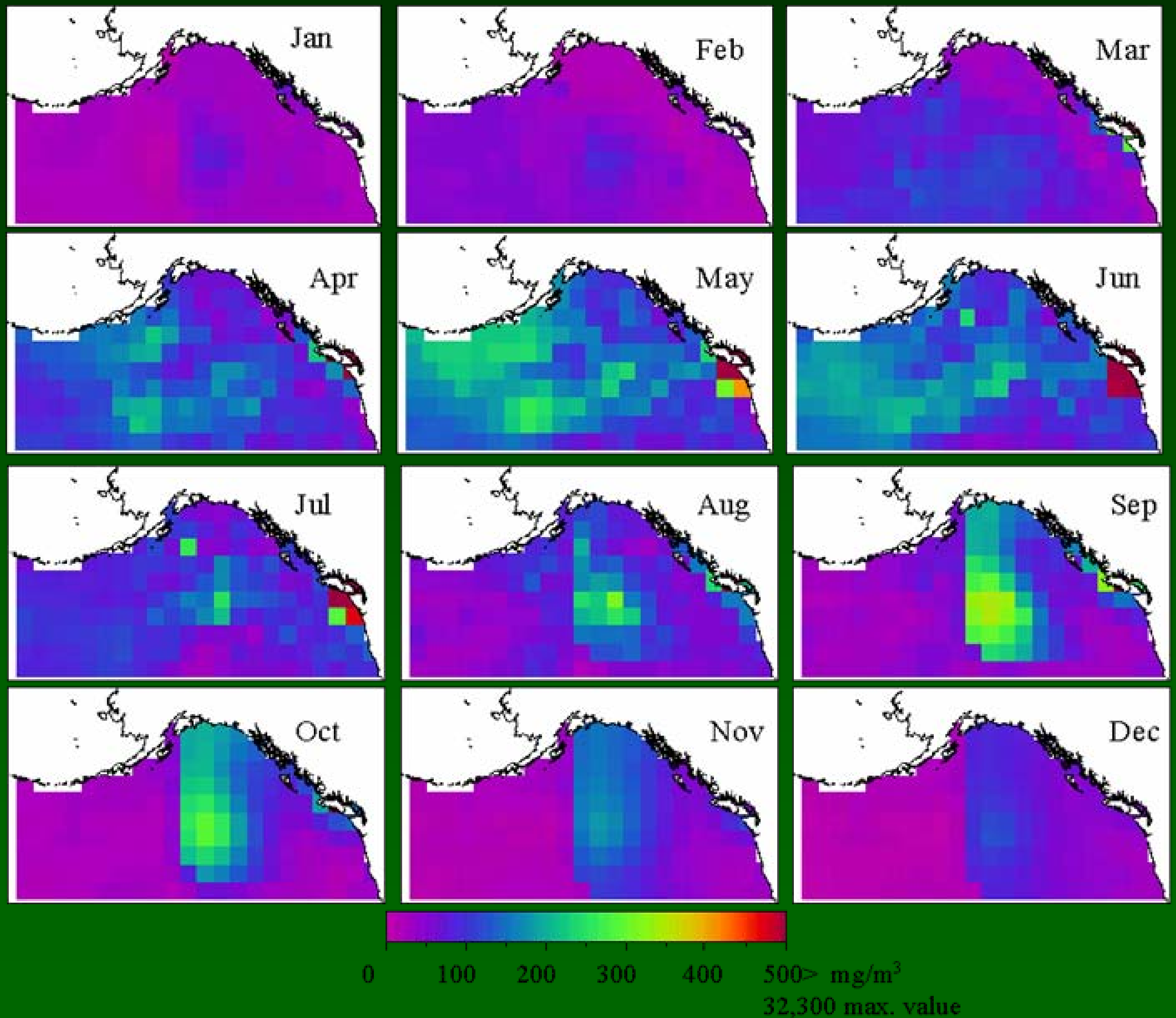
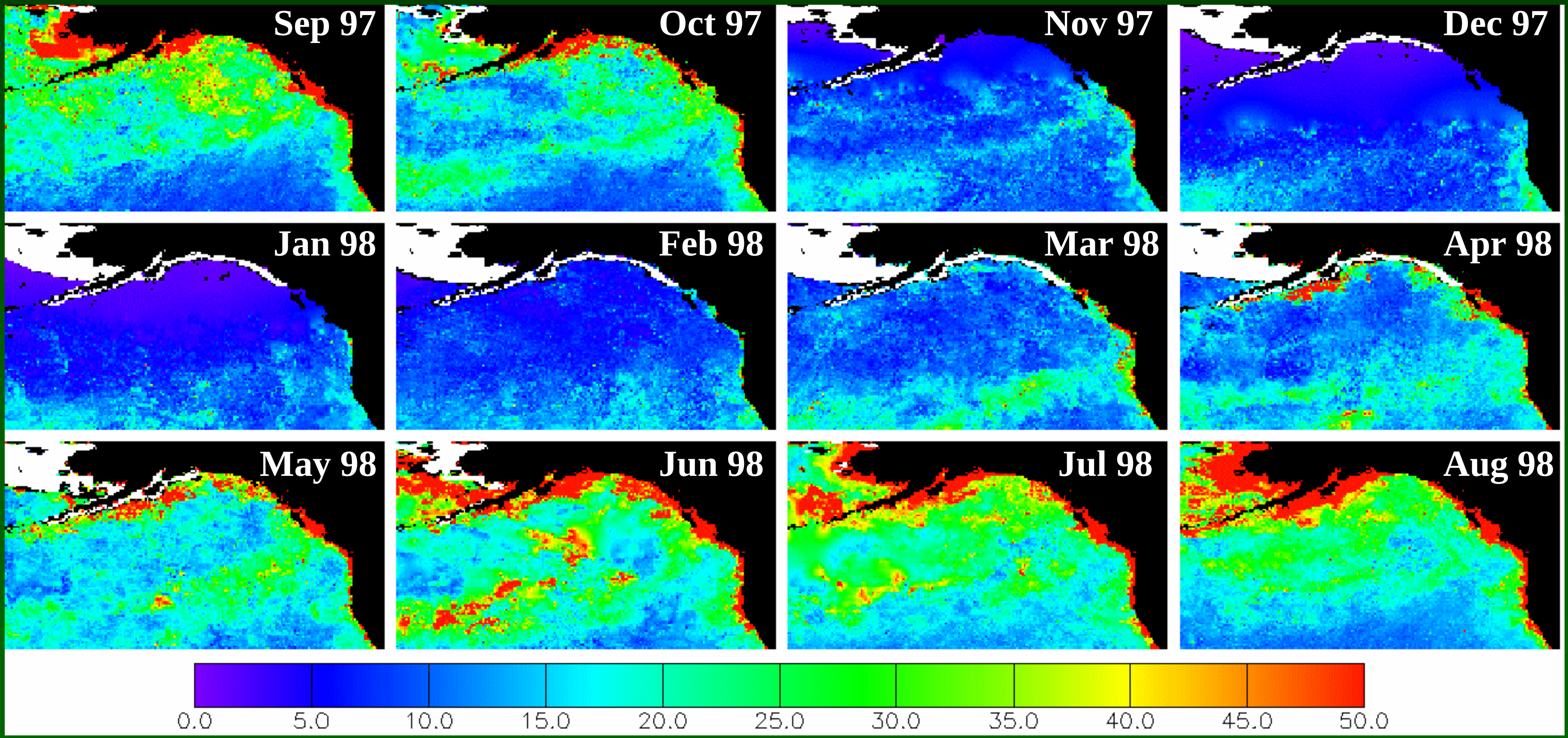
Zooplankton density



NE Pacific surface Chlorophyll (g C/m^2) from SeaWIFS



Framework

1) The primary drive of individuals is to reproduce

2) Natural selection favours those traits that increase the fitness of individuals

Migratory Behavior

A fitness maximizing behavior evolved as a response to take advantage of predictable changes in the temporal and spatial distribution of environmental conditions, resources, and risk.