Expressions of Growth

- Absolute growth = \( Y_2 - Y_1 \)
- Absolute growth rate = \( \frac{(Y_2 - Y_1)}{(t_2-t_1)} \)
- Relative growth = \( \frac{(Y_2 - Y_1)}{y_1} \)
- Relative growth rate = \( \frac{(Y_2 - Y_1)}{[y_1 / (t_2-t_1)]} \)
- Instantaneous growth rate or specific as %
- \( G = \frac{(\ln Y_2 - \ln Y_1)}{(t_2-t_1)} \)

Physiological and Biochemical Indices

- Protein synthesis
- RNA : DNA ratio : (DNA relatively constant, RNA varies with protein synthesis)
- Condition Factors, HIS
- Proximate contents - water, lipid, protein, carbohydrate, ash
Proximate Composition

• What does it mean?
• What about carbohydrates?
• What about energy content?

What about thermal relationships to growth

• We know temperatures affect body processes

• Different species may have different life history stages that use different temps?

• What are some examples?
Thermal growth coefficient

- Degree days approach to growth.
- Assumptions have limitations
- It works if the relationships are the same for different temperatures.
- If growth in length is constant over all time

\[ W_t = W_0 + \left( \frac{T}{1000} \right) t \]

Length weight relations \( W \sim L^3 \)

Solve for time \( t \)

\[ W_t = \left( \frac{3}{3} W_0 + [(T/1000) \times t] \right)^3 \]
Thermal growth coefficients can be different

**Atlantic Salmon Growth at 10°C**

- GF3 = 2.25
- GF3 = 2.5
- GF3 = 2.75

**Production Aquaculture Versus Conservation Aquaculture?**

- Fast - efficient
- Slower and efficient
- ????
Temperature and Physiology
Effects are Evident

• Individual
• Population
• Community
• Evolutionary processes

Bioenergetics
Growth, Nutrition

Some approaches to understanding the dynamic processes of feeding, digestion, somatic growth, reproduction, excretion
Energetics – Processes

Hormonal Control

Ingestion → Storage → Mobilization → Adsorption → Excretion
Lipid Carbohydrate Lipid Carbohydrate Renal Stomach Intestinal
Protein

Growth → Reproduction

Energy Budgets

Intake (I = Income)
- Macronutrients
  - Carbohydrates
  - Lipids
  - Proteins
- Micronutrients
  - Vitamins
  - Essential
    - Fatty Acids
    - Amino Acids
    - Sugars

Energy Use (E = Expenditure)
- Respiration
- Osmoregulation
- Movement
- Feeding
- Digestion
- Reproduction

IF
I = E  Growth = 0
I < E  Growth = -
I > E  Growth = +
Specific Growth or Absorption Rates, Gut Reactor Models

- Feed conversion ratio, conversion efficiencies
- \( \frac{d tL}{dt} \) or \( \frac{d wt}{dt} \) or \( \frac{d \text{ protein elaborated}}{dt} \) / \( \frac{d \text{ protein ingested}}{dt} \)
- Considers Gut Evacuation, Transit and Intake Parameters

\[ R = \text{max rate nutrient can be absorbed} \]

Nutrient gain

Sibly Model from GI into Blood - ingestion to absorption, single constituent

time \( t_1 \) \( t_2 \) Maximum Efficiency
Gut Evacuation Approaches

- Malcolm Jobling – University of Tromsø, Norway.
- Scores of publications bolus with markers –
- Recent models of dilution related to aquaculture production to achieve desired flesh constituents- fish oil derivatives
- The mathematical description of this dilution

Jobling 2003

- Critical look at the thermal growth coefficient

- Does coefficient of condition remain the same over time?

- Rate of temperature affecting growth is often bell shaped for one size of fish
Influence of temperature on the growth of Baltic salmon *Salmo salar* L. (a) The growth rate - temperature relationship. The dashed line indicates that the specific growth rate (SGR) at 11 °C is the same as that at 20.5 °C.

\[
\text{SGR} = \left[ \frac{\ln W_t - \ln W_0}{t} \right] \times 100
\]

(b) The change in the thermal growth coefficient (TGC) with increasing temperature. The arrow indicates the estimate of the TGC at 20.5°C (~0.75).

But Consumption Changes with Weight
Ecosystem and Community

- Change in quality and availability of foods, predators, timing of spawning events, migrations

Global Warming

- Effects in your lifetime
- Temperatures
- pH shifts in the oceans
- Extremes more common
Temperature and Fish Physiology

- Thermal biology dominated by constraints of respiration
- Limited solubility of O\textsubscript{2} in H\textsubscript{2}O
- High heat capacity of water ensures blood is equilibrated with water
- Thus heat generated by metabolism is carried to gills and lost to environment.

- Temperature determines rate of chemical reactions
- Temperature dictates point of equilibrium in reactions
- Temp affects structural flexibility components for protein and biological membranes.
- Thus, significant changes in body temperature pose a serious challenge to maintenance of physiological functions
• Some (very few) fish are endothermic
• Most fish are isothermal with environment and must contend with variable body temperatures
• However, fluctuations are not exceptionally large compared with what can happen in the air

Poikilothermy - Ectothermy

• Most typical for fishes (inverts, reptiles, amphibians)
• Ambient conditions dictate temperature
• Behavioral adjustments (thermal refugia for summer and winter conditions)
Adjustments to Temperature Changes

- Some adaptation such as increasing surface circulation
- Evolutionary adaptation to specific environments
- Evolitional distinctions in tolerance
  - Eg polar fishes versus desert fishes
  - Antifreeze proteins

Membranes- Lipid Composition

- Phospholipid acyl chains
  - Brain fatty acids in Antarctic fish have 24 carbon polyunsaturated fatty acids
  - PUFA vs SFA ratio changes with temperature
  - Unsaturated pack less efficiently, and have lower melting points than saturated homologues
  - Increased membrane un saturation offsets direct effects of low temperature by reducing membrane order and increasing fluidity
Proteins

• High heat can completely denature them, but enzyme systems are evolved for efficiency at a particular temperature range.
• Rate of reactions are chemical balance sheets affected by substrate, temperature and feedback mechanisms.

Thermal Tolerances

• The main idea of this concept is the existence of so-called *pejus*-temperatures or thresholds. The suboptimal temps characterized by decreasing performance before critical temperature limits are reached at the high and low end of the thermal tolerance window.
Hypothesized borders characterized by the transition to hypoxemia, i.e. internal (systemic) hypoxia caused by a limited capacity of oxygen supply mechanisms (ventilation, circulation) at extreme temperatures. The temperature-induced hypoxemia delineates the first line of thermal limitation and occurs in fully oxygenated waters.

Critical thermal maximum (CTM; ---) : thermal preference; lower and upper incipient lethal temperatures (LILT and UILT), are positively correlated with acclimation temperature.
Heat Shock Proteins

- Family of proteins expressed in invertebrates and vertebrates in response to wide range of biotic and abiotic stressors
- Widespread phenomenon
- Intracellular proteins among diverse organisms

HSP (proteins)

- Named by molecular mass (kDa) as determined by SDS Page electrophoresis or other methods such as western blot.
- HSP 70 is one of the most highly conserved of the HSP groups
- Almost all studied cells have HSP
- The DNA sequences for HSP are more than 50% similar among bacteria yeast and drosophila.
• Vital role in cell. Protein assembly, correct folding, and translocation and regulating interactions between hormones and receptors.

Elevated Temperatures

• Heat shock proteins (HSP) expression is increased when the cells are exposed to elevated temperatures.
• Increase in expression is transcriptionally regulated.
• Up regulation of the heat shock proteins induced mostly by heat shock factor (HSF) is a key part of the heat shock response.
Consequences

• Heat shock proteins trigger immune response through activities that occur both inside the cell (intracellular) and outside the cell (extracellular).

Intracellular

• Normal functions of heat shock proteins inside the cell (such as helping proteins fold, preparing proteins for disposal, etc.)
• HSPs end up binding virtually every protein made within the cell. Thus, they represent a ‘library’ of all the proteins inside the cell.
• HSP bind to normal peptides and abnormal peptides (infectious diseased, old, cancerous).
Extracellular

- Extracellular HSPs are one of the most powerful ways of sending a ‘danger signal’ to the immune system in order to generate a response that can help to get rid of an infection or disease.
Viral Infections (possible link to fever repair?)

- Viral infection induces Hsp expression.

Oxidative Stress

- Immune cells release nitric oxide and superoxide in the attack on invading cells.
- Host cells express Hsps to protect against oxidative damage.
- Pathogens also mount a protective response with massive overproduction of Hsps.
Emotional and Physical Stress

- When rats are physically restrained, their vascular endothelial cells express elevated levels of Hsp70. The response has been linked to an abrupt increase in blood pressure.

- Elevated Hsp70 expression protects against cardiac failure. Hearts of transgenic mice that express elevated Hsp70 sustain less damage.

Neural Receptors

- Some evidence that mechanism transports Hsps from support cells to neurons during stress.
Model for Regulation (Proteotoxicity model)

- Denatured or foreign proteins are potent inducers
- HSP 70 is key sensor and mediator of events leading to further production.

Cell Lines

- Many proteins are expressed in different fish cell lines, including RTG, and H, CHSE, FHM
Cell Lines Can Help Study

- Simple
- Excellent experimental systems

Whole Animal Studies

- Induction in many tissues with temperature
  - Muscle, liver, heart, brain

- Induction with environmental contaminants
Autoradiograph of CHSE cells after 3 dosages of hydrogen peroxide
From Iwama et al. 1998

Western Blot  Liver Tissues infected with R. sal
From Iwama et al.